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Determination of Optimum Seed Rate and Row Spacing of Upland Rice in Amhara region, Ethiopia

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ABSTRACT

Farmers in the major upland rice growing areas of Ethiopia are advised to use blanket seed rates as there are no appropriate seed rate recommendations developed. Seed rate and row spacing experiment was conducted on rainfed upland rice production at Fogera and Libokemkem areas, Amhara Region, Ethiopia. Randomized complete block design in factorial arrangements was deployed. The treatments were seven seed rates (40, 60, 80, 100, 120, 140, and 160 kg ha^{-1}) and 4 row spacings (15, 20, 25, 30 cm). The commonly grown NERICA-4 rice variety was used. Data were collected on major agronomic parameters and subjected to analysis of variance. Economic analysis was also carried out. The results of the experiment indicated that the main effect of seed rate was significantly affecting plant height, panicle length, total tillers/m, effective tillers/m, filled spiklets/panicle, grain yield and straw yields. On the other hand, the main effect of row spacing was significantly affecting panicle length, total tillers/m, effective tillers/m, filled spiklets/panicle. With respect to the interaction effect of seed rate and row spacing, significant effects were observed on total tillers/m, effective tillers/m, thousand seeds weight and straw yields. The highest and statistically significant grain yield (3.06 t ha^{-1}) was obtained from the seed rate of 120 kg ha^{-1}. The combined use of 120 kg ha^{-1} seed rate and 20 cm row spacing is the most profitable treatment. It is thus concluded that combined use of 120 kg ha^{-1} seed rate and 20 cm row spacing is the best recommended for upland rice production in Fogera, Libokemkem and other similar upland rice production areas.

Keywords: Rain-fed, drilling, profitable.

INTRODUCTION

Rice *(Oryza sativa* L.) is an annual cereal grain and it is the most important food crops for the world's population, especially in South Asia, Middle East, Latin America and West India (Zhao et al., 2011). It is the principal food for one third of the world's population (Subedi et al., 2019). In Ethiopia, rice production was started three decades ago in the early 1970's. The country has reasonable potential to grow rice. According to the report of MoARD (2010) the potential rice production area in Ethiopia is estimated to be about 39,354,190 hectares, of which 5,590,895 ha is highly suitable, 24,910,629 ha is suitable and 8,852,666 is moderately suitable. Most of Ethiopia's rice production potential area lies in the western part of the country. Though rice is a recent introduction to the country, its importance is well recognized as the production area coverage of about 10,000 ha in 2006 has increased to over 50,000 ha in 2018 (CSA, 2018). The area coverage in domestic rice production has increased considerably linked with expansion of production in the wetland and upland areas with the introduction of suitable rice varieties for the agro-ecologies. In line with the area expansion, the production levels have been increasing consistently over years. CSA (2018) data indicate that rice production increased from 71,316.07 tons in 2008 to 171,854.1 tons in 2018. The number of farmers engaged in rice production has also grown year after year. Rice production has brought a significant change in the livelihood of farmers and created job opportunities for a number of citizens in different areas of the country. Amhara, Southern Nations, Nationalities and Peoples Region (SNNPR), Oromiya, Somali, Gambella, BeniShangul Gumuz, and Tigray regions are the rice producing areas in Ethiopia (MoARD, 2010). The Amhara region takes the lion's share of producing the crop and accounted for 74-81% of the area coverage and 78-85% of the production in the years 2016-2018 (CSA, 2016; CSA, 2017; CSA, 2018).

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Various rice ecologies are existing in Ethiopia mainly in rain fed lowland, upland and irrigated ecosystems (Mulugeta & Heluf, 2014). In recent years, the upland rice area coverage is showing a faster increase in Ethiopia. Rice cultivation is a water intensive enterprise. Lowland rice fields have relatively high-water requirements and their sustainability is threatened by increasing water shortages (Jana et al., 2018). As water availability for rice irrigation by flooding decreases in many parts of the world, upland rice cultivation is increasing in importance (Lacerda & Adriano, 2016). The usual way of planting upland (aerobic) rice is the same as we would plant the other cereal crops like wheat, oats or maize by direct seeding. Compared with flooded lowland rice, aerobic rice requires 30-50% less water (Jana et al., 2018). Aerobic rice system is the rice for future (Jana et al., 2018). Hence, shifting gradually from traditional rice production system to growing rice in aerobic condition especially in upland and mid-upland situation can mitigate the problem.

The Ethiopian national average yield of rice is about 2.8t ha^{-1} (CSA, 2018) which is lower compared to the world average productivity of 4.6 tones ha^{-1} (FAOSTAT, 2018). Weeds, pests, soil nutrient deficiencies, terminal moisture stress and inappropriate agronomic practices are the major causes of low rice productivity in Ethiopia (MoARD, 2010; Gebey et al., 2012). Improper seed rates and plant spacings are among the major factors limiting rice production in Ethiopia. Worldwide, the grain yield levels realized by the farmers under upland situations are still lower (Jana et al., 2018). Among many factors, method of sowing and seed rate influences the crop yield level greatly under upland situations (Jana et al., 2018). Plant population is important yield contributing factor which should be addressed efficiently in direct seeded rice. Plant population has either asymptotic or parabolic relationship with yield. In the asymptotic relation, yields increase linearly with increased population over the lower range of population. However, in parabolic relationship the total yield decline at higher population and there is an identifiable optimum value (Zewdineh, 2019).

Both the biological and economic yields increase with increasing plant population up to a certain optimum point and beyond the optimum spacing and economic yield decreases (Zewdineh, 2019). Rasool et al. (2013) stated that in densely plants, the farmers cannot obtain enough yield due to the plants competition for nutrients, light and air, which results in mutual shading, lodging and thus favor more straw yield than grain yield. On the other hand, a wider inter row spacing also allows more competition among crop plants and weeds. As a result, plant growth slows down and their grain yield decreases due to high weed infestation. Hence, it is necessary to determine optimum plant population per unit area and spacing to obtain high yield. Therefore, the present experiment was conducted to recommend appropriate levels of row spacing and seed rates for rainfed upland rice production in Fogera and Libokemkem areas of the Amhara Region, Northwest Ethiopia.

MATERIALS AND METHODS

Area description:

Seed rate and row spacing experiment was conducted on rainfed upland rice production at Fogera and Libokemkem areas of the Amhara Region, Northwest Ethiopia in two cropping seasons of the years 2017 and 2018 on a total of twelve farmers' fields. The study at Fogera area is situated at 11 °54.4'46.3"N to 11 °57'03.0"N latitude and 37 °41'23.9"E to 37 °42'32.2" E longitude at elevation range of 1787-1812 m.a.s. The study site has minimum and maximum temperatures of 12.75°C and 27.37°C, respectively. The area receives averages mean annual rainfall of 1219 mm. The long-term rainfall data (1986-2017) years indicated that much of the rainfall appear in June and September. The geographical location of the experimental area at Libokemkem is located at 12º 1′ 30″ N to 12º 12′ 00″ N latitude and 37º 31′ 30″ E to 37º 52′ 30″ E longitudes with the altitude range of 1804 to 1910 m.a.s.l. Average annual rainfall of Libolemkem is 900-1400 mm per year and rainfall pattern is predominately uni-modal with the main rainy season from mid-June to September. The mean maximum and minimum temperatures are 22.9ºC and 11ºC, respectively.

The experimental sites soil was found to be heavy clay with pH range of 5.87-6.63, which is slightly acidic and it is a preferred range for most crops (Table 1). Total nitrogen content was with range of 0.09-0.16%, which is within the range of low levels (0.02-0.5%) for tropical soils. The organic matter content of the soil was between 2.13-3.09%, which is within a range of medium (2-4%) for Ethiopian soils as per criteria developed by Murphy (1968). The available P content of the

Table 1: Relevant soil physicochemical properties of the experimental rice field before planting in Fogera Plain of Ethiopia.

Soil properties	Units	Min. Value	Max. value
Textural class		Heavy clay	Heavy clay
Chemical properties			
pH (H_2O) 1:2.5 g soil	-	5.87	6.63
Total nitrogen (TN)	%	0.09	0.16
Organic carbon (OC)	%	1.24	1.93
Organic matter (OM)	%	2.13	3.09
Available Phosphorus	Ppm	11.4	25.13

experimental sites soil was 11.4-25.13 ppm, which lies in a range of deficiency (< 20-40 ppm) for most crops (Landon, 1991).

Treatments:

The experimental treatments were comprised of factorial combinations of seven seed rates (40, 60, 80, 100, 120, 140, and 160 kg ha^{-1}) and 4 row spacings (15, 20, 25, 30 cm). Line sowing by drilling was the method of planting. The gross size of plots was 2m x 4m accommodating the number of rows per plot of 13, 10, 8 and 6 for the respective row spacings. The net plot size was 1.65m*3 m (4.95m^2) for 15cm, 1.6m*3 m (4.8m^2) for 20cm, 1.5m*3m (4.5 m^2) for 25cm and, 1.2m *3 m (3.6 m^2) for 30cm inter row spacing which were made by excluding both the right and left of two outer rows, and the top and bottom border effect of 0.5m each side of the gross plot for each treatment unit. The commonly grown NERICA-4 upland rice variety was used for the experiment.

Data collection:

Data were collected on plant height, panicle length, number of total tillers/m, number of effective tillers/m, number of fertile spikes/panicle, thousand seeds weight, grain yield, straw yield and harvest index. The plant height was taken at physiological maturity of the crop by selecting five random tillers. Number of tillers were counted just before harvesting by random sampling using rulers. The total sundried biomass of the harvested rice was recorded before threshing. The harvest index was calculated as the ratio of grain yield to biological yield following the equation (Payman & Surjit, 2008).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

The rice grain yield and thousand seeds weight were adjusted at 14% standard moisture content.

Data analysis:

All collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.2 (SAS-Institute, 2008). Since the test of homogeneity of variances for each parameter across locations and years was non-significant, combined analysis of variance was done (Gomez & Gomez, 1984).

Wherever treatment differences are be found significant, mean separation of treatments was calculated based on results of F-test and probability levels of 0.01 and 0.05 depending the results of the ANOVA. Economic analysis was carried out by following CIMMYT (1988) procedures by taking all variable costs. The prevailing cost of inputs and out puts in year 2019 considered for the analysis. Paddy rice grain and seed prices of Birr 13.5kg^{-1} and straw price Birr 1.2 Birr kg^{-1} were considered for the economic analysis. Following the CIMYYT (1988) partial budget analysis method, grain and straw yield adjustments, calculations of total variable costs (TVC), gross benefits (GB) and net benefits (NB) were performed (Table 6). Dominance analysis was carried after arranging the treatments in their order of TVC. A treatment will be considered as dominated if it has higher TVC but lower NB than a previous treatment with lower TVC and higher NB. Non dominated treatments were taken out and marginal rate of return (MRR) was computed (Table 7). According the to the CIMYYT (1988) partial budget analysis methodology, treatments exhibiting the minimum or more MRR (>100%) will be considered for the comparison of their NB.

RESULTS

The analysis of variance indicated that the main effect of seed rate was significantly affecting plant height, panicle length, total tillers/m, effective tillers/m, filled spiklets/panicle, grain yield and straw yields. On the other hand, the main effect of row spacing was significantly affecting panicle length, total tillers/m, effective tillers/m and filled spiklets/panicle.

The comparison among the seed rates indicated that the highest values of plant height (67.1 cm) and panicle length (17.6 cm) and numbers of fertile spiklets per panicle (88.9) were recorded at the 40 kg ha^{-1} seed rate (Table 2). The highest number of total tillers/m (85) and number of effective tillers/m (78.4) were recorded at the seed rate of 160 kg ha^{-1}. Among the seed rates, the highest grain yield (3.06 t ha^{-1}) and the highest straw yield (5.0 t ha^{-1}) were obtained at the seed rate of 120 kg ha^{-1} (Table 2).

In the current experiment, it was observed that panicle length, fertile spikes per panicle, grain and straw yields decreased much as the seed rate keep on increasing after the rate of 120 kg ha^{-1}. Between the row spacings, significant and higher values of panicle length (16.9 cm), number of total tillers per m row (83.0), number of effective tillers per m row (77.0) and fertile spikes per panicle (82.9) were recorded at the 30 cm row spacing (Table 3).

With respect to the interaction effect of seed rate and row spacing, total tillers/m, effective tillers/m, thousand seeds weight and straw yields were significantly affected (Table 5). Concerning the significant interaction effects, highest number of total tillers per 1m row (102.9) was obtained at the combinations of 160 kg ha^{-1} seed rate and 30 cm row spacing (Table 4). The significantly higher number of effective tillers per 1m row (86.9) was observed at the interaction of 160 kg ha^{-1} seed rate and 25 cm row spacing (Table 4). The combination of 100 kg ha^{-1} seed rate and 20 cm row spacing gave the highest thousand seeds weight (27.6 g) (Table 4). Highest straw yield of 5.84 t ha^{-1}was recorded at the interaction of 120 kg ha^{-1} seed rate and 20 cm row spacing (Table 4).

Economic management of agronomic practices is essential for improving crop productivity and environmental sustainability (Yousaf et al., 2016). Highest NB (Birr 43283.47 ha^{-1}) with acceptable level of MRR (868.6) was observed at the combined application of 120 kg ha^{-1} seed rate and 20cm row spacing (Table 8).

Table 2: Effect of seed rate on rice growth and yield parameters of rice

Seed Rate (kg/ha)	Plant height (cm)	Panicle length (cm)	Total tillers/m row	Effective tillers/m row	Fertile spikes/ Panicle	Grain Yield (t ha^{-1})	Straw Yield (t ha^{-1})
40	67.2^{a}	17.6^{a}	60.6^{f}	55.4^{f}	88.9^{a}	2.51^{c}	4.2^{d}
60	64.9^{b}	16.8^{bc}	63.3^{ef}	57.9^{ef}	87.1^{ab}	2.70^{b}	4.5^{cd}
80	64.0^{bc}	16.9^{b}	67.2^{ed}	62.7^{de}	82.4^{bc}	2.90^{a}	4.6^{a-d}
100	63.2^{c}	16.5^{cd}	71.1^{cd}	65.8^{cd}	79.9^{c}	2.91^{a}	4.5^{bcd}
120	61.8^{d}	$16.4d^{e}$	73.4^{cb}	67.9^{bc}	74.3^{d}	3.06^{a}	5.0^{a}
140	61.7^{d}	16.0^{e}	76.6^{b}	71.4^{b}	72.7^{d}	2.90^{a}	4.9^{ab}
160	61.2^{d}	16.2^{de}	85.0^{a}	78.4^{a}	70.5^{d}	2.97^{a}	4.8^{abc}
SE ($\pm$)	3.67	1.09	13.89	13.51	14.74	0.45	1.01

Table 3: Effect of row spacing on rice growth and yield parameters of rice

Row Spacing (cm)	Panicle length (cm)	Total tillers/m row	Effective tillers/m row	Fertile spikes/Panicle
15	16.5^{c}	59.4^{d}	54.6^{d}	78.8^{ab}
20	16.51^{bc}	67.8^{c}	62.7^{c}	76.1^{b}
25	16.8^{ab}	74.0^{b}	68.3^{b}	79.9^{ab}
30	16.9^{a}	83.0^{a}	77.0^{a}	82.9^{a}
SE ($\pm$)	1.09	13.89	13.51	14.74

Table 4. Effects of seed rate and row spacing on upland rice yield components

Row space	Seed Rate	Total No of Tillers/m row	No of Effective tillers/m row	1000 seed weight (g)	Straw Yield (t ha^{-1})
15	40	58.7^{gf}	54.7^{g-j}	26.4^{a-d}	4.1^{bc}
15	60	53.2^{g}	47.5^{j}	27.1^{a-d}	3.9^{c}
15	80	56.4^{gf}	53.1^{hij}	26.2^{cd}	4.7^{abc}
15	100	59.9^{gf}	54.7^{g-j}	27.4^{abc}	4.5^{abc}
15	120	57.6^{gf}	52.5^{hij}	26.8^{a-d}	4.9^{abc}
15	140	65.0^{efg}	59.7^{e-j}	26.7^{a-d}	4.5^{abc}
15	160	65.1^{efg}	59.9^{e-j}	26.6^{a-d}	4.9^{abc}
20	40	53.7^{g}	48.9^{ij}	26.6^{a-d}	4.5^{abc}
20	60	61.4^{gf}	57.2^{g-j}	27.1^{a-d}	4.8^{abc}
20	80	62.7^{efg}	58.5^{f-j}	27.0^{a-d}	4.3^{bc}
20	100	69.2^{c-g}	64.2^{c-h}	27.6^{a}	4.8^{abc}
20	120	70.9^{c-f}	64.1^{c-i}	26.1^{cd}	5.84^{a}
20	140	78.3^{b-e}	73.8^{b-e}	26.6^{a-d}	5.4^{ab}
20	160	78.4^{b-e}	72.5^{b-f}	26.8^{a-d}	4.5^{abc}
25	40	63.5^{efg}	57.4^{g-j}	26.9^{a-d}	4.2^{bc}
25	60	69.1^{c-g}	63.7^{c-i}	26.7^{a-d}	5.0^{abc}
25	80	66.5^{d-g}	60.7^{e-j}	26.9^{a-d}	5.1^{abc}
25	100	73.1^{c-f}	67.3^{c-h}	26.3^{bcd}	4.1^{bc}
25	120	73.0^{c-f}	68.7^{c-f}	26.2^{cd}	4.7^{abc}
25	140	79.4^{b-e}	73.3^{b-f}	26.4^{a-d}	4.9^{abc}
25	160	93.5^{ab}	86.9^{ab}	26.0^{d}	5.3^{abc}
30	40	66.5^{d-g}	60.7^{e-j}	25.91^{d}	4.1^{bc}
30	60	69.5^{c-g}	63.3^{d-i}	26.7^{a-d}	4.2^{bc}
30	80	83.4^{bc}	78.7^{bc}	26.5^{a-d}	4.3^{bc}
30	100	82.4^{bcd}	77.0^{bcd}	26.6^{a-d}	4.6^{abc}
30	120	92.3^{ab}	86.3^{ab}	26.8^{a-d}	4.5^{abc}
30	140	83.9^{bc}	78.8^{bc}	27.5^{ab}	4.8^{abc}
30	160	102.9^{a}	94.4^{a}	27.4^{abc}	4.6^{abc}
SE ($\pm$)		13.89	13.51	1.287	1.01

Table 5: Mean square values of Analysis of variance (ANOVA) for rice yield and yield components

Source of Variation	DF	Plant height (cm)	Panicle length (cm)	Total tillers/m row	Number of Effective tillers/ m row	No. of fertile spikes/panicle	Grain Yield (t ha^{-1})	1000sw/g	Straw Yield (t ha^{-1})	HI (%)
Location	4	5022.43**	41.88NS	9310.45**	6760.65**	5906.078**	46.80**	13.98**	104.43**	3628.15**
RS_cm	3	20.89NS	4.01*	10397.13**	9368.12**	826.86**	0.42NS	2.74NS	1.14NS	1.24NS
Rep	2	15.90NS	64.31**	1973.16**	847.86**	52.38NS	1.33**	4.16NS	2.67NS	47.11NS
SR_kg	6	268.97**	16.47**	4150.55**	3739.31**	3098.13**	2.074**	2.55NS	4.15**	56.28NS
Location*RS_cm	12	13.50NS	1.23NS	338.52NS	275.78NS	261.86NS	0.50*	1.90NS	0.45NS	46.47NS
Location*Rep	8	91.55**	25.51**	2535.47**	1297.44**	934.42**	0.39NS	2.74NS	2.47*	54.57NS
Location*SR_kg	24	15.104NS	1.041NS	258.69NS	265.88NS	299.70NS	0.18NS	1.43NS	1.85*	36.34NS
Rep*RS_cm	6	13.78NS	0.54NS	331.33NS	318.42NS	125.25NS	0.14NS	6.65**	0.62NS	12.45NS
RS_*SR	18	12.54NS	1.300NS	414.29**	413.39**	330.52NS	0.30NS	3.26*	2.47**	39.30NS
Rep*SR	12	14.50NS	1.99NS	274.26NS	293.80NS	177.48NS	0.23NS	6.22**	0.98NS	44.55NS
Location*Rep*RS	24	14.66NS	1.30NS	256.05NS	221.61NS	143.17NS	0.36*	1.98NS	1.07NS	27.69NS
Location*RS*SR	72	13.96NS	1.12NS	221.98NS	214.81NS	181.15NS	0.24NS	1.67NS	1.26NS	27.94NS
Location*Rep*SR	48	13.46NS	1.373NS	187.86NS	162.72NS	202.23NS	0.13NS	0.99NS	1.06NS	24.28NS
Rep*RS*SR	36	14.93NS	1.742NS	246.72NS	227.371NS	192.91NS	0.29NS	3.18**	1.476NS	33.23NS
Error	144	13.50	1.18	193.03	182.6439	217.23	0.22	1.6	1.012	33.45
SE ($\pm$)		3.67	1.09	13.89	13.51	14.74	0.45	1.28	1.01	5.78

Note: - RS= Row spacing, SR= Seed rate, DF= Degrees of Freedom.

Table 6: Grain and straw yield adjustments, total variable cost, gross and net benefit analysis

Row space (cm)	Seed Rate (kg ha^{-1})	GY (t ha^{-1})	SY (t/ha)	AGY (t ha^{-1})	ASY (t ha^{-1})	TVC (Birr ha^{-1})	GB (Birr ha^{-1})	NB (Birr ha^{-1})
15	40	2.5	4.1	2.3	3.7	2140	35147.9	33007.9
15	60	2.7	3.9	2.4	3.6	2410	36658.5	34248.5
15	80	2.8	4.7	2.6	4.3	2680	39647.8	36967.8
15	100	3.0	4.5	2.7	4.0	2950	41494.9	38544.9
15	120	2.9	4.9	2.6	4.4	3220	40947.4	37727.4
15	140	2.6	4.5	2.4	4.1	3490	36658.6	33168.6
15	160	2.7	4.9	2.5	4.4	3760	38692.1	34932.1
20	40	2.5	4.5	2.3	4.1	1740	35427.7	33687.7
20	60	2.7	4.8	2.5	4.3	2010	38386.7	36376.7
20	80	2.8	4.4	2.5	3.9	2280	38501.4	36221.4
20	100	3.0	4.8	2.7	4.3	2550	41782.7	39232.7
20	120	3.3	5.8	3.0	5.2	2820	46103.5	43283.5
20	140	3.2	5.4	2.8	4.8	3090	44136.8	41046.8
20	160	2.9	4.6	2.6	4.1	3360	40485.4	37125.4
25	40	2.4	4.2	2.2	3.8	1540	34296.3	32756.3
25	60	2.8	5.0	2.5	4.5	1810	38914.6	37104.6
25	80	3.1	5.1	2.8	4.6	2080	43464.8	41384.8
25	100	2.8	4.1	2.5	3.7	2350	38634.4	36284.4
25	120	3.2	4.7	2.9	4.2	2620	44165.8	41545.8
25	140	2.9	4.9	2.6	4.4	2890	40273.0	37383.0
25	160	3.1	5.3	2.8	4.8	3160	43693.3	40533.3
30	40	2.6	4.1	2.3	3.7	1440	35499.2	34059.2
30	60	2.7	4.2	2.4	3.8	1710	36871.6	35161.6
30	80	2.9	4.2	2.6	3.8	1980	39495.2	37515.2
30	100	2.8	4.6	2.5	4.1	2250	39347.1	37097.0
30	120	2.9	5.8	2.6	5.2	2520	41414.8	38894.8
30	140	3.0	4.8	2.7	4.3	2790	41473.5	38683.5
30	160	3.1	4.6	2.8	4.2	3060	42428.8	39368.8

Key: - GY=Grain Yield, SY=Straw Yield, AGY=Adjusted Grain Yield, ASY=Adjusted Straw Yield, TVC= Total Variable Cost, GB=Gross Benefit, NB=Net Benefit

DISCUSSION

In line with the present findings, the reports of Tekle and Wedajo (2014) and Harris and Vijayaragavan, (2015) indicated that rice plant height was significantly affected by seed rate. Alhassan & Isah (2018) had stated that the seed rate affected rice panicle length. Similar to the current observation, Matsumoto et al. (2017) found that more tillers/m^2 resulted from higher plant density of rice. The results of Harris & Vijayaragavan (2015) similarly also revealed that the seed rate of 143.5 kg ha^{-1} compared to 60 kg ha^{-1} significantly increased the number of panicles m^{-2}, the number of spikelets/panicle and percentage of filled grains.

Cognizant to the current finding, total biomass weight was significantly ($P < 0.001$) affected by seed rate in the study of Tekle and Wedajo (2014). The investigation of Harris and Vijayaragavan (2015) has also showed that increasing seed rate beyond 140 kg ha^{-1} will not be beneficial as it will increase the mutual shading which will result in lower yields. It should also be noted that though the rise in plant density increases the number of panicles/unit area, it did not compensate for the reduction in above yield parameters, thus resulting in a decrease in yield (Harris & Vijayaragavan, 2015). The inverse response of basic yield components to increased seed rate beyond the optimum may most probably associated with the induced competitions for light due to mutual shading, and fertilizer nutrients, resulting in lower grain-filling rate and grain-weight/grain, which could be particularly important in upland rice cultivation (Jana et al., 2018; Matsumoto et al., 2017).

Higher seeding rate is one approach that helps in increasing crop competitiveness against weeds (Sharif et al., 2014). At low seeding rate rice crop plants take more time to close their canopy which encourages the weed growth (Sharif et al., 2014). High seeding rate facilitate quick canopy closure, which helps suppress weeds more effectively. Despite improvement in weed management, higher seeding rate may exacerbate problems like lodging, insect and diseases infestation and rat damaged that

Table 7: Dominance Analysis

Row space (cm)	Seed Rate (kg/ ha)	TVC (Birr/ha)	NB (Birr/ha)	D
30	40	1440	34059.2	
25	40	1540	32756.3	D
30	60	1710	35161.6	
20	40	1740	33687.7	D
25	60	1810	37104.6	
30	80	1980	37515.2	
20	60	2010	36376.7	D
25	80	2080	41384.8	
15	40	2140	33007.9	D
30	100	2250	37097.1	D
20	80	2280	36221.4	D
25	100	2350	36284.4	D
15	60	2410	34248.5	D
30	120	2520	38894.8	D
20	100	2550	39232.7	D
25	120	2620	41545.8	
15	80	2680	36967.8	D
30	140	2790	38683.5	D
20	120	2820	43283.5	
25	140	2890	37383.0	D
15	100	2950	38544.9	D
30	160	3060	39368.8	D
20	140	3090	41046.8	D
25	160	3160	40533.3	D
15	120	3220	37727.4	D
20	160	3360	37125.4	D
15	140	3490	33168.6	D
15	160	3760	34932.1	D

D – Dominance

Table 8: Marginal Rate of Return (MRR) Analysis

Row space (cm)	Seed Rate (kg/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
30	40	1440	34059.2	
30	60	1710	35161.6	408.3
25	60	1810	37104.6	1943.1
30	80	1980	37515.2	241.5
25	80	2080	41384.8	3869.7
25	120	2620	41545.8	29.8
20	120	2820	43283.5	868.8

harm the crop yield (Jana et al., 2018). Thus, maintaining optimum seed rate considering efficient utilization of growth resources, weed management and overall productivity is a crucial issue.

The report of Jana et al. (2018) indicate that higher value of panicle number was produced in wider spacing which have the capacity to capture more sunlight because of less mutual shading effect among the leaves and less competition for nutrients in wider spacing. Similarly, Baloch et al. (2002) stated that the increased plant spacing considerably resulted in vigorous plant growth and caused a significant increase in number of panicles per hill and filled grain per panicle of rice.

Significant effects of row spacing and seed rate of rice on number of effective (panicle bearing) tillers is reported by different authors (Jana et al., 2018). In line with the current result, Harris and Vijayaragavan (2015) reported maximum 1000-grain weight at 143.5, kg ha^{-1} (Table 4) and the lowest thousand grain weight observed at 205 kg ha^{-1}. The higher value was probably owing to more filling of starch in better grain development. Among the measured parameters, the harvest index (HI) was affected neither by the main nor by the interaction effects of the seed rates and row spacings (Table 2). In conformity to the current study, Payman and Surjit (2008) stated that seed rate and row spacing did not influence the harvest index of rice.

In conclusion, use of optimum plant population is important to insure better productivity of rice. The present experiment was conducted to recommend appropriate levels of row spacing and seed rates for rainfed upland rice production in Fogera and Libokemkem areas of the Amhara Region, Northwest Ethiopia. Highest grain yield (3.06 t ha^{-1}) was obtained from the seed rate of 120 kg ha^{-1}. Based on the statistical and economic analysis it is concluded that combined use of 120 kg ha^{-1} seed rate and 20 cm row spacing is the best recommended for upland rice production in the study area and other similar upland rice production ecologies

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