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Effect of Seed Rate on Yield and Yield Components of Aerobic Rice (*Oryza sativa* L.) Under White Nile State Conditions

Amna A. Abdalla, Ahmed A. Elsiddig and Alawia O.Hassan

White Nile Research Station, P. O. Box 300 Kosti, Sudan

Abstract: A field experiment was conducted for two consecutive seasons (2014 and 2015), at the White Nile Research Farm, Kosti, White Nile State, Sudan, to determine the seed rate for aerobic rice (*Oryza sativa* L.). The variety Kosti1 was sown directly on flat dry soil with varying seed rates: 40, 60, 80 and 100 kg/ha. The experiment was arranged in a randomized complete block design with three replications, in the two seasons. The land was pre-irrigated and then disc harrowed and leveled. The crop was planted during the first week of July in both seasons. Characters studied were, Phenology, yield, biological yield and yield components. The combined and single analyses of variance for both seasons showed that seed rate treatments exhibited highly significant differences in grain yield and yield components. The results showed that, increasing seed rate significantly increased number of panicles/ m^2, the percentage of empty grains, plant height, grain yield and biological yield. However, increasing seed rate reduced days to 50% flowering, the filled grains and the 1000- grain weight. The results indicated that the seed rate (80 kg/ha) significantly increased the number of panicles/m^2, biological yield and grain yield (kg/ha). The lowest and the highest yields/ha were obtained at the seed rates of 40 and 80 kg/ha, respectively. The results indicated that, increasing seed rate from 40 to 60 kg/ha increased grain yield by 10 % and 16 % in the first and second seasons, respectively; and that grain yield could be improved significantly in the two seasons by 6 % and 18 % by increasing seed rate from 60 to 80 kg/ha. However, increasing seed rate from 80 to 100 kg/ha reduced the grain yield by 17 % and 23 % in the first and second seasons, respectively. The highest marginal rate of return (MRR) 1496 % was obtained from the 80 kg/ha seed rate. Therefore, it is concluded that the optimum seed rate under the conditions of the present investigation was 80 kg/ha.

Key words: *oryza sativa*, aerobic rice, seed rate, yield components, marginal rate of return

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important global food crops and a primary source of calories for more than half of the world's population. Rice production increased steadily during the green revolution era primarily as a result of introducing high-yielding rice varieties. World rice production increased at a rate of 2.3 %–2.5 % per year during the 1970s and 1980s, but this rate of growth was only 1.5 % per year during the 1990s. The yield growth rate for rice has further declined during the first decade of this century. However, the populations in the major rice-consuming countries continue to grow at a rate of more than 1.5 % per year (Jong-Seong *et al.* 2011). Rice is planted on about 148 million hectares annually, *i.e.* on 11 % of the world's cultivated land. It is the only major cereal crop that is consumed almost exclusively by humans (Khush 1997). The world's production of rice in 2010 was 701.128 million tons in an area of 161.762 million hectares and yield of 4.3 ton/ha. (FAO 2013).

Aerobic rice is a rice that can grow in well-drained, non-puddle and non-saturated soils and combines drought tolerance of upland rice and yield potential of lowland rice. Therefore, aerobic rice is "improved upland rice" in terms of yield potential, and "improved lowland rice" in terms of drought tolerance.

Sudan has a total estimated potential rice area of more than 300.000 hectares. If this area is properly managed, it will meet the local consumption demand to fill the gap for non-course food grains. In the White Nile State, rice is grown as a flood crop in an area of 8403.4 hectares (20000 feddan); the yield is low (0.98-1.2 t/ha), compared to yield at a research station (3.0 t/ha), due to the fact that the farmers use poor production technologies mainly low- yielding cultivars .

Aerobic rice is a potential crop in the White Nile State, where big irrigated schemes exist along the White Nile, presence of knowledge about the crop in general and availability of irrigation water. In addition,

rice is a cash crop for export benefiting both farmers and government and, therefore, would be a suitable option for the farmers.
Recently, the Agriculture Research Corporation has released four aerobic rice varieties (Kosti 1, Kosti 2, wakra and Umgar) (Mustafa *et al.* 2010). However, few and scattered research efforts were carried out to generate integrated packages for these varieties. The crop depends largely on temperature, solar radiation, moisture and soil fertility for its growth and nutritional requirements. A dense population of the crop may have limitations in the optimum level of these factors. It is, therefore, necessary to determine the optimum density of plant population per unit area for obtaining maximum yields. A number of workers have reported that maintenance of a critical level of rice plant population in the field was necessary to maximize grain yields. Counce (1987) suggested that population density ranging from 159 to 304 plants per m^2 could produce maximum yield under dry seeded and flooded rice production systems. The seeding rates of 50 to 168 kg/ha are necessary for obtaining maximum yield under direct seeded cultures depending on the inter-row spacing (Bari *et al*. 1984; Jones and Synder 1987; Bisht *et al*. 1999) and panicles per m^2 (Miller *et al*. 1991; Gravois and Helms 1992). Moreover, crop establishment is one of the key factors that affects the success of grain crop (Oghalo 2011). Optimum crop establishment not only improves crop performance but also reduces seeding rates needed for field planting. Optimum plant density is the principal factor for obtaining higher yield in rice (Sivaesarajah *et al* .1995). Hence, the objective of this study was to determine the suitable seed rate for the newly released aerobic rice cultivar Kosti1.

MATER IALS AND METHODS

An experiment was conducted at the White Nile Research Farm at Kosti, White Nile State, Sudan, (latitude 13° 10́ N, longitude 32° 40́ E and altitude 410 metres above sea level) during 2014 and 2015 cropping seasons. The climate of the locality is semi-arid with a cool dry winter and a hot summer. The rainy season extends from July to October with peak in August. The mean annual rainfall is around 330 mm. The monthly mean maximum and minimum temperatures, relative humidity and rainfall during the experimental period were recorded for the two seasons

from Kosti Agro meteorological Station. The soil of the farm is characterized by high clay content, heavily cracking Vertisols.
The released rice variety Kosti1 was sown directly on flat dry soil with varying seed rates as follows:
1- T1= 40 kg/ha
2- T2= 60 kg/ha
3- T3 = 80 kg/ha
4- T4 = 100 kg/ha

The treatments were arranged in a randomized complete block design with three replications. The land was pre-irrigated and then prepared by disc harrowing and leveling. The crop was planted on the first week of July during both seasons. The plot size was 7m * 6 m and 3m * 6 m in the first and second seasons, respectively; the inter-row spacing was 0.2 m. Triple super phosphate fertilizer was applied uniformly at a rate of 43 kg P_2O_5 /ha at land preparation. N fertilizer in the form of urea was applied at a rate of 86 kg N /ha in two split doses, after full emergence (10-14 days after sowing) and at maximum tillering (3 weeks from the first dose). The crop was kept weed free by hand weeding whenever needed. Irrigation was done every 8 days till heading then every 3-5 days till maturity.

Data were collected on:

1. Phenology: Days to flowering and days to maturity.
2. Plant height at maturity.
3. Number of tillers/plant.
4. Number of panicles / m^2
5. Number of fertile grains /panicle.
6. Percentage of empty grains (sterility).
7. 1000 grain weight (g).
8. Grain yield (kg/ha)
9. Biological yield (kg/ha)
10. Harvest index (%)

The data were collected according to standard evaluation systems for rice SES (IRRI 2002). Ten randomly selected plants in the middle of the rows of each plot were used for data collection. Data were statistically analyzed using IRRISTAT computer program.

Economic evaluation

Economic evaluation was conducted, using partial budget analysis, to calculate the economic return and net benefits of the different seed rates. Economic evaluation was conducted to reach the most economic and profitable levels. The marginal rate of return (MRR) was equal to the marginal net benefit (MNB) divided by the marginal cost (MC) times 100.
MRR (%) = MNB/MC*100

RESULTS AND DISCUSSION

Crop phenology:

The results showed that, seed rate significantly influenced days to flowering (Table 1). The lowest seed rate treatment (40 kg/ha) took longer time to flower, i.e. 84, 82 and 83 days in the first and second seasons and combined analysis, respectively, in comparison to high seed rate treatment (100 kg/ha) which took 74 and 77 days to flower in the first and second seasons, respectively (Table 1). However, the seed rate treatment of 60 kg/ha took 81 days to flower in the two seasons, while the seed rate treatment 80 kg/ha reached flowering after 81, 79 and 80 days in the first, second and combined analysis, respectively (Table 1). The result showed that, the seed rate treatments did not affect the maturity stages in the two seasons (Table 1).

Plant height was statistically different among seeding treatments (Table1). In the two seasons, plants were highest at the seed rate of 100 kg/ha. The seed rate of 40 kg/ha recorded the lowest values of plant height in the two seasons. However, plant height of 75, 86.5 and 80.8 cm in the first, second and combined analysis, respectively, were observed at seed rate treatment 60 kg/ha. ,while the values 78.2, 86.6 and 82.4 cm were recorded for 80 kg/ha seed rate treatment in the first, second and combined analysis, respectively (Table 1). This indicates that when the plant spacing is closer (high seeding rate), the plant tends to grow taller in search for light. That means as the number of plants/m^2 increases , plants compete for light. Thus, The plants grow taller. This result is consistent with those reported by Sharma (1994), Zhang *et al.* (2006), and Harris and Vijayaragavan (2015). In contrast, Akbar and Ehsanullah (2004) reported that seeding density had no significant effect on plant height.

Number of tillers / plant

Seed rate treatments affected the number of tillers / plant. The highest number obtained was in low seed rate which recorded 2.3, 2.5 tillers / plant in the first and second seasons, respectively (Table 2). The results indicated that there were no significant difference among the seed rates of 60, 80 and 100 kg/ha (Table 2).

Table 1. Effect of different seed rates on days to 50 % flowering, days to 80 % maturity and plant height (cm) of aerobic rice in seasons 2014, 2015 and their combined analysis

Seed rate (kg/ha)	Days to 50 flowering			Days to 80 % maturity			Plant height (cm)		
	2014	2015	Comb-ined	2014	2015	Com-bined	2014	2015	Com-bined
40	84	82	83	101	106	104	70.9	86.0	78.5
60	81	81	81	101	106	104	75.0	86.5	80.8
80	81	79	80	98	102	100	78.2	86.6	82.4
100	74	77	76	97	98	98	81.8	89.7	85.8
Means	**80**	**80**	**79.8**	**99**	**103**	**101**	**76.5**	**87.2**	**81.9**
SE±	1.2*	1.3^{NS}	0.91*	3.9^{NS}	0.25^{NS}	1.97^{NS}	2.0*	1.1*	1.1**
C.V	2.7	2.9		6.9	1.0		4.5	2.2	

*, **, = Significant at 5% and 1%, probability level, respectively.
NS = Not significant
SE± standard error of adjacent means
C.V. coefficient of variability.

Number of panicles/ m^2

Increasing seed rate significantly increased number of panicles/ m^2.The highest seed rate (100 kg/ha) recorded the highest number of panicles/ m^2 and the lowest seed rate (40 kg/ha) recorded the lowest value (Table 2). Although the highest seed rate produced higher number of panicles/ m^2 compared to the lower seed rate, it could not compensate for the reduction in number of fertile grains and 1000 -grain weight to gain the highest grain yield. Similar findings were reported by Mahajan *et al.* (2010) who stated that higher than optimum initial seeding density resulted in more panicles/m^2, yet was accompanied by reduced panicle size and 1000 -grain weight, and high rate of spikelet sterility. Likewise, Harris and Vijayaragavan (2015) reported that, although yield per plant was higher at the lowest seed rate, this did not compensate for the contribution in terms of yield by more plants at the higher density.

Table 2. Effect of different seed rates on number of tillers /plant, number of panicles / m^2 and number of filled grains/ panicle of aerobic rice in seasons 2014, 2015 and their combined analysis

Seed rate (kg/ha)	No of tillers /plant			Number of panicles / m^2			Number of filled grains/panicle		
	2014	2015	Com-bined	2014	2015	Combi-ned	2014	2015	Com-bined
40	2.3	2.5	2.4	249	252	251	71	68	69
60	2.1	2.1	2.1	254	292	273	67	65	66
80	1.8	2.1	1.9	258	335	296	65	65	65
100	1.8	2.1	1.9	275	348	312	52	59	56
Mean	**2.0**	**2.2**	**2.1**	**259**	**307**	**283**	**64**	**64**	**64**
SE$\pm$	0.12^{NS}	0.11^{NS}	0.92^{*}	2.7^{*}	11.6^{**}	7.6^{***}	2.7^{*}	2.5^{NS}	1.8^{**}
C.V	10.9	10.7		4.8	6.8		7.3	6.8	

*, **, *** = Significant at 5%, 1%, and 0.1% probability level, respectively.
NS = Not significant

Number of filled grains/plant

The highest number of filled grains/panicle was obtained at 40 kg/ha in the first, second seasons and combined analysis, respectively (Table 2). As seeding rate increased, the filled grains per panicle remarkably decreased, which is in agreement with Murata *et al.* (1957) who reported that when seed rate was increased beyond an optimum point, it increased the photosynthetic apparatus and vegetative parts per unit area, thus increasing the respiration which in turn could lead to a reduction of filled grains. Other similar reports were by Baloch *et al* (2002), Akbar and Ehsanullah (2004), and Harris and Vijayaragavan (2015). This indicates that compared to panicle density, the effect of filled grains per panicle is the most important factor in contributing to yield.

Percentage of empty grains

Increasing seed rate significantly increased the percentage of empty grains (sterility). The highest percentage of empty grains were recorded for the high seed rate of 100 kg/ha (Table 3). Similar findings were reported by Mahajan *et al.* (2010) who stated that higher than optimum initial seeding density for obtaining more panicles/m^2 was often accompanied by reduced panicle size and high rate of spikelet sterility.

1000- grain weight (g)

The highest 1000- grain weight was recorded at 40 kg/ha in the combined and single analysis of both seasons (Table 3) and the lowest was recorded at 100 kg/ha, yet differences among rates were not significant in both seasons; the higher values were probably due to better grain filling. Similar findings were reported by Harris and Vijayaragavan (2015) who showed that increasing seed rate beyond the optimum will not be beneficial as it would increase the mutual shading and respiration.

Grain yield, biological yield and harvest index

Seed rate significantly influenced grain yield and biological yield (Table 4). The highest grain yield and highest biological yield were obtained by the 80 kg/ha seed rate (Table 4). The results indicated that harvest index was not significantly affected by seed rate in the first and second seasons and in the combined analysis (Table 4).

The high grain yield at 80 kg/ha seed rate probably resulted from high number of panicles/ m^2, number of fertile grains, and 1000- grain weight (Tables 2 and 3). Similar results have been reported by Baloch *et al*. (2002). The plants at low seed rate had sufficient space and this enabled them to use more nutrients, water and solar radiation for better photosynthesis (Harris and Vijayaragavan 2015). On the other hand, plant height, panicles /m^2, and percentage of empty grains increased with increasing seed rates. Supporting results were also reported by Bhagirath *et al*.(2011). Moreover, it may be possible that at the 80 kg/ha seed rate, the contribution from each plant towards flower and grain formation is greater than that from the lowest seed rates together with greater radiation during the reproductive and ripening stages (Evans and De Datta 1979). The highest yield may also be due to the higher panicle and spikelet number /m^2, 1000- grain weight and harvest index (Harris and Vijayaragavan 2015). Furthermore, the grain yield per unit area depends on the performance of individual plants, panicle density as well as the plant density. The performance of individual plants grown with wider spacing was better than that of plants with narrower spacing. A balance has, therefore, to be made between the performance of individual plants and the plant density per unit area for obtaining optimum crop yields (Baloch *et al.* 2002).

Table 3. Effect of different seed rates on % of empty grains and 1000 grain weight (g) of aerobic rice in seasons 2014, 2015 and their combined analysis

Seed rate (kg/ha)	% of empty grain			1000 grain weight (g)		
	2014	2015	Combined	2014	2015	Combined
40	24	30	27	28.7	28.2	28.5
60	30	31	31	28.5	28.1	28.3
80	36	34	35	28.0	27.9	27.9
100	38	39	39	27.6	27.7	27.6
Means	**32**	**33**	**33**	**28.2**	**28.0**	**28.1**
SE+	3.3*	1.7*	1.9**	0.39^{NS}	0.15^{NS}	0.21*
C.V	17.8	9.0		2.4	1.0	

*, **, = Significant at 5% and 1%, probability level, respectively.
NS = Not significant

Table 4. Effect of different seed rates on grain yield (kg/ha) , biological yield (kg/ha) and harvest index(%) of aerobic rice in seasons 2014, 2015 and their combined analysis.

Seed rate(kg /ha)	Grain yield (kg/ha)			Biological yield(kg/ha)			Harvest index (%)		
	2014	2015	Com-bined	2014	2015	Comb-ined	2014	2015	Com-bined
40	2820	2619	2720	8993	7697	8345	31.2	33.6	32.4
60	3129	3121	3125	9465	10745	10105	33.1	28.9	31.0
80	3344	3801	3572	10160	10833	10497	32.9	35.1	34.0
100	2868	2663	2765	9589	8264	8926	29.9	31.3	30.6
Means	**3040**	**3051**	**3046**	**9552**	**9385**	**9468**	**31.8**	**32.2**	**32.0**
SE$\pm$	175^{NS}	210*	137**	232*	794*	414*	1.6^{NS}	2.2^{NS}	1.3^{NS}
CV	10	12		4.2	14.7		8.5	11.7	

*, **, = Significant at 5% and 1%, probability level, respectively.
NS = Not significant.

Economic analysis:

Gross marginal, dominance and partial budget analysis for different rice seed rates treatments are presented in Tables 5 and 6. The seed rates of 60 and (80 kg/ha) gave positive net return. The highest marginal rate of return 1496 % was obtained from the seed rate of 80 kg /ha.

Table 5. Partial budget and dominance analysis of rice seed rates

Seed rate (kg/ha)	Grain yield (kg/ha)	Seed cost (SDG/ha)	Gross benefits (SDG/ha)	Net benefits (SDG/ha)	dominance
40	2720	560	27200	26640	
60	3125	840	31250	30410	
80	3572	1120	35720	34600	
100	2765	1400	27650	26250	D

(Data are average of two seasons, 2014 and 2015)
Seed price = 14 SDG/kg
Grain price =10 SDG/kg

Table 6. Marginal analysis of rice seed rates

Seed rate (kg/ha)	Seed cost	Net benefit	MR	MC	MRR%
40	560	26640	0	0	
60	840	30410	3770	280	1346
80	1120	34600	4190	280	1496

MR= marginal return
MC= marginal cost
MRR=marginal rate of return

CONCLUSION

Increasing seed rate of aerobic rice from 40 to 60 kg/ha increases grain yield by 10% to 16%. Grain yield could also be improved significantly in the two seasons by 6% and 18% by increasing seed rate from 60 to 80 Kg/ha. However, further increase of seed rate from 80 to 100 kg/ha reduces the grain yield by 17% and 23% in the first and second seasons, respectively. The highest marginal rate of return (1496%) could be obtained from the seed rate of 80 kg /ha. Therefore, this study concludes that, the optimum seed Rate for rice under the conditions of the present investigation is 80 kg/ha.

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أثر معدل البذر على انتاجية ومكونات الانتاجية لمحصول الارز الهوائى تحت ظروف ولاية النيل الابيض

امنه احمد عبدالله واحمد عبدالقادر الصديق وعلوية عثمان حسن
محطة بحوث النيل الأبيض، ص ب 300، كوستي- السودان

المستخلص: أجريت تجربة حقلية لموسمين متتاليين خلال عامى 2014 و 2015 بمزرعة محطة بحوث النيل الابيض, لتحديد معدل البذر الامثل لمحصول الارز الهوائى. تمت زراعة صنف الارز المجاز كوستى1 مباشرة على تربة جافة ومسطحة بمعدلات بذر مختلفة: 40, و60, و 80, و 100 كيلوجرام للهكتار. صممت التجربة على أساس القطاعات العشوائية الكاملة بثلاثة مكررات . تم رى الارض قبل الحراثة ثم حضرت بتمشيط قرصى وسطحت بعد ذلك. تمت الزراعة فى الاسبوع الاول من شهر يوليو للموسمين. الصفاة التى تمت دراستها شملت: الازهار, والنضج, والوزن الحيوى, والانتاجية ومكوناتها. أظهرت نتائج تحليل التباين الفردى والتجميعى لمعاملات معدل البذر اثراً معنوياً عالياً للانتاجية ومؤشراتها. اوضحت النتائج ان زيادة معدل البذر تزيد معنوياً عدد السنابل فى المتر المربع, ونسبة الحبوب الفارغة, وطول النبات, وانتاجية الحبوب والوزن الحيوى. وعلى العكس فأن زيادة معدل البذر انقصت عدد الايام الى 50% ازهار, والحبوب الممتلئة ووزن الالف حبة. اظهرت نتائج هذه الدراسة ان معدل البذر 80 كجم/هـ يزيد معنوياً عدد السنابل فى المتر المربع, والوزن الحيوى وانتاجية الحبوب (كجم/ هـ). ادنى واعلى انتاجية للهكتار حصلت من معدل بذر 40 و80 كجم/ هـ ، على التوالى . اوضحت النتائج ان زيادة معدل البذر من 40 كجم/هـ الى 60 كجم/هـ تزيد انتاجية الحبوب ب 10% و 16% فى الموسم الاول والثانى، على التوالى. امكن رفع انتاجية الحبوب معنوياً فى كلا الموسمين من 6% و 18% بزيادة معدل البذر من 60 كجم/هـ الى 80 كجم/هـ. ولكن زيادة معدل البذر من 80 كجم/هـ الى 100 كجم/هـ انقصت انتاجية الحبوب ب 17% و 23% فى الموسم الاول والثانى, على التوالى. تم اجراء التقييم الاقتصادى للحصول على اعلى مستوى اقتصادى ربحى, فكان اعلى معدل عائد حدى (1496%) من معدل البذر 80 كجم/هـ. عليه خلصت هذه الدراسة الى ان انسب معدل بذر تحت ظروف البحث الحالية هو 80 كجم/هـ.