© October 2022 | IJIRT | Volume 9 Issue 5 | ISSN: 2349-6002

Effect of Land Fertility Gradient on Yield of Rice

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***Abstract* - Among thirty ecological zones in Bangladesh, the cultivable land for agriculture is mostly not homogenously fertile. For rice cultivation, Bangladesh has high, medium-high, medium, and low land ecosystems. Due to the differential and low land fertility among different ecosystems, the productivity of rice is often compromised. On-farm evaluation trials are essential to be conducted in homogenously fertile plots for better evidence-based decision-making scenarios for the identification of promising rice hybrids, and their advancement. In the present study effect of land, and fertility gradients on productivity was judged based on the responses of two hybrids two hybrid varieties, and two breeding lines. The experiment was conducted in the Mawna region of Bangladesh in 2021 in the Aman (wet) season to assess the effect of soil fertility gradients on yield and yield contributing characteristics. Significant differences were observed in yield and yield contributing parameters of these 4 genotypes, recorded from homogenous and non-homogenous fertile lands. The percentage of yield loss due to land fertility gradient of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261was 13.89, 16.25, 7.76, and 14.00 respectively. Thus, the study shows that the land fertility gradient significantly affects yield and the contributing characteristics of rice.**

Keywords: Hybrid, Rice, Fertility gradients, homogenous land, soil, evaluation trial

I. INTRODUCTION

Global population is increasing and so does the demand for food production, which has already created tremendous pressure on soil, a finite resource for mankind. Global population is increasing and so does the demand for food production, which has already created tremendous pressure on soil, a finite resource for mankind. Global population is increasing and so does the demand for food production, which has already created tremendous pressure on soil, a finite resource for mankind.

Rice (*Oryza sativa*) is an important cereal, fulfilling the food necessities of more than half of the world's population (Maiti et al., 2020). Globally, rice is cultivated over 162.1 million hectares, producing 504.2 million metric tons of milled rice in 2019 (Shahbandeh, 2021). Rice is mainly grown and consumed in Asian countries (China, India, Indonesia, Bangladesh, Vietnam) with 80% of global production (Abdullah et al., 2020). The agricultural sector accounts for 19.29% of Bangladesh's GDP (Gross Domestic Product) and is a major source of employment. Further, 13.4% of this 19.3% is derived from crop production and rice alone contributes 46% of it. The significance of rice in Bangladesh is evident from the fact that it accounts for 91% of the total food grain production. It is a staple food for more than 99%

of its population. Per capita consumption of rice is around 416 gm per person per day (Maiti et al., 2020). Thus, rice is at the center of the food security-environment-sustainability web in Bangladesh. The global population is increasing and so does the demand for food production, which has already created tremendous pressure on soil, a finite resource for mankind (Biswas et al., 2019). As the population increase rate is very high, it is necessary to produce more rice for feeding more people in the future. Therefore, choosing an appropriate rice variety/ hybrid is very much important to mitigate the feeding challenge of the increasing population. The field trials are a very effective way of selecting the best-performing rice genotypes. Selecting suitable land for the experiment is important for genotype selection based on their performance.

Soil fertility is the ability of soil to sustain plant growth by providing essential plant nutrients and favorable chemical, physical, and biological characteristics as a habitat for plant growth. The impacts of soil fertility are reflected in most of the Sustainable Development Goals, as they contain economic, social, and environmental aspects. The fertility gradient is one of the most important factors for conducting trials for a rice breeder (Fageria, 2007). In a non-homogenous plot with varying fertility gradients, the actual performance of a genotype is not expressed properly. Besides, soil nutrient availability is limiting in cultivated lands of tropical countries because of low inherent soil fertility (FAO, 2011). Soil fertility gradients are responsible for decreased or unstable rice yield at smallholder farms. So, it is important to design soil fertility management interventions considering the yield loss of rice-growing farmers (Tittonell et al., 2007). Possible causes underlying these fertility gradients at the farm level are differences in inherent soil properties due to a specific position in the landscape, referred to as soil-scapes by Deckers (2002), distance to the homestead, or farmer-induced differences in the management of the different fields.

The land is the most important natural resource that provides a livelihood for the majority of people in Bangladesh. There are thirty agroecological zones in Bangladesh. All along the agroecological gradient, spatial and temporal variability of yield gaps (Becker et al., 2003). That is why there are different types of land in Bangladesh such as high, medium-high, medium, low land, etc. Mostly, the lands are not fertile homogeneously, also land fertility has directions. Sometimes the fertility gradient is in a single direction (Taplin et. al., 1994), and sometimes it is in several directions that cause a part of the land to be more fertile, and another part to be less. It is believed that more than 65% of the total agricultural land is suffering from declining soil fertility and about 85% of the net area suitable for cultivation has organic matter below the minimum requirement (TFR, 1991). Soil analysis of 460 samples from 43 profiles from the same locations between 1967 and 1995 revealed a decline in fertility (Ali et al., 1997) although this decline in soil fertility has not been explicitly linked to the green revolution. Thus, the pattern of fertility gradients should be considered before conducting trials to get accurate results. To identify the best performing rice genotypes through a yield trial, the plant breeders must conduct the trials of rice over the seasons. This present study was conducted with a yield trial considering variable land fertility gradients to confirm the effect of yield (Vanlauwe et al., 2011) during the year 2021during T. Aman season (Wet season), and the following objectives were set for the experiment:

1. To know the effect of soil fertility gradient on yield and yield contributing factors.
2. To estimate the yield loss due to the fertility gradient of the land.

II. MATERIALS AND METHODS

The trial of this study was conducted in the year 2021 at T. Aman (wet) season Mawna area (at 24 15’ 18” North and 90 18’ 00” East), district Gazipur, Bangladesh. The land fertility of the trial plots was measured with soil pH. Two lands were selected, one had fertility directions, and another was homogenously infertile. All essential nutrients are available at a soil pH of less than 7, and the soil is regarded as fertile. In the case of more fertile land, we found soil pH was 6, on the other hand, 7.5 soil pH was found on less fertile land.

The trial was conducted using 2 hybrid rice varieties (BRRI Hybrid Dhan5, and BRRI Hybrid Dhan6) and 2 advanced rice breeding lines (NASH 260, and NASH 261) which were taken from Bangladesh Rice Research Institute (BRRI) and Advanced Chemical Industries Limited (ACI) respectively. The seeds were sown on 7 July 2021 and transplanting was done 21 days after sowing. Single seedlings were transplanted in the field with a spacing of 20 cm plant to plant and 20 cm row to row. Each plot size was maintained as $10.08m^2$. Standard crop management practices mimicking growers' schedules for T. Aman rice were followed for all the trials. Two research experiments were implemented in the same season using a randomized completed block design (RCBD) with 3 replications.

For ensuring the accuracy of the experiment, secondary data on days to maturity, plant height, effective tiller, grains per panicle, sterility (%), and yield were considered for this study. Data for BRRI Hybrid Dhan5 & BRRI Hybrid Dhan6 were collected from the BRRI website (www.brri.gov.bd). The other two advanced lines NASH 260 & NASH 261 which were developed by ACI Limited, the data were collected from the ACI database, (Giller et al., 2011). Member of the Society of Teachers of the Alexander Technique (MSTAT-C) program was used to analyze this experiment's data.

III. RESULTS AND DISCUSSION

Soil fertility gradient determination should be measured in the short and long term to calculate their effect on crop yield and the environmental adaptation of rice genotypes under varied smallholder farms. For this, it is necessary to develop and implement field trials in an effective way to get the optimum performance of the tested genotypes. The secondary data, collected from the BRRI website and ACI database of the four rice genotypes is shown in Table 1. The average life cycle of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 was 144 days, 115 days, 145 days, and 142 days respectively. The plant height of BRRI Hybrid Dhan5, and BRRI Hybrid Dhan6 was 110 cm followed by 108 cm in NASH 260 and 105 cm in NASH 261. Effective tiller numbers of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 were 13, 14, 12, and 11 respectively. The yield of BRRI Hybrid Dhan5 and BRRI Hybrid Dhan6 was 9.0 t/ha and 6.5 t/ha respectively, and9.5 t/ha was found in both NASH 260 and NASH 261.

Table1. Basic characteristics of selected hybrid varieties/lines available in public domain. BRRI website (Source: www.brri.gov.bd) and ACI Databases (Source: acib4r.org).

Sl.	Name of variety/line	Days to maturity (days)	Plant Height (cm)	Effective tiller (number)	Yield (t/ha)
1	BRRI Hybrid Dhan5	144	110	13	9.0
2	BRRI Hybrid Dhan6	115	110	14	6.5
3	NASH 260	145	108	12	9.5
4	NASH 261	142	105	11	9.5

Table2 represented the data obtained from homogenously fertile land. The date to maturity of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 was 148 days, 122 days, 150 days, and 147 days respectively. Plant height was 109 cm, 109 cm, 110 cm, and 104 cm, and effective tillers were 11, 13, 11, and 9, the yield was 7.73 t/ha, 5.23 t/ha, 7.33 t/ha, and 7.07 t/ha respectively. Comparing the data from table 1 and table 2, we can say that all the data obtained from the trial in homogenously fertile land (table 2) shows a difference from the secondary data (table 1). According to the data obtained from the experiment, days to maturity increased, and almost all other three parameters *ie.* plant height, effective tiller no, and yield decreased than the secondary data.

Table2. Date of maturity, plant height, effective tiller, and yield of selected varieties/lines, collected from the homogenous land.

Sl.	Name of variety/line	Days to maturity (days)	Plant Height (cm)	Effective tiller (number)	Yield (t/ha)
1	BRRI Hybrid Dhan5	148 B	109 A	11.00 B	7.73 A
2	BRRI Hybrid Dhan6	122 D	109 A	13.00 A	5.23 C
3	NASH 260	150 A	110 A	10.67 B	7.33 B
4	NASH 261	147 C	104 B	8.667 C	7.07 B
	SE	0.00	0.46	0.51	0.08
	LSD	0.006	1.597	1.762	0.275
	CV (%)	0.00	0.74	8.14	2.02

SE=Standard Error; LSD=Least Significant Difference

The data obtained from land with fertility directions were presented in table3. The land fertility directions were divided into two parts, one part was a more fertile area of land another was a less fertile area. So, the land was not homogenous in fertility. This type of land was selected because we have found out any effect on land fertility direction. In more fertile areas date of maturity of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 were 148 days, 122 days, 150 days, and 147 days respectively. Plant height was 109 cm, 107 cm, 109 cm, and 105 cm, effective tiller of was 11, 12, 9, and 8, and the yield was 7.20 t/ha 5.17 t/ha. 6.83 t/ha and 6.43 t/ha respectively. In the case of less fertile areas, the date of maturity of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 was 148 days, 122 days, 150 days, and 147 days respectively. Plant height was 107 cm, 106 cm, 102 cm, and 100 cm; effective tiller of was 10, 10, 8, and 7; the yield was 6.20 t/ha 4.33 t/ha, 6.30 t/ha, and 5.53 t/ha respectively.

In the study comparing the data (table 3) obtained from more fertile land and less fertile land, we can say that there was no difference in days to maturity, but the other three parameters ie, plant height, effective tiller, and yield showed the difference. Therefore, it was observed that yield decline was evident due to the land fertility gradient (Kihanda and Warren, 2012).

The differences were described in the graph below (Fig. 1, 2 and 3). When the data of table3 was compared with the secondary data (table 1) it indicated the difference within the characters.

Table3. Date of maturity, plant height, effective tiller, and yield of selected hybrids variety/lines, collected from the land with fertility direction.

Sl.	Name of variety/line	Days to maturity (days)	Plant Height (cm)	Effective tiller (number)	Yield (t/ha)
More fertile land					
1	BRRI Hybrid Dhan5	148 B	109 AB	11.00 A	7.20 A
2	BRRI Hybrid Dhan6	122 D	107 B	11.67 A	5.17 D
3	NASH 260	150 A	109 A	9.333 B	6.83 B
4	NASH 261	147 C	105 C	8.000 C	6.43 C
	SE	0.00	0.51	0.22	0.10
	LSD	0.006	1.762	0.745	0.340
	CV (%)	0.0	0.82	3.73	2.65
Less fertile land					
1	BRRI Hybrid Dhan5	148 B	107 A	10.33 A	6.20 A
2	BRRI Hybrid Dhan6	122 D	106 A	10.00 A	4.33 C
3	NASH 260	150 A	102 B	8.33 B	6.30 A
4	NASH 261	147 C	100 B	7.33 C	5.53 B
	SE	0.00	0.62	0.17	0.05
	LSD	0.006	2.132	0.576	0.179
	CV (%)	0.0	1.03	3.21	1.58

It was observed that there were significant differences in plant height, effective tillers, and yield due to the effect of fertility gradients. Figure1 represents an increase in plant height from 107 to 109 in BRRI Hybrid Dhan5, 106 to 107 in BRRI Hybrid Dhan6, 102 to 109in NASH 260, and 100 to 105 in NASH 261. So we can say that the soil fertility gradient affected the plant height (Fig.1).

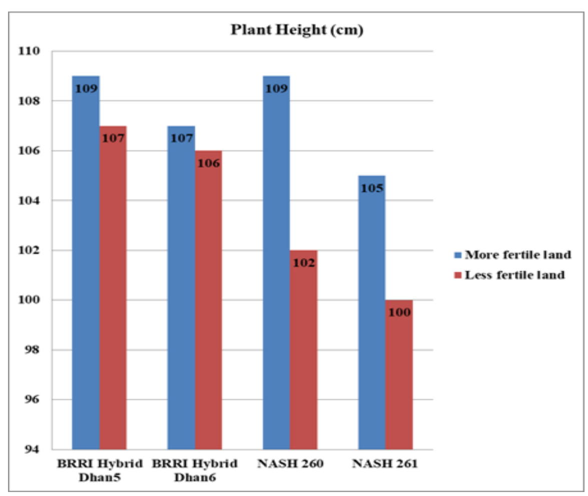

Fig.1: Effect of land fertility gradient on plant height (cm)

Figure 2 represents the increase of effective tiller in more fertile land than less fertile land for all four rice genotypes. Effective tiller increased from10.33 to 11 in BRRI Hybrid Dhan5, 10 to 11.67 in BRRI Hybrid Dhan6, 8.33 to 9.33 in NASH 260, and 7.33 to 8 in NASH 261. Therefore we can say that effective tiller no. was also influenced by the fertility gradients.

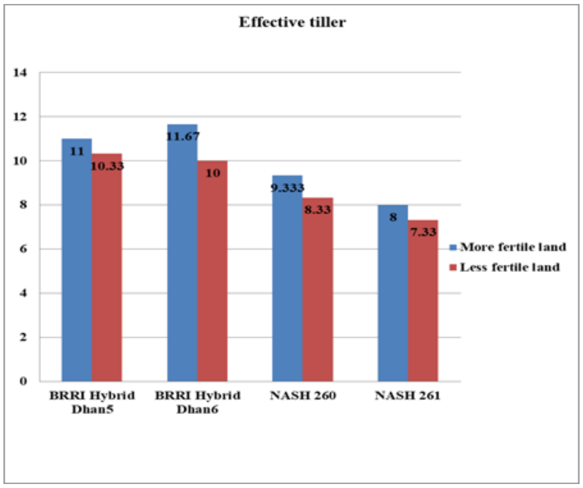

Fig.2: Effect of land fertility gradient on the effective tiller

Figure 3 represents the increase of yield, about 16%, 19%, 8%, and 16% in BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 respectively. So, it is clearly indicated that land fertility gradient affects yield and yield contributing characteristics.

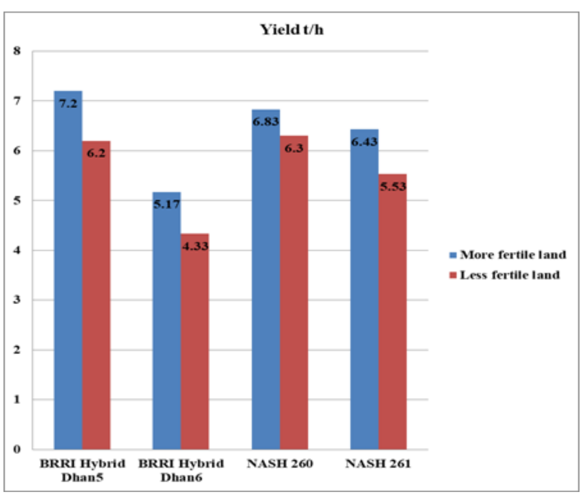

Fig.3: Effect of land fertility gradient on yield (t/ha)

In table 4, the calculated yield loss by fertility gradient of the land. The average yield loss observed across all the genotypes was 12.97% whereas individually highest yield loss was evident in BRRI Hybrid Dhan6 (16.35%), followed by NASH 261 (14.0%) and then BRRI Hybrid Dhan5 (13.89%) and the least in NASH 260 (7.76%). The yield loss was recorded at 7% to 14% by soil fertility gradient, which indicated that the yield loss was very much influenced by soil fertility gradient.

An easy way to determine soil fertility determination is a soil pH test. In the breeding yield trial, it was very important to ensure accurate results for determining the performance of a genotype. Further research will be needed to identify the way/method to recover the loss of yield by soil fertility gradient.

Table 4. Determination of percentage of yield loss by fertility gradient of land.

Sl.	Variety/line	Yield (t/ha)		Yield loss (%)
		More fertile land	Less fertile land	
1	BRRI Hybrid Dhan5	7.20 A	6.20 A	13.89
2	BRRI Hybrid Dhan6	5.17 D	4.33 C	16.25
3	NASH 260	6.83 B	6.30 A	7.76
4	NASH 261	6.43 C	5.53 B	14.00
	SE	0.10	0.05	
	LSD	0.340	0.179	
	CV (%)	2.65	1.58	

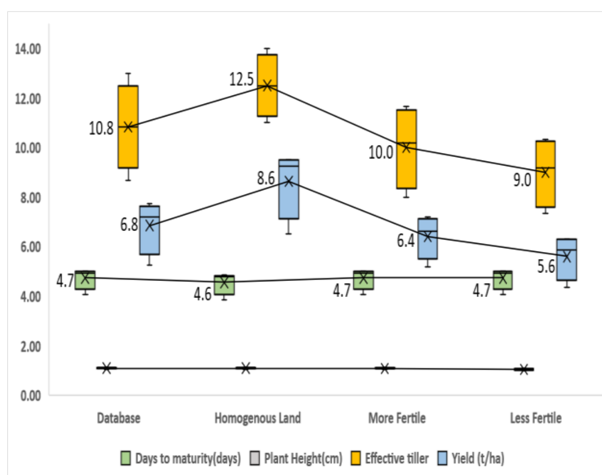

Fig.4: The cumulative effect of land fertility gradient on yield and yield dependent parameters

There was a significant difference evident in the cumulative data of yield and yield-dependent characteristics within homogenous, more fertile, and less fertile land compared with public domain data (Fig. 4). Irrespective of the genotypes in the homogenous plot there was a 16% increase in effective tiller number than with public domain data, 25% increase than more fertile land and 39% increase than the less fertile land. Similarly, irrespective of the genotypes in the homogenous plot there was a 26% increase in the observed yield (t/ha) than with public domain data, a 34% increase in more fertile land, and a 54% increase in the less fertile land. There are no significant differences observed in days to maturity and plant height across all the land types and even compared with the public domain data. This analysis confirms that the reduction in effective tiller number due to soil fertility gradient translated into lower yield in non-homogeneous land compared with the homogenously fertile land irrespective of genotypes tested.

IV. CONCLUSION

The soil fertility gradient approach aims at eliminating the influence of other factors affecting yield like crop, climate, and management by choosing one field over which elaborate treatments are superimposed to obtain crop responses for correlating with soil test values which are artificially created by differential fertilizer treatments before conducting the regular experiment and provides a scientific basis for balanced fertilization between applied and soil available forms of nutrients. Yield may decrease in different ways, including fertilizer deficiency, nutrient deficiency, lack of good agronomical practices, soil infertility, and soil fertility gradient. It is very important to identify the loss of yield by specific factors. In the study, it was very essential to identify the effect of soil fertility gradient on the performance of rice hybrids as well as advanced breeding lines. A significant difference was observed in plant height, effective tiller, and yield on different soil fertility gradients, and the percentage of yield loss by land fertility gradients of BRRI Hybrid Dhan5, BRRI Hybrid Dhan6, NASH 260, and NASH 261 was 13.89, 16.25, 7.76 and 14.00 respectively. Therefore, we can easily conclude that the land fertility gradient significantly affects yield and its contributing characteristics. A recommendation is always to set experiments in homogeneous fertile land, if it is not possible to set homogenous land then set experiments with proper randomization. So, the experiment is a continuous process as every breeder should have to know whether their experimental field's fertility gradient is homogenous or not.

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