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PLANT POPULATION STUDIES IN TRANSPLANT RICE

Part I.—Hill Density and Yield in Transplant Aman Rice

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Highest grain yield was not all the way associated with the highest plant population in transplant *aman* rice. 'Nigersail' variety when transplanted 3, 4, 5, 6, 7, 8, 9, and 10 in. apart with one seedling per hill in 10 and 12 in. apart rows, tended to give highest grain yield at within-row hill spacing of 5 in. although the grain yields of 3, 4, 5, 6, and 7 in. hill spacings were statistically identical. Grain yield tended to gradually decline as the within-row hill spacing increased or decreased from 5 in. While the grain yield in rice is proposed to be the joint function of (a) the average number of hills per unit area, (b) the average number of ears per hill, (c) the average number of grains per ear, and (d) the average weight of an individual grain, the straw yield is proposed to be joint function of (a) the average number of hills per unit area and (b) the average straw-weight of an individual hill. Formular expressions for these two crop characters—the grain yield, and the straw yield—have been proposed and discussed in the paper.

In East Pakistan, transplant rice constitutes the bulk of the total rice crop comprising three groups of rice—*aus*, *aman*, and *boro*. Of these, *aman* rice commands larger acreage and contributes the greater part of the total rice production in the province. In transplant rice, hill density per unit area is of paramount importance for producing the highest yield under a certain set of growing conditions.[1,3,9,13,21] The work reported herein sought to determine the influence of hill density on the yield of transplant *aman* rice. It may be mentioned that for convenient operations of mechanical weed control and other interculture without hurting the crop plants, experience showed that the row spacing should not be closer than 10 in. Ideal plant population density was aimed to be obtained by conveniently regulating the hill spacing.

Materials and Methods

The study was conducted at the Agronomy Field Laboratory of the East Pakistan Agricultural University at Mymensingh in 1968. The experimental land, belonging to the Bramaputra Alluvial Soil Tract[11] of the province, was medium high in elevation with sandy loam soil having a pH range of 6.4 to 6.6. The N, P_2O_5, K_2O and organic matter contents of the soil were 0.080, 0.087, and 1.53% respectively. The total monthly rainfall received at the experiment station from July to December were 17.65, 8.88, 11.28, 2.94, 1.35, and 0.00 inches respectively. The daily average temperature and the day length during the period of experimentation ranged from 76 to 91°F and 10.50 to 13.50 hr respectively.

Thirty-two-day old seedlings of a local high yielding variety, Nigersail, of transplant *aman* rice were transplanted in well-puddled land on 1st September in 10 and 12 in. apart rows at hill spacings of 3, 4, 5, 6, 7, 8, 9, and 10 in. in the rows with one seedling per hill. The crop was fertilized with an added nutrient dose of 40 lb N, 20 lb P (element), and 30 lb K (element) per acre. Half of N and the whole of P and K were applied 2 days before transplantation, the remaining half of N being applied at the Lag-vegetative phase[15,16] of the crop (at the plant age of 75 days in this case). Weeds were controlled by two hand weedings, 3 and 6 weeks after transplantation. No irrigation was given.

The experiment was laid out in split-plot design with the row spacings in the main plots and the hill-spacings in the unit plots using three replications. The net area of a unit plot was 0.01 acre.

The experimental crop was studied for the following crop characters: (1) average number of ears per hill, (2) average number of grains per ear, (3) average weight of an individual grain (in terms of weight of 1000 grains) in g, (4) grain yield per plot, and (5) straw yield per plot.

The crop was harvested on 23rd December i.e. after a total growth duration[15,16] of 145 days. Individual plots were harvested and processed separately. Sun-dried grains and straw were weighed to record grain and straw yields per acre respectively. Ten hills, per plot, were tagged at random during the early stage of plant growth and data in respect of crop characters under serial numbers 1 to 3 above were recorded from them in the usual way.

Results

The mean results obtained in respect of the crop characters studied have been presented in

Tables 1 and 2 and Figs. 1, 2, and 3. Statistical significance of the mean differences were tested in LSD method[24] at $p=0.05$ and 0.01. However, in the case of the values presented in the tables respective S.E. have been given to enable the readers to test the significance of mean differences in other methods as well.

Row spacing significantly influenced the production of the number of grains per ear only (Table 1). Although the 12-in. row crop produced significantly greater number of grains per ear than did the 10-in. row crop, the ultimate grain yield produced were statistically identical (Table 1). The reason is obvious. Better performance of smaller number of individual hills in 12-in. row crop could not statistically outyield the contribution of larger number of hills of relatively inferior performance in 10-in. row crop.

Within-row hill-spacing significantly influenced all the crop characters studied except 1000 grain weight (Table 2). It is very important to note that the hill-spacings closer than 5 in. in significantly tended to depress the yield-contributing crop characters with the exception of 1000 grain weight that remained unaffected (Figs. 1 and 2). On the other hand, the hill-spacings wider than 5 in. significantly encouraged or in significantly tended to encourage the performance of an in-

TABLE 1.—EFFECT OF ROW SPACINGS ON THE YIELD AND YIELD-FORMING CROP CHARACTERS IN 'NIGERSAIL' VARIETY OF TRANSPLANT *Aman* RICE. A Plot=0.01 Acre.

Row spacing (in.)	Average number of ears per hill	Average number of grains per ear	Average 1000-grain weight (g)	Grain yield per plot (lb)	Straw yield per plot (lb)
10	11.15	132.68	17.03	31.75	56.54
12	12.24	134.48	17.24	25.21	46.47
S.E. ±		0.20			
L.S.D. p=0.05		0.86			
L.S.D. p=0.01		1.98			

TABLE 2.—EFFECT OF HILL SPACING AND HILL DENSITY ON THE YIELD AND YIELD-FORMING CROP CHARACTERS IN 'NIGERSAIL' VARIETY OF TRANSPLANT *Aman* RICE. A Plot=0.01 Acre.

Hill spacing and Hill density	Average number of ears/hill	Average number of grains/ear	Weight of 1000-grains(g)	Grain yield per plot (lb)	Straw yield per plot (lb)
10 in.× 3 in. i.e. 2,09,088 hills/acre	6.8	105.5	16.93	34.0 ab*	60.7 b
10 in.× 4 in. i.e. 1,56,816 hills/acre	8.5	113.6	16.95	36.0 ab	63.3 a
10 in.× 5 in. i.e. 1,25,453 hills/acre	10.1	130.6	17.01	39.7 a	72.7 a
10 in.× 6 in. i.e. 1,04,544 hills/acre	11.3	136.8	17.03	33.7 ab	56.7 b
10 in.× 7 in. i.e. 89,609 hills/acre	12.8	141.3	17.15	29.7 b	50.0 c
10 in.× 8 in. i.e. 78,408 hills/acre	13.3	143.2	17.18	29.7 b	52.0 b
10 in.× 9 in. i.e. 69,696 hills/acre	13.4	144.5	17.17	26.7 b	50.0 c
10 in.×10 in. i.e. 62,726 hills/acre	13.7	146.0	17.12	24.7 bc	47.0 c
12 in.× 3 in. i.e. 1,74,240 hills/acre	8.1	106.9	17.07	25.0 bc	44.7 c
12 in.× 4 in. i.e. 1,30,680 hills/acre	10.1	121.3	17.19	27.0 b	46.0 c
12 in.× 5 in. i.e. 1,04,544 hills/acre	10.8	137.4	17.23	28.3 b	50.0 c
12 in.× 6 in. i.e. 87,120 hills/acre	12.0	135.1	17.17	25.3 bc	44.7 c
12 in.× 7 in. i.e. 74,674 hills/acre	13.3	142.7	17.19	26.7 bc	44.7 c
12 in.× 8 in. i.e. 65,340 hills/acre	14.4	143.6	17.36	25.3 bc	44.0 c
12 in.× 9 in. i.e. 58,080 hills/acre	14.8	143.5	17.33	23.7 bc	42.0 c
12 in.×10 in. i.e. 52,272 hills/acre	15.1	145.3	17.38	20.3 c	41.3 c
S.E. ±	0.42	2.44	—	3.06	5.06
L.S.D. p—0.05	0.86	5.00	—	6.27	10.33
L.S.D. p—0.01	1.16	6.73	—	8.44	24.07

* In a column, values followed by no common alphabet are significantly different at p=0.05.

dividual hill in respect of all the crop characters studied except the 1000 grain weight (Figs. 1 and 2). Both grain and straw yields tended to be highest in 10×5 in. hill crop and these yields progressively declined or insignificantly tended to decline in crops with hill-spacings closer or

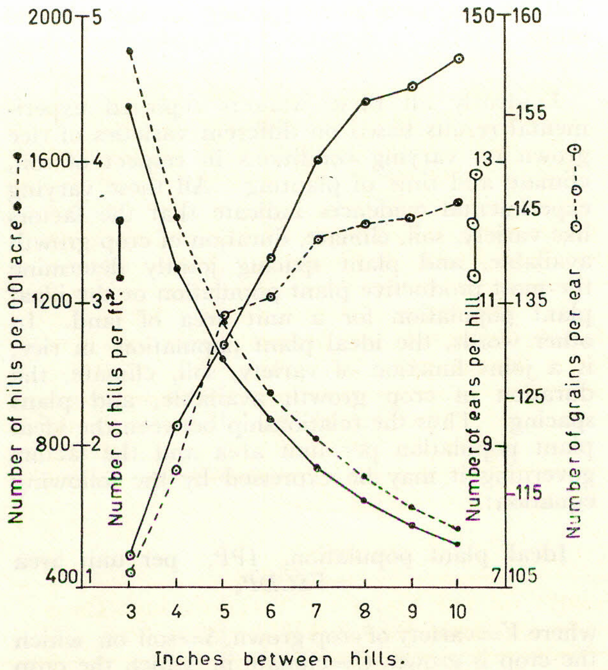

Fig. 1.—Influence of within-row hill spacing on the number of hills per plot, number of hills per square foot of land, number of ears per hill, and the number of grains per ear.

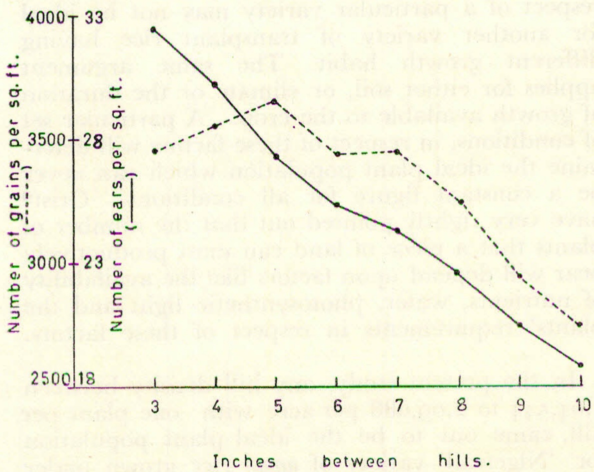

Fig. 2.—Influence of within-row hill spacing on the number of ears per square foot of land and the number of grains per square foot of land.

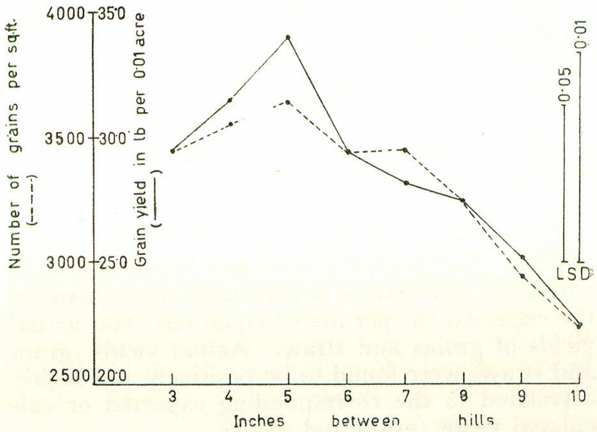

Fig. 3.—Influence of within-row hill spacing on the number of grains per square foot of land and the ultimate grain yield.

wider than 10 in.×5 in. (Table 2). In hill-spacings closer than 5 in., plants possibly suffered from overcrowding and the phenomena associated with it, while in hill-spacings wider than 5 in. grain yield progressively declined or tended to decline with the widening of hill-spacing due to the decline in hill-density per plot. Here also relatively better performance of an individual hill in respect of grain and straw production could not outyield the total contribution of relatively more number of hills in closer spacings. This folows that the best combination of hill-density and hill-performance will result in the highest yield (Figs. 1 and 3). 5 in. hill crop tended to give the highest grain yield which, though statistically identical to those of 3-, 4-, 6-, and 7-in. hill crops, was significantly greater than those of 8-, 9-, and 10-in. hill crops. 3-, 4-, and 6-in. hill crops produced significantly higher yields than that of 10-in. hill crop (Fig. 3).

Interaction of row-spacing and hill-spacing was not statistically significant. This means that the hill-spacings influenced the crop characters studied to the same extent in both the row-spacings of 10 and 13 inches.

In rice, and also in other cereals, grain yield is a joint function of the yield contributing crop characters: (a) number of hills per unit area, (b) number of ears per hill, (c) number of grains per ear, and (d) the individual grain weight. This, it is proposed, may be given by the equation:

Grain yield, $Y_g = HEGW_g$

where H=average number of hills per unit area, E=average number of ears per hill, G=average number of grains per ear, and W_g=average weight of an individual grain.

Similarly, straw yield in rice may be expressed, by the equation:

Straw yield, $Y_s = HS_w$

where H=average number of hills per unit area, and S_w=average straw weight of an individual hill.

To test the validity of these new theoretical yield equations, correlation studies were made between the expected (as per above equations) and actual yields of grains and straw. Actual yields (grain and straw) were found to be positively and highly correlated to the corresponding expected or calculated yields (grain and straw).

An important point needs mentioning here that although there was a highly significant positive correlation between the expected grain yield and the actual grain yield, there was an alarming difference between the two sets of values (expected and actual). This obviously suggests that the difference between the expected grain yield and the actual grain yield has been due (1) partly to sampling error and (2) primarily to loss of grains due to (a) shattering of grains during harvesting and carrying the crop from the field to the barn, (b) incomplete threshing of grains, (c) handling loss in sunning, cleaning and bagging, and (d) lifting of grains by birds and rodents during the entire process from harvesting to bagging.

Discussion

Experimental evidence available on row-spacing, hill-spacing, and the number of plants per hill—in short, the plant population density and distribution—in transplant rice are conflicting and inconclusive. Varying results have been reported by different workers from different rice growing areas of the world in the past to the recent years.[1–10, 12–14, 17–23, 25–27]

Some workers reported that grain yield in transplant rice was associated with the number of hills per unit area. Although wider spacing improves the performance of individual hills, close spacing ultimately increases the grain yield.[1,2,8,10,13,21,25,26] On the other hand, other workers findings[14,20,22,23] disagreed with those of the aforesaid ones. They observed that the higher grain yield in transplant rice was not necessarily associated with closer spacing. Within a wide range of spacings they obtained highest yield in some intermediate spacings. Kirano *et al.*[14] obtained yield twice as much from 24 cm × 24 cm (i.e. 9.5 in. × 9.5 in.) planting as from 18 cm × 18 cm (i.e. 7 in. × 7 in.)-spaced crop.

While some workers[10,22] observed significant influence of the number of seedlings per hill on grain yield, others [3,13,21] reported that the number of seedlings per hill was statistically immaterial. Further, Rosher[12] reported that planting date (early, normal, and late) did not influence the yield response to spacing of hills or number of seedlings to be planted per hill, while Khan and Shafi[13] suggested closer spacing for late planted crops.

Evidently all these workers reported experimental results based on different varieties of rice grown on varying conditions in respect of soil, climate and time of planting. All these varying experimental evidences indicate that the factors like variety, soil, climate, duration of crop growth available, and plant spacing jointly determine the most productive plant population or the ideal plant population for a unit area of land. In other words, the ideal plant population, in rice, is a joint function of variety, soil, climate, the duration of crop growth available, and plant spacing. Thus the relationship between the ideal plant population per unit area and the factors governing it may be expressed by the following equation:

$$\text{Ideal plant population, IPP, per unit area} = VSCDP_s$$

where V=variety of crop grown, S=soil on which the crop is grown, C=climate in which the crop is grown, D=duration of crop available, and P_s=plant spacing.

It evidently follows that the ideal plant population and their mode of distribution in the field in respect of a particular variety may not be ideal for another variety of transplant rice having different growth habit. The same argument applies for either soil, or climate or the duration of growth available to the crop. A particular set of conditions, in respect of these factors will determine the ideal plant population which can never be a constant figure for all conditions. Grist[9] have very rightly pointed out that the number of plants that a piece of land can most productively bear will depend upon factors like the availability of nutrients, water, photosynthetic light and the plants' requirements in respect of these factors.

In the present study, any hill density between 1,04,544 to 2,09,088 per acre with one plant per hill, came out to be the ideal plant population for 'Nigersail' variety of *aman* rice grown under the East Pakistan soil and climatic conditions as described earlier. These plant populations and spacing are expected to be ideal for other varieties of transplant *aman* rice having similar growth habits and requirements as of 'Nigersail', when grown under comparable conditions. The findings of the present study agreed with the findings of other workers[14,20,22,23] who reported that the maximum yields were not necessarily associated all the way with the maximum plant population density. In the present study the grain increased with increasing plant population up to a limit of 1,25,453 plants (or hills in this case) per acre beyond which grain yield tended to decline. This decline was probably due to overcrowding of plants resulting in mutual shading, lack of sufficient light and air and their inefficient utilization and all other phenomena associated with overcrowding of crop plants. It is true that with wider spacing the performance of individual hills were better (Fig. 1), but at the same time the ultimate number of grains produced per square foot of land became fewer (Figs. and 2 and 3). On the other hand, with closer spacing, the performance of individual hills gradually went down but the ultimate number of grains produced per square foot of land area gradually went up due to relatively larger number of hills contributing to it (Figures 2 and 3). As a result, the maximum grain yield was obtained at a spacing (5 in.) where there was a compromise between these two trends (Fig. 1).

The ultimate grain yield in rice is constituted by the total number of grains produced per unit area and the average weight of an individual grain. Since in the present study the weight of individual grains (as expressed in terms of weight of 1000-grains) did not vary with hill spacing, the grain yield was solely dependent upon the number of grains produced per unit area. It will be very clearly seen from Figs. 2 and 3 that the number of grains produced per square foot of land was highest in hill spacing of 5 in. and so was the ultimate grain yield. In the cases of spacings below or above 5 in. the number of grains produced per square foot of land gradually tended to decline and so did the ultimate grain yield. Hence, any spacing that will produce highest number of total grains with heaviest individual grain weight is sure to produce the highest grain yield per unit area.

The new yield equations proposed in the present paper deserve a little discussion on them. One has to agree that the equations are based on scientific principles. With careful sampling and proper application of these equations, the expected yields, of grain and straw, of a rice crop may be conveniently calculated out to evaluate the crop immediately before harvesting and final processing.

One more point also needs mentioning. The after-harvest loss of grains is not that negligible, under East Pakistan condition, as is usually thought to be. This loss is considerably high. To check or reduce this after-harvest loss of grains, the steps to be taken will be (a) to reduce grain shattering, (b) to ensure efficient grain threshing, (c) to keep the birds and rodents out, and (d) to check losses in cleaning, drying, and bagging.

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