EFFECT OF RAINFALL ON THE YIELD OF RICE AND EVALUATION OF WATER REQUIREMENT

by M. N. BASAK, *Department of Agriculture, West Bengal, Calcutta*

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INTRODUCTION

Geographical distribution of rice-growing areas in the world over regions of heavy rainfall in the relatively short period of the cropping season indicates that water supply is probably the chief limiting factor to the growth and production of rice. Knowledge about water requirement of rice is, however, meagre and estimates are quite variable. In Japan, water requirement was estimated to vary from 27.6 to 51.5 acre inches (Leonard, 1948) and in Thailand, it was 72 acre inches (Grist, 1953). In Louisiana and Texas, 38 to 60 acre inches of water (Fortier, 1926) and in California, 60 to 72 acre inches were estimated to be required for the crop. According to Roe (1950), water requirement varied from 48 to 93 acre inches while Robertson's reports on irrigation experiments in Biggs indicated that average annual use of water for the 3-year period was 54 acre inches. In India with seventy-five million acres under this crop constituting about twenty-two per cent of her cultivated lands, there has hardly been any work on water requirement of rice except determination of the transpiration ratio (Hector, 1925–28; Singh *et al.*, 1935; Ganguli, 1950; Ghose *et al.*, 1956).

An attempt has been made to evaluate the water requirement of transplanted rice from the effect of rainfall on yield. Determination has been made of the water requirement of the crop for the entire growing season as well as the different stages of its growth and maturity, and of the precise level of soil moisture suitable for promotion of high yield. Loss of moisture from rice fields by way of transpiration, evaporation, percolation and run off have been worked out and correlated with water requirement. Physiological significance of the depth and frequency of rainfall in flowering and fertilisation processes and the nutritional rôle of nitrogen supplied by rain water along with probable mechanism of its absorption and utilisation have been discussed.

EFFECT OF RAINFALL ON YIELD OF RICE

In course of manurial experiments on rain-fed transplanted rice, it was observed (Basak, 1956) that even under apparently identical conditions, there was considerable variation in the magnitude of yield obtained in different years from same sets of plots under same sets of treatments and it was related to rainfall feeding the crop from transplatantion to harvesting (Table 1 and Fig. 1). In fact, progressive increase in rainfall induced a fairly corresponding increase in yield of grain and the effect of rainfall on yield was statistically significant. These results gave a clue to the present investigations. It was argued that if data on grain yield of rice grown over a large number of years in regions under varying magnitude of rainfall could be obtained along with corresponding data on rainfall feeding the crop, it might possibly reveal a close correlation between yield and rainfall and thereby suggest a way for evaluation of the water requirement of rice.

TABLE 1

Average yield of rice (Patnai 23) in mds. per acre

Burdwan Farm Treatment	1951	1952	1953
	Rainfall 29.6 inches	Rainfall 25.1 inches	Rainfall 35.9 inches
	Grain	Grain	Grain
No manure	21.70	16.00	28.52
Manure	34.29	24.17	42.45

From the accumulated mass of published results (Dept. Agric. Ann. Rep., 1924–42) of replicated unmanured varietal trials conducted on a group of six heavy-yielding late-ripening varieties of rice at more than ten different experimental stations located at different soil-climatic regions of the State, the data

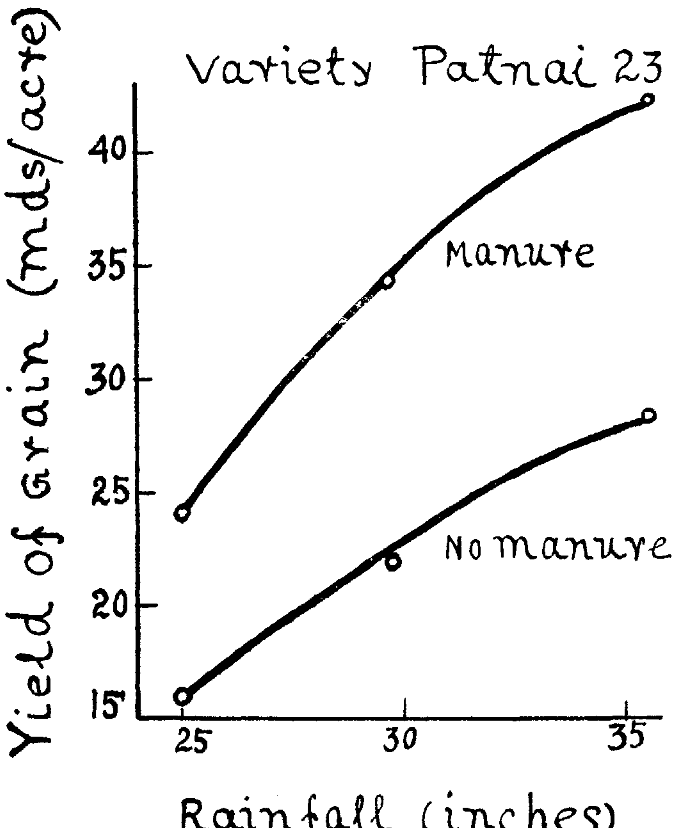


FIG. 1

of variety-wise grain yield along with the correspondng data of rainfall feeding the crop from transplantation to harvesting were compiled, classified and processed. The data of rainfall and grain yield were tabulated *in seriatim* in the ascending order of magnitude of rainfall and the average was drawn up of rainfall at different domains and of the corresponding grain yield within that domain (Table II). Positive correlation was found between yield and rainfall. Considering all the 29 values in the Table, the correlation coefficient between average grain yield and average rainfall worked out at +0.72. From 18 values where the rainfall total was within the domain of 30 inches, the corrleation coefficient came out as +0.82, which was highly significant. In case of the remaining 11 values, where rainfall exceeded 30 inches, the correlation coefficient was only +0.54, which was not significant even at 5% level. Inclusion of the values relating to higher ranges of rainfall over 30 inches had thus reduced the correlation coefficient from +0.82 to +0.72,

TABLE II

Average yield of rice and amount of rainfall

Variety of rice	No. of experiments	Average grain yield (mds./acre)	Average rainfall (inches)	
			From transplantation to harvesting	During 30 days before transplantation
Bhasamanik	6	14.6	10.6	9.4
	14	22.1	20.2	11.5
	13	24.3	30.3	16.4
	8	25.2	38.6	19.0
	1	25.3	62.8	32.7
Dudsar	6	14.6	10.5	9.9
	8	21.6	20.7	11.8
	14	24.0	30.3	16.6
	9	24.2	38.3	19.0
	2	25.8	62.6	36.4
Jhingasail	6	13.8	10.6	9.5
	12	21.8	20.1	12.8
	6	22.8	30.1	16.1
	7	22.0	36.8	19.7
	1	25.6	62.8	32.7
Latisail	4	18.3	10.7	11.1
	6	23.8	21.3	13.0
	13	25.0	30.2	17.0
	8	25.0	36.4	16.0
	3	25.7	50.3	28.0
Indrasail	5	15.0	9.4	8.9
	5	23.1	19.8	12.2
	17	23.9	30.6	15.4
	4	24.0	42.0	21.5
	1	26.6	62.8	32.7
Nagra	1	13.1	22.9	6.2
	1	24.4	26.8	17.8
	5	27.3	30.3	15.1
	4	27.3	46.1	22.7

Correlation coefficient between average yield and average rainfall = +0.72

Data of average rainfall at different domains and corresponding average grain yield were plotted against each other and a set of six yield-rainfall curves was obtained for six varieties of rice (Figs. 2 to 7). Yield-rainfall curves showed that increasing amount of rainfall from ten to twenty inches induced a progressive and almost proportional increase in the yield of grain; with higher rainfall over twenty inches the increase fell off progressively till at the level of about thirty to thirty-two inches, the curves were flattened off and continued to do so till the highest level of sixty-three inches of rainfall was obtained. Any additional rainfall over thirty to thirty-two inches in the growing season did not exhibit any additional effect on yield. The minimum amount of rainfall required to produce optimum grain yield in different varieties of rice was thus calculated from the yield-rainfall curves.

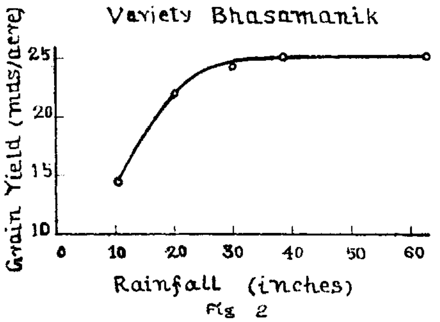
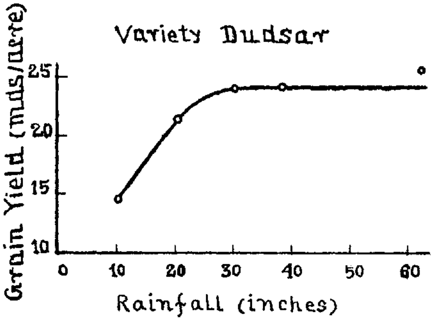


Fig 2



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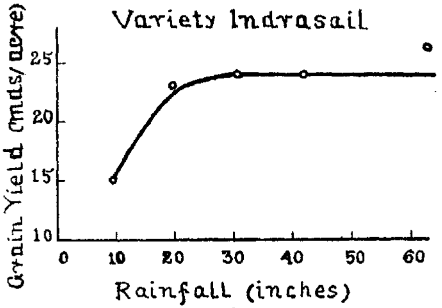

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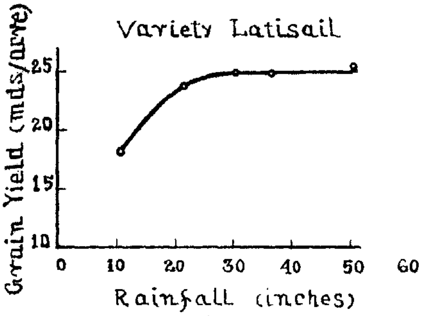

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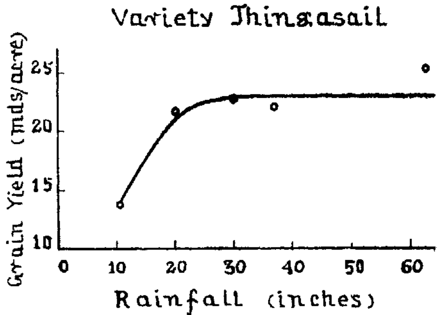

Fig 6

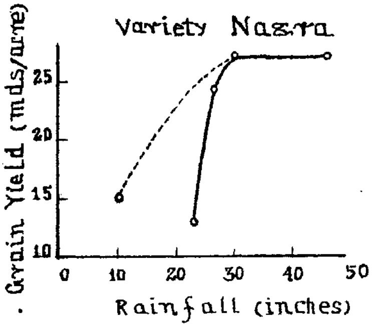

Fig 7

Variety of rice	Minimum amount of rainfall inducing optimum grain yield (inches)	Grain yield (mds./acre)
Bhasamanik	32	25.0
Dudsar	30	24.0
Indrasail	29	24.0
Latisail	28	25.0
Jhingasail	30	23.0
Nagra	31	27.0
Average for varieties	30	24.7

It was significant to observe that at the lower domain of rainfall (below 30 inches), yield-rainfall curves of rice exhibited a similar behaviour to yield-water curves of upland crops but at the higher domain of rainfall, a completely different one. In the case of upland crops under limiting supply of water, progressive increase in water application tended to increase production of dry matter and yield of crops until a maximum was reached after which the effect was completely reversed. A seven-year average yield-water curve for wheat at Gooding, Idaho and a ten-year average yield-water curve for corn at Logan, Utah, (USDA Bulletin no. 1340) showed that increasing water application increased the yield of grain, although progressively slowly, till the maximum yield was obtained for wheat at 2 acre-feet and for corn at 3.25 acre-feet after which yield declined progressively sharply. Such a behaviour was also observed for some other upland crops (Roe, 1950). But the yield of rice, after attainment of a maximum, remained practically unaffected under increasing level of water supply, as the yield-rainfall curves would show. Indeed the rice crop could grow and flourish under moist, water-logged and even heavily submerged conditions. The success of cultivation of deep-water varieties in certain low-lying areas in India (West Bengal and Assam), East Pakistan, Burma, Thailand, Cambodia and Cochin China, where the plants in their early period of growth could withstand a rising column of flood water anything up to a level of twenty feet above field surface and even survive temporal over-flooding (Grist, 1953), was a testimony to the water tolerance capacity of the rice crop. This characteristic water tolerance capacity, rare in field crops, was probably one of the overriding reasons for its widest adaptations to the earth's surface to provide staple food for over half of its inhabitants.

Effect of Supplemental Irrigation on Yield

Earlier attempt made by the workers in this Department (Chakravorty, 1937–42) to find out the effect of supplemental irrigation on rice yield was not rewarded by any positive conclusions. Two typical transplanted water-logged varieties of rice (Bhasamanik and Patnai 23) were grown in well-bunded replicated plots under controlled conditions, one set of plots receiving normal rainfall and the other set an additional amount of irrigation water applied at an interval of a fortnight. Data of average grain yield and rainfall are given in Table III. The results showed that supplemental irrigation apparently had no beneficial effect on yield over mormal rainfall. But the minimum amount of rainfall feeding the crop during any growing season was as high as 30.96 inches and it was evident that this amount of rainfall was adequate to meet the water requirement of rice so that a higher dose of rainfall or irrigation water had no influence on yield.

TABLE III

Effect of supplemental irrigation on rice cultivation
(Rice Research Station, Chinsurah, West Bengal)

Year	Variety	Average yield of grain (mds. per acre)		Average rainfall (inches) during the growing period	
		No irrigation	Irrigation	No irrigation	Irrigation
1937-38	Bhasamanik	35.8	36.0	33.11	33.87
	Patnai 23	37.5	36.4	,,	,,
1939-40	Bhasamanik	21.6	31.9	40.07	53.95
	Patnai 23	26.7	30.4	,,	,,
1940-41	Bhasamanik	29.3	29.5	30.96	38.09
	Patnai 23	23.9	24.9	,,	,,
1941-42	Bhasamanik	24.7	21.6	39.74	43.26
	Patnai 23	23.8	23.4	,,	,,
Average of 8 experiments		27.91	29.26		

WATER REQUIREMENT IN RELATION TO LOSS OF MOISTURE FROM RICE FIELD

Estimation of moisture losses from rice fields during the cropping season was attempted at elucidation of water requirement and soil-plant-water relations.

LOSS OF MOISTURE BY TRANSPIRATION

In America, Briggs and Shantz (1914) calculated the average transpiration ratio of rice as 519 in 1912 and 744 in 1913. In India, the average transpiration ratio was found to be of similar order of magnitude (Hector, 1925–28; Singh *et al.*, 1935). Recent determinations of transpiration ratio of the same and allied varieties of rice under comparable soil-climatic conditions gave an average of 626.6 (Ganguli, 1950). From the transpiration ratio, average optimum grain yield (24.7 mds. per acre) and straw grain ratio of 1.5, transpirational loss of water could be calculated as below :

Cured weight	*Dry weight*
Grain—2038 lb	2038(1.00−0.15) = 1732 lb
Straw—3057 lb	3057(1.00−0.20) = 2446 lb
	Total = 4178 lb
Roots at $\frac{4178}{11}$	= 380 lb
Total dry matter produced per acre	= 4558 lb

The equivalent of the transpiration ratio of water of depth over 1 acre

$$= \frac{4558 \times 626.6 \times 12}{43{,}560 \times 62.5} = 12.56 \text{ inches.}$$

LOSS OF WATER BY EVAPORATION

Information is not available regarding evaporational loss of moisture from waterlogged rice fields during the growing season. Fundamental equations have been developed recently (Penman, 1948), which would seem to subscribe to the particular sets of climatic and field conditions as were normally associated with cultivation of transplanted rice. Application of the micro-climatic data, under collection in this Department for the last few years, to the Penman equation given below would render possible the calculation of the evaporational loss.

$$E = 0{\cdot}35\ (e_s - e_d)\ (1 + 0.0098\ u_2)\ \text{mm. per day, where}$$

E is the rate of evaporation,
e_s is the vapour pressure of the water at the water surface,
e_d is the vapour pressure in the bulk of air at the dew-point, and
u_2 is the speed of the wind 2 metres above ground-level in miles per day.

Five-year average of micro-climatic data, collected on rice fields at the State Rice Research Station at Chinsurah under this Department, along with monthly rates of evaporation from waterlogged rice fields calculated from the above equation and observed rate of evaporation from free water surface are given in Table IV. Monthly rates of evaporational loss from rice fields during the growing season of rice are summarised below :

TABLE IV

Evaporation of water from waterlogged rice fields during crop growth
(Average of five years, 1951–55)

Month	August	September	October	November	December
Mean temp. (°F)	83.0	83.8	80.9	71.3	65.5
Mean humidity (%)	86.6	87.2	87.4	73.0	69.4
Vapour pressure of water at 2 ft. above water surface in rice field (mm.)	25.3	25.7	25.5	15.3	12,3
Vapour pressure in the bulk of air at dew point (mm.)	21.6	22.5	20.6	10.5	7.8
Mean velocity of wind at 10 ft. above rice field (miles/hour)	3.72	3.09	2.26	1.57	1.58
Monthly evaporation from rice field (equation) (inches)	3.01	2.29	3.23	2.80	2.77
Monthly evaporation from free water surface (inches)	3.94	3.92	4.12	5.66	6.22

Month	Evaporational loss of water from waterlogged rice fields (inches)	Evaporational loss of water from free water surface (inches)
August	3.01	3.94
September	2.29	3.92
October	3.23	4.12
November	2.80	5.66
December	2.77	6.22
	14.10	23.86

Since the average date of transplantation was Aug. 10 and that of harvesting Dec. 16 (Table V), the evaporational loss during the growing period was calculated as 11.88 inches.

Loss of water by percolation

The problem of percolation, which depended on texture, structure and chemical composition of soil and sub-soil, depth to water-table, hydrostatic pressure of soil moisture and surface gradient, was further complicated in waterlogged rice fields through formation of compact cluster structure brought about by puddling of soils in soft and wet conditions under pressure. Puddling tended to make soils impervious though, hydrostatic pressure of standing water and possible movement of soil animals through soil profile could admit of slow percolation. But there was no precise information about the rate of such percolation. Indication was, however, obtainable from the balance-sheet of monthly rainfall and of corresponding moisture losses from rice fields. In addition to rainfall feeding the crop from transplantation to harvesting, an additional amount of moisture was available from puddled soil representing the difference between its moisture content at transplanting and harvesting times. Soils could hardly be puddled, unless the moisture content attained the *saturation capacity*, whereas the moisture content of soils at the time of harvesting of crop was sometimes above but usually below the *field capacity*, as was evidenced by the phenomenon of development of cracks. According to Kramer (1949), the moisture content of clay loam soils at field capacity was about 43 per cent and at saturation capacity 73 per cent of soils on dry weight basis. Hence

Depth of water per square inch in 12-inch layer of top soil at field capacity $\frac{12\times85}{62.5}\times\frac{43}{100} = 7.01$ inches

Depth of water per square inch in 12-inch layer of top soil at saturation capacity $\frac{12\times85}{62.5}\times\frac{73}{100} = 11.91$ inches

Additional amount of water available from puddled soils thus worked out at 4.90 acre-inches and total minimum water requirement at 34.90 acre-inches. Deducting the transpirational and evaporational losses, the loss by percolation worked out at 10.46 acre-inches.

Effect of Distribution of Rainfall on Yield

The value of rainfall to agriculture depends as much and often more on its distribution as on its absolute amount. Even under a given rainfall total in

TABLE V

Monthly distribution of rainfall

Level of rainfall (inches)	No. of experiments	Average date of			Average rainfall (inches)						Average yield of grain (mds/acre)
		Planting	Harvesting	Flowering	July	Aug	Sept.	Oct.	Nov.	Dec.	
10.23	26	Aug. 26	Dec. 15	Oct. 18	—	1.80	7.30	1.02	0.11	Nil	15.1
20.39	28	Aug. 14	Dec. 12	Oct. 25	—	9.62	7.51	3.25	Nil	0.01	22'0
30.08	53	Aug. 10	Dec. 16	Oct. 28	—	9.03	12.21	7.72	1.06	0.06	24.7
30.07 (Selected pattern)	25	Aug. 11	Dec. 18	Oct. 31	—	7.66	11.14	9.29	1.90	0.08	31.5
40.39	30	July 27	Dec. 18	Oct. 20	3.29	16.40	13.35	7.30	0.02	0.03	24.7
62-93	7	Aug. 4	Dec. 19	Oct. 25	—	28.32	20.88	13.43	0.30	Nil	24.7

any growing season, the pattern of distribution that serves more closely the physiological water need of the crop at the different stages of its growth and maturity ovbiously gives a better crop response. Determination of the distribution pattern that induced optimum crop production was, therefore, important for assessment of water requirement at different phases of crop growth and ultimate regulation of the dose and timing of water application in any irrigational practice. It was also likely to give an indication of the extent of conservation or run-off under similar and different ranges of rainfall totals. For this purpose, the results were picked up of all those experiments where total rainfall feeding the crop during the growing season was in the neighbourhood of 30 inches corresponding to the point of inflexion of the yield-rainfall curves, monthly rainfall distribution figures were tabulated and an average was drawn up (Table V). Whether this pattern of distribution or any other was more conducive to yield was a matter of considerable importance. Plotting of grain yield against monthly rainfall and selection of distribution patterns recording some of the highest individual yields revealed that the selected distribution pattern induced about 27.5 per cent higher grain yield than the average distribution pattern of 30 inches or other ranges of rainfall totals (Table V).

Balance-sheets of loss and gain of water by rice fields in different months of the growing season under different ranges of rainfall totals have been drawn up on the basis of monthly rainfall and corresponding monthly losses of water (Table VI), and the resulting levels of soil moisture including depth of standing water on rice field have been graphically represented in Fig. 8 in order to bring out their comparative effect on physiological behaviour of rice in relation to yield. From Table VI, it would appear that under the selected distribution pattern (pattern 2), the soil was a little above puddled stage in August and there was a standing depth of about 2–3 inches of water in September and about 4 inches in October. Under distribution pattern 1 of same rainfall total, plants endured a deeper submergence of 5 to 7 inches in September and more than 7 inches in October corresponding to the period of active tillering. That the moisture conditions prevailing in rice fields under pattern 2 were suitable for optimum tiller formation had been demonstrated by Ghosh (1954) and other workers of this Department (Annual Report, 1925–26) and elsewhere in India (Sen, 1937; Singh *et. al.*, 1935), who had also shown that heavier depth of standing water at earlier stages of growth (7–8 weeks) over the puddled stage progressively suppressed tiller formation. Not only the number of tillers but also total leaf area, total dry matter and grain yield, which were highest under water at soil level, gradually decreased with rise of water level. Plant height and water content of both stem and leaf were also found to increase with rise in water level (Ghosh, 1954), thereby rendering the plants more susceptible to lodging. Deeper water level also adversely affected meristematic activity at regions of tiller formation and efficiency of utilisation of absorbed nitrogen in production of dry matter. Choudhuri and Ganguli (1948) found that 3–4 inches submergence during the growing period was best for tiller formation and grain yield. In Japan, the standard depth of water on rice field during the growing period was reported to vary from 1–2 inches (Grist, 1953).

The physiological rôle of standing depth of water and requirement of soil moisture during subsequent stages of growth relating to earing, flowering and and fruiting was yet little understood. It was, however, shown by Chakladar (1946), working on the influence of soil moisture on rice yield, that none of the plants under 33 per cent saturation formed seeds though some of them had flowered, while plants under 50–75 per cent saturation formed seeds. In both the distribution patterns of 30 inches rainfall, there was standing water till the middle of November. On the whole, 125 per cent saturation was maintained in soil under rainfall distri-

TABLE VI

Balance sheet of monthly rainfall and moisture losses from rice field

Level of rainfall (inches)	Month	Rainfall (inches)	Loss of moisture (inches) from rice field			Total loss of moisture (inches)	Level of standing water/soil moisture at the end of the month (inches)	Average soil moisture during the month (% saturation)
			Transpiration	Evaporation	Percolation			
30.08 (General pattern) Pattern 1	Aug. (22 days)	9.03	2.14	2.13	1.79	6.06	+2.97	112
	Sept.	12.21	2.92	2.29	2.43	7.64	+7.54	144
	Oct.	7.72	3.02	3.23	2.51	8.76	+6.50	159
	Nov.	1.06	2.92	2.80	2.43	8.15	−0.59	125
	Dec. (16 days)	0.06	1.56	1.43	1.30	4.29	−4.82	77
30.07 (Selected pattern) Pattern 2	Aug. (21 days)	7.66	2.58	2.04	1·71	6.33	+1.33	105
	Sept.	11.14	3.69	2.29	2.43	8.41	+4.06	123
	Oct.	9.29	3.82	3.23	2.51	9.56	+3.79	133
	Nov.	1.90	3.69	2.80	2.43	8.92	−3.23	102
	Dec. (18 days)	0.08	2.22	0.54	0.48	3.24	−6.39	60
10.23	Aug. (6 days)	1.80	0.41	0.58	0.49	1.48	+0.32	101
	Sept.	7.30	2.05	2.29	2.43	6.77	+0.85	105
	Oct.	1.02	2,11	2.77	2.02	6.90	−5.03	83
	Nov.	0.11	2.05	0.84	—	2.89	−7.81	46
	Dec. (15 days)	Nil	1.02	0.01	—	1.03	−8.84	30
20.39	Aug. (18 days)	9.62	1.66	1.75	1.46	4.87	+4.75	120
	Sept.	7.51	2.77	2.29	2.43	7.49	+4.77	140
	Oct.	3.25	2.87	3.23	2.51	8.61	−0.59	118
	Nov.	Nil	2.77	2.01	1.45	6.23	−6.82	69
	Dec. (12 days)	0.01	1.11	0.01	—	1.12	−7.93	38
							Potential level of standing water (inches)	Level of standing water/soil moisture after allowing runoff losses over 10″ on field level (inches)
40.39	July (5 days)	3.29	0.44	0.55	0.41	1.40	+ 1.89	+ 1.89
	Aug.	16.40	2.68	3.01	2.52	8.21	+10.08	+10.00
	Sept.	13.35	2.60	2.29	2.43	7.32	+16.11	+10.00
	Oct.	7.30	2.68	3.23	2.51	8.42	+14.99	+ 8.98
	Nov.	0.02	2.60	2.80	2.43	7.83	+ 7.18	+ 1.17
	Dec. (18 days)	0.03	1.56	1.61	1.44	4.61	+ 2.60	− 3.41
62.93	Aug. (28 days)	28.32	2.55	2.72	2.28	7.55	+20.77	+10.00
	Sept.	20.88	2.73	2.29	2.43	7.45	+34.20	+10.00
	Oct.	13.43	2.82	3.23	2.51	8.56	+39.07	+10.00
	Nov.	0.30	2.73	2.80	2.43	7.96	+31.41	+ 2.34
	Dec. (19 days)	Nil	1.73	1.70	1.54	4.97	+26.44	− 2.63

bution pattern 1, and 102 per cent saturation under pattern 2 during the month of November.

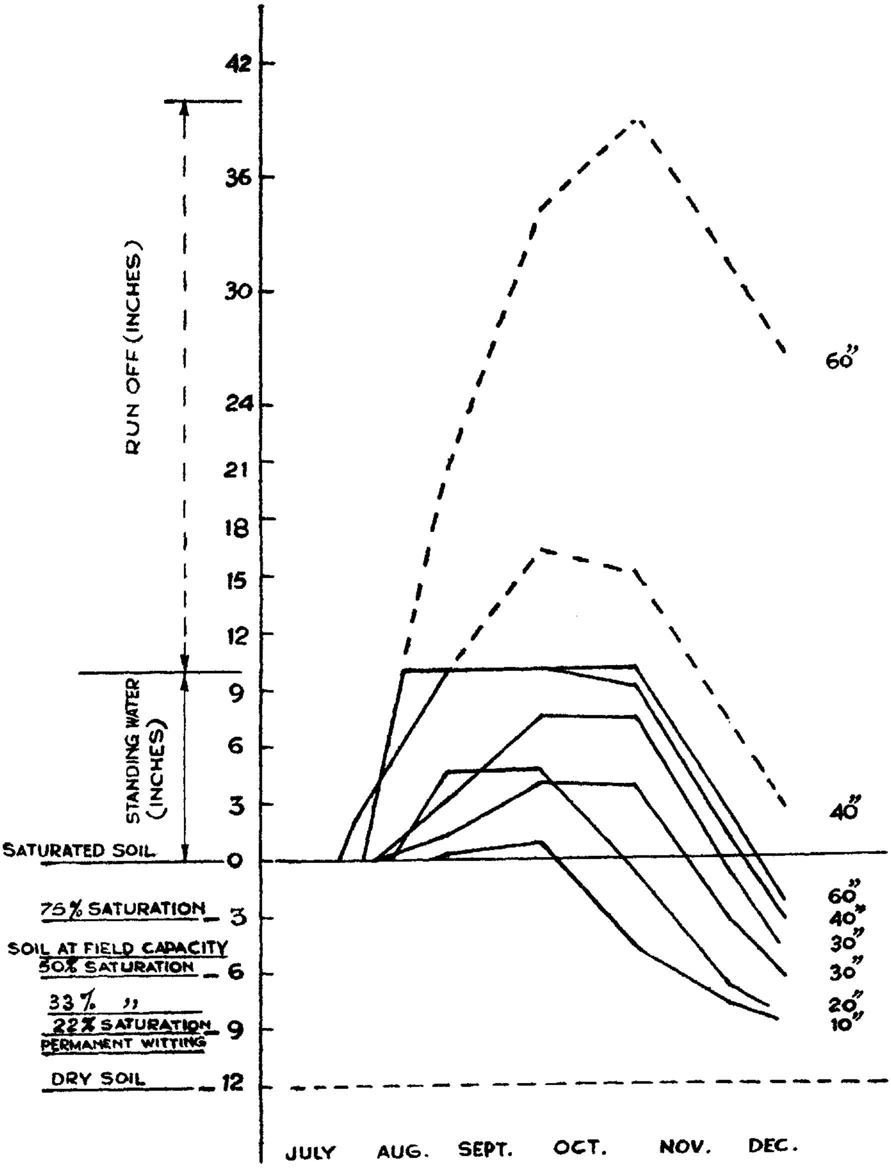

FIG. 8

At the level of 10 inches rainfall, the field was just at puddled stage in August and September but standing water was dried up in early October before emergence of ears took place. Soil moisture was reduced to 83 per cent saturation on average in October and to 46 per cent saturation in Nobemver. Moisture condition in August and September was not quite unsuitable for tillering, though available period for tillering was shorter due to slightly delayed transplantation (August 26) caused by inadequacy of preceding rainfall. Delayed transplantation might affect yield (Dept. Agric. Anna. Rept, 1934–39; Ganguli, 1950), though the main reason for abnormally low yield would seem to be inadequate earing coupled with under-development of seeds due to grave deficiency of soil moisture. At the level of 20 inches rainfall, there was suitable depth of standing water in August and September for adequate tillering but at the fruiting stage (Nov.), soil moisture was reduced to 69 per cent saturation. It would seem to show that 69 per cent saturation during fruiting stage was not sufficient for optimum grain formation. At the level of 40 and 63 inches rainfall, there was plenty of moisture in the field at all stages of growth and development for adequate tiller and grain formation. But heavier rainfall was likely to result in so much accumulation of water on well-bunded rice field as to cause proportionate run off.

It was thus evident that maintenance of certain specific levels of standing water and soil moisture in rice fields at different stages of crop growth and maturity was essential for optimum tillering and grain formation in a transplanted rice crop. Such specific levels of soil moisture could scarcely be maintained under field conditions except through controlled irrigation and drainage. The overriding influence of water control on the success of rice cultivation was sought to be brought out in course of technical discussions on soil-plant-water relations at the Fifth session of the International Rice Commission in Calcutta in November, 1956. Evidence was adduced that countries having controlled systems of water supply consistently obtained higher outturns of rice than those growing the crop otherwise under rain-fed conditions and instances were cited that water control in Japan and Italy was primarily responsible for higher rice yields than other countries of Asia including South East Asia and the world.

EFFECT OF FREQUENCY AND DEPTH OF RAINFALL ON YIELD

Average frequency of rainy days during different months in the growing season and depth of showers per rainy day at 30 inches of rainfall total have been calculated in Table VII.

TABLE VII

Frequency of rainy days and depth of shower (30 *inches rainfall*)

Month	Average number of rainy days per month	Average depth of water per rainy day (inches)
August	20	0·70
September	16	0·75
October	7	1·02
November	1·5	0·70

Frequency and depth of precipitation (Table VII) at 30 inches rainfall did not indicate run-off losses in view of lower level of standing water on rice fields (Table VI and Fig. 8) in relation to height of protective bunds, though higher rainfall ranges and even concentrated downpour on any or closely successive occasions could cause it. The estimated requirement of 30 inches rainfall would seem to secure maximum possible conservation and utilisation of received rainfall.

The pattern of frequency and depth of precipitation in different months of the growing season would seem to have important physiological bearing on rice plants particularly relating to yield. Frequent light showers in August and September helped in cooling the atmosphere of the hot summer and in further lowering of temperature of leaf and stem surface through evaporation of intercepted rains. Lower temperatures and higher humidity both contributed to reduction of intensity of transpiration and oxidative catabolic processes leading to more rapid fixation of dry matter; they also reduced evaporational losses thereby effecting overall economy in water utilistion. On the other hand, less frequent showers of heavier depth in October caused less dissipation of moisture in the atmosphere and more accumulation in the field, which was helpful in carrying the crop through the "critical stages" of flowering and fruiting. Besides, higher frequency of rainfall had a deleterious effect on flowering and fertilisation. Choudhuri and Ganguli (1948) observed that while flowering of rice was at its maximum between 10 to 11 A.M. and was finished before midday in sunny days, in rainy days and even in cloudy weather flowering began late and continued upto 3 to 4 P.M. The flowers opening in the afternoon were likely to do so with their anthers already dried up (Burkill as quoted by Grist, 1953), thereby affecting the chance of enclosed pollens of bursting out and fertilisation. High altitude angular bombardment of rain drops on opening flowers and also accompanying wind could cause wasteful shedding of anthers in plenty. These reasons, therefore, reflected the advantage of wider interval and perhaps complete cessation of rains during the period of flowering for promotion of yield.

WATER REQUIREMENT FOR RAISING SEEDLINGS AND PRE-TRANSPLANTATION AGRICULTURAL OPERATIONS

Thirty days old seedlings were considered to be best for transplantation in normal times (Dept. Agric. Ann. Rep. 1934–39; Choudhuri and Ganguli, 1948; Roe, 1950), and hence water requirement for raising such seedlings was calculated. It was known that seedlings would grow well in a soil at or above field capacity and that they would not grow at all unless the soil moisture was above the limit of permanent wilting. From the moisture content of clay loam soils at field capacity and at permanent wilting range and from the rate of evaporational and transpirational losses of moisture during 30 days of growth of seedlings, minimum and adequate water requirement was calculated as in Table VII.

The results (Table IX) of field experiments on raising of 30 days old seedlings to suitable heights for transplantation (Dept. Agric. Ann. Rep., 1933), showed that the amount of rainfall (10·8 inches) received by these seedlings closely reconciled with the magnitude of adequate water requirement calculated in Table VIII (10·74 inches). Adding up water requirement (4·90 acre-inches) for puddling of a clay loam soil, already at field capacity, up to a depth of 12 inches representing the puddling zone and the potential rhizosphere, the total water requirement for the entire process of raising seedlings and conducting tillage and other pre-transplantation agricultural operations including puddling of soils was calculated at 15·64 acre-inches.

Water requirements for the above processes were also found out from the field data by a different method. The amount of rainfall recorded during 30 days of pre-transplantation period in individual experiments (Table II) were plotted against the corresponding number of rainy days. The majority of points representing about two-thirds of the total number were found to cluster within the

TABLE VIII

Water requirement for raising seedlings

Nature of water requirement	Amount of water requirement (inches)	
	Minimum	Adequate
Water required to bring the twelve-inch layer of surface soil to moisture level of	Permanent wilting point $\left(12 \times 1{\cdot}36 \times \frac{16}{100}\right)$ 2·61	Field capacity $\left(12 \times 1{\cdot}36 \times \frac{43}{100}\right)$ 7·02
Water required to recompense evaporational loss in 30 days in July (Penman equation)	3·41	3·41
Water required to recompense transpirational loss in 30 days	0·31	0·31
Total	6'33	10·74

TABLE IX

Rainfall for raising seedlings (Experimental Farm—Pabna, 1933)

Variety	Date of sowing in seed-bed	Quantity of Niciphos added/acre	Age of seedlings (days)	Height of seedlings (inches)	Average rainfall received (inches)
Indrasail	14-6-32	20 lb. N 20 lb. P_2O_5	31	16.0	11.2
,,	,,	Nil	34	13.5	12.3
Dudsar	3-7-32	20 lb. N 20 lb. P_2O_5	24	15.2	8.8
,,	,,	Nil	29	13.5	10.6
Chinsurah II (Bhasamanik)	13-7-32	20 lb. N 20 lb. P_2O_5	29	13.0	10.0
,,	,,	Nil	35	10.5	11.9
		Average	30	13.6	10.8

orbit of a very small circle (Fig. 9) and the average rainfall calculated from these clustered points was found to be 12.9 inches. Adding the moisture content of field soils, which had never been completely dry but retained moisture not usually below the wilting range prior to this period, water requirement worked out as 15°.5 acre-inches.

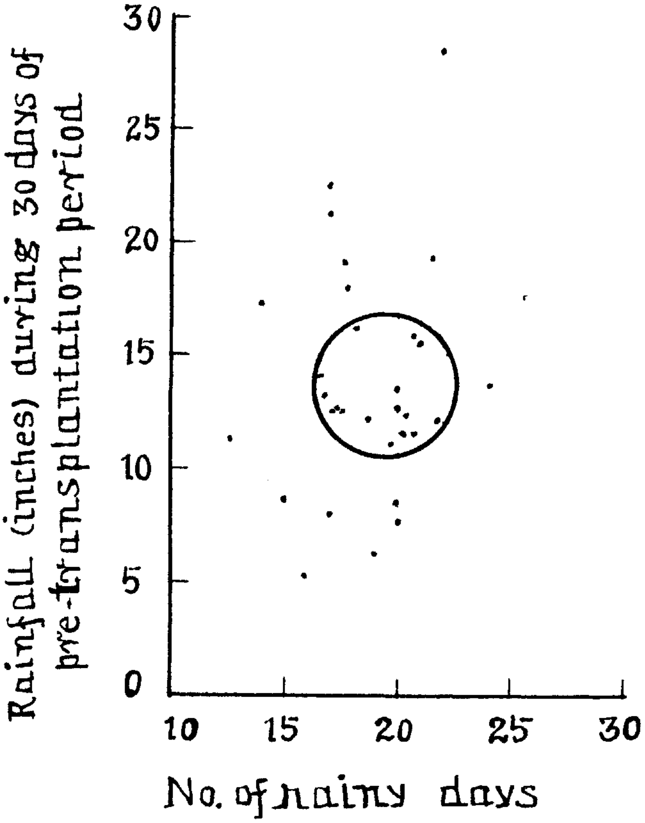

Fig. 9

Rôle of Rainfall on Nitrogen Supply

Rain water contains nitrogen, mainly as ammonium nitrate and nitrite and partly as free ammonia (Partington, 1953), varying from 1 to 2 parts per million parts. It is estimated that 30 inches rainfall can supply about 10 lb. of nitrogen per acre. In terms of 20 lb rice grain obtainable per lb. of nitrogen applied in the form of manures and fertilisers at the level of 30 lb. N_2 per acre (Basak *et. al.*, 1957), 10 lb N_2 of rain-water can, therefore, contribute to production of at least 200 lb (2.5 mds.) of additional grain per acre and probably a little more in accordance with the law of diminishing returns.

The supply of ammonium nitrogen in any downpour was obviously insignificant in comparison to its supply from waterlogged rice soils. The concentration of ammonium nitrogen, which was practically nil at flooding time, rose to 1.25 mg. per 100 gm. dry soil after 20 days of submergence and increased slowly to the higher concentration of 2.5–3.0 mg/ 100 gm. dry soil with prolongation of submergence (Basak, unpublished results). Thus in addition to maintaining supply of ammonium nitrogen requirement of growing rice crop, 2 million lb. of top soil contained 25 lb. of ammonium nitrogen per acre after 20 days of submergence and higher amounts of 50–60 lb on prolonged submergence. Hence contribution of any individual shower of rains to reflect any change on NH_4—N concentration of soil in the rhizosphere was likely to be negligible. Under the circumstances the assumption by rice plants of characteristic liveliness and vigour coupled with deepening of colour closely following a shower would seem to indicate that nitrogen of rain water was probably directly absorbed and quickly assimilated by the intercepting leaves and growing parts of the plants as were nearest to the *foci* of active systhesis and rapid deposition of dry matter. Recent work on plant metabolism with suitable and radioactive isotopes has already shown the occurrence of such direct absorption of nutritional elements (N^{15}, P^{32} and K^{42}) by the leaves and their subsequent migration to and utilisation in the requisite parts of plants (Thorne, 1955). Since only 35–40 per cent of nitrogen applied to water-logged soils was recoverable by a rice crop (Mitsui, 1955; De and Digar, 1955; Basak *et al.*, 1957), such direct absorption of nitrogenous nutrients was indicative of high level of efficiency and economy in assimilation and utilisation of applied nitrogen than feeding it in bulk through the soil.

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SUMMARY

Attempt was made at determination of water requirement of transplanted rice from the effect of rainfall on yield. Significant positive correlations were found between average grain yield and average rainfall. The correlation coefficient was highly significant upto 30 inches rainfall but at higher ranges of rainfall total, it was not significant. Similarly, the yield-rainfall curves showed that increasing amounts of rainfall over 10 inches induced a progressive increase in grain yield till the optimum yield was attained at 30 inches rainfall total. Thereafter, any additional rainfall did not produce any additional effect on yield. It was concluded that water requirement of rice from transplantation to harvesting was of the order of 30 acre-inches. Results of supplemental irrigation confirmed these conclusions.

Loss of moisture from water-logged rice fields was determined for elucidation of the physical and physiological basis of water requirement. Loss of moisture by transpiration was calculated at 12.56 inches, by evaporation during the growing period from transplantaton to harvesting at 11.88 inches and by percolation at the level of 30 inches rainfall during the same period at 10.46 inches.

Patterns of monthly distribution of rainfall, during the growng period of rice, under different ranges of rainfall total were studied to find out the phased water requirement at different stages of crop growth. The ideal pattern of rainfall distribution that served the phased water requirement for production of optimum yield was determined as follows :

August (21 days)	7.66 inches
September	11.14 ,,
October	9.29 ,,
November	1.90 ,,
December (18 days)	0.08 ,,

Balance sheets were drawn up of monthly rainfall and corresponding monthly losses of moisture by transpiration, evaporation, percolation and run-off so as to evaluate the resulting levels of soil moisture and standing water on rice fields during the different stages of crop growth and maturity and their relative influence on yield. The ideal level of soil moisture

and standing water that contributed to optimum tillering and grain formation has been given below and the importance of water control on success of rice cultivation has been discussed.

August ..	1 to 2 inches of standing water
September ..	2 to 3 ,, ,, ,,
October ..	3 to 4 ,, ,, ,,
November ..	100 per cent saturation of soil moisture
December ..	50 ,, ,, ,,

Frequency and depth of rainfall in different months of the growing season and their physical influence on temperature control and water economy and physiological significance on plant metabolism and crop yield were studied. Frequent light showers during the earlier stages of growth from tillering to ear emergence and less frequent but heavier depth of showers at subsequent stages were found suitable for promotion of yield. The effect of rainfall on flowering and fertilisation has been discussed.

Water requirement for raising 30 days old seedlings and for tillage and other agricultural operations including puddling of soils has been found to be 15.5 acre-inches. Thus the total water requirement for raising a good crop of transplanted waterlogged rice from the time of sowing of seeds to harvesting of the crop has been calculated as 45.5 acre-inches.

Contribution of rainfall to supply of nitrogen in the nutrition of rice crop and the probable mechanism and efficiency of its absorption and assimilation have been elucidated.

REFERENCES

Basak, M. N. (1956). *J. Indian Soc. Soil Sci.*, **4**, 95–103.

Basak, M. N., Dutta, T., and Nag, D. K. (1957). *J. Indian Soc. Soil Sci.*, **5**, 55–63.

Briggs, L. J., and Shantz, H. L. (1914). *Jour. Agri. Res.*, **3**, 1–63.

Chakladar, M. N. (1946). *Ind. Jour. Agri. Sci.*, **16**, 152–157.

Chakravorty, S. C. (1937–42). Annual Reports of the Department of Agriculture, Bengal Govt. Press, Calcutta.

Choudhuri, S. D., and Ganguli, P. M. (1948). Dept. Agric. Assam Paddy Series Bulletin No. 4, Assam Govt. Press, Shillong.

De, P. K., and Digar, S. (1955). *J. Agric. Sci.*, **45**, 280–282.

Department of Agriculture, Bengal (1924–42). Annual Reports, Bengal Govt. Press, Calcutta.

Department of Agriculture, Bengal (1934–39). Annual Reports of Rice Research Stations at Chinsurah and Bankura, Bengal Govt. Press, Calcutta.

Fortier, S. (1926). Use of Water in Irrigation. McGraw-Hill Book Co., Inc. N.Y.

Ganguli, P. M. (1950). Rice in Assam, Paddy Series Bull. No. 6, Assam Govt. Press, Shillong.

Ghose, R. L. M., Ghatge, M. B., and Subrahmanyan, V. (1956). Rice in India. Indian Council of Agricultural Research. New Delhi.

Ghosh, B. N. (1954). *Proc. Nat. Inst. Sci. India*, **20**, 371–387.

Grist, D. H. (1953). Rice. Longmans, Green & Co., London.

Hector, G. P. (1925-26 & 1927-28). Annu. Rep. Dept. Agric. Bengal, Bengal Govt. Press, Calcutta.

Kramer, Paul. J. (1949). Plant and Soil Water Relationships. McGraw-Hill Book Co., Inc., New York.

Leonard, W. H. (1948). *J. Amer. Soc. Agron.*, **40**.

Mitsui, Shingo (1955) Inorganic Nutrition, Fertilisation and Soil Amelioration for Lowland Rice. Yokendo Ltd., Tokyo.

Partington, J. R. (1953). Text-Book of Inorganic Chemistry. Macmillan & Co., London.

Penman, H. L. (1948). *Proc. Roy. Soc.*, **193A**, 120.

Robertson, R. D. (1917). Irrigation of rice in California. *Calif. Agri. Expt. Sta. Bull.* 279.

Roe, Harry Burgess (1950). Moisture Requirements in Agriculture. McGraw-Hill Book Co. Inc. N.Y.

Sen, P. K. (1937). *Ind. Jour. Agri. Sci.*, **7**, 89–117.

Singh, B. N. *et. al.* (1935). *Proc. Ind. Acad. Sci.*, **1**, 471–495.

Thorne, Gillian (1955). Field Crop Abstracts, **8**, No. 3

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