STUDIES ON THE PHYSIOLOGY OF RICE

VII. Effect of varying water levels on growth of rice in relation to nitrogen absorption

by B. N. Ghosh,* *Department of Botany, Calcutta University*

(Communicated by I. Banerji, F.N.I.)

(*Received February 16; after revision September 10; read December 4, 1953*)

Introduction

It has been found in America by Briggs and Shantz (1914) and in Bengal at the Dacca Agricultural Farm (1925-26) that water requirement of rice is not much different from cereals like rye which are grown in dry field conditions. But rice is well known for its characteristic adaptation to wet condition. In practice rice is grown under a variety of field conditions. At one end, fields are situated at high levels without standing water and at the other, there are fields which are several feet under water during the growing period of the plant, and there are many intermediate conditions between these extremes. In low lands it is practically the only cereal crop grown. So the relation of water to operations like puddling the soil and transplanting the seedlings and also the maintenance of proper conditions in the fields is very important. The success of the crop depends on an adequate supply of water. Excessive supply by irrigation not only consumes water that might advantageously be used elsewhere, it has also an injurious effect on the soil, causing deterioration of its physical condition, accumulation of soluble salts and the formation of toxic products. Further it is expensive to irrigate the fields while rainfall is uncertain. These present difficult problems in rice cultivation. It therefore seems essential to investigate the optimum water relations of the plant as well as to study the resistance of varieties to comparative drought and flood water.

In order to elucidate the water relations of the rice plant under different conditions and to determine its optimum water requirements and the critical stages of watering, investigations have been taken up in this laboratory. The present paper deals with a study of the effect of watering on growth and nitrogen content of three varieties of rice, *Kataktara*, *Bhutmuri* and *Bhasamanik*, which are widely cultivated in West Bengal.

Experimental Procedure

The effects of water supply were studied in plants grown in pots in the cemented tanks situated in the fields of the Department of Botany, Calcutta University. There were four levels of watering: (A) no water in the tank, pots watered to maintain a certain condition of soil moisture; (B) water in the tank up to the soil level of the pots; (C) and (D) 3″ and 6″ water level above the soil surface. The experimental tanks are shown in Fig. 1; these are 10′×7′ in size and 2′ deep, one foot below the ground level and one foot above. The tanks were provided with stoppered outlets at different levels so that they could either be completely drained

---

* Present address, State Agricultural Research Station, Chinsurah, District Hooghly.

out or the desired level of water could be maintained in them. Four such tanks were used for the four watering treatments.

Seeds of pureline varieties of early ripening *aus*, *Kataktara* and *Bhutmuri* and a late ripening *aman*, *Bhasamanik*, were graded for uniformity of size and colour, sterilized in 0·2% formalin for four hours, dried and sown in replicated seedbeds on June 4, 1934. After six weeks of sowing, the seedlings were transplanted in 10″×10″ earthenware pots which were filled with an equal quantity of soil previously well mixed with one-eighth part by volume of cowdung manure.

The seedlings were carefully uprooted from the seedbeds, and their roots washed. They were selected for uniformity of size and any seedling showing a tiller was rejected. They were transplanted singly. At the time of transplantation the pots were immersed in water and a level of water approximately an inch above the soil in pots was maintained in all the four tanks for five days after transplantation to enable the seedlings to settle in their new habitat. Ten seedlings of each variety were taken for each treatment. The pots were placed in the middle of the tank in five rows of six pots each, leaving about one and a half to two feet space between these and the walls to avoid shading of the plants.

Watering treatment was started from the sixth day after transplantation. Tank 'A' was completely drained. Water level in tank 'B' was lowered up to the soil level in the pots. In tanks 'C' and 'D' there were three and six inches of water standing on the soil in pots. When ear emergence was complete in these varieties the plants were gradually brought to condition 'A' with a view to bring them under drier condition during the period of ripening.

Tiller count and measurement of growth in height of the plants were made every week during their growing period. Ear emergence note was taken in *Kataktara* and *Bhutmuri*, during the 7th, 8th and 9th week after transplantation; ears in *Bhasamanik* were counted only at harvest.

Five out of ten plants of each variety under all the watering treatments were sampled during the 7th week after transplantation. To make the sampling uniform, equal number of plants of the different varieties under the different treatments were taken every day. In all, sixty pots were sampled at this time, twenty-four pots a day on the first two days and twelve pots on the third day. The leaves were removed at their base, weighed and kept in a beaker dipping their cut ends in the water. Their area was subsequently determined. At this stage one or two leaves on the plant were dead; these were separated from the green leaves and their dry weight only was determined. The plants were separated from the roots at the base. The crown was cleared by removing the soil attached to it. The stems were then weighed. The roots in the pot were thoroughly washed in a stream of water in a sieve. To obtain the dry weights, the different parts were dried to constant weight in an electric oven at 100°C. The replicates were subsequently mixed, ground and then stored in sealed bottles for nitrogen determinations.

The remaining pots were sampled at harvest. *Kataktara* and *Bhutmuri* were harvested on October 10 and 11 and *Bhasamanik* on November 19, 1934.

The final height of the plant was determined by measuring the length of the longest shoot of the plant. The ears were separated from the shoots at the node and their length measured. The dry weight of the straw, the ears and the roots were determined. The grains were subsequently separated from the ears and their dry weights determined. The grains of the replicated plants were mixed and the dry weight of a single grain was determined at the average of 750 grains taken from these at random.

Experimental Results

The results are presented without statistical analysis as the individual data are not now available. The differences between the treatments are so marked that valid conclusions can be drawn without statistical evidence.

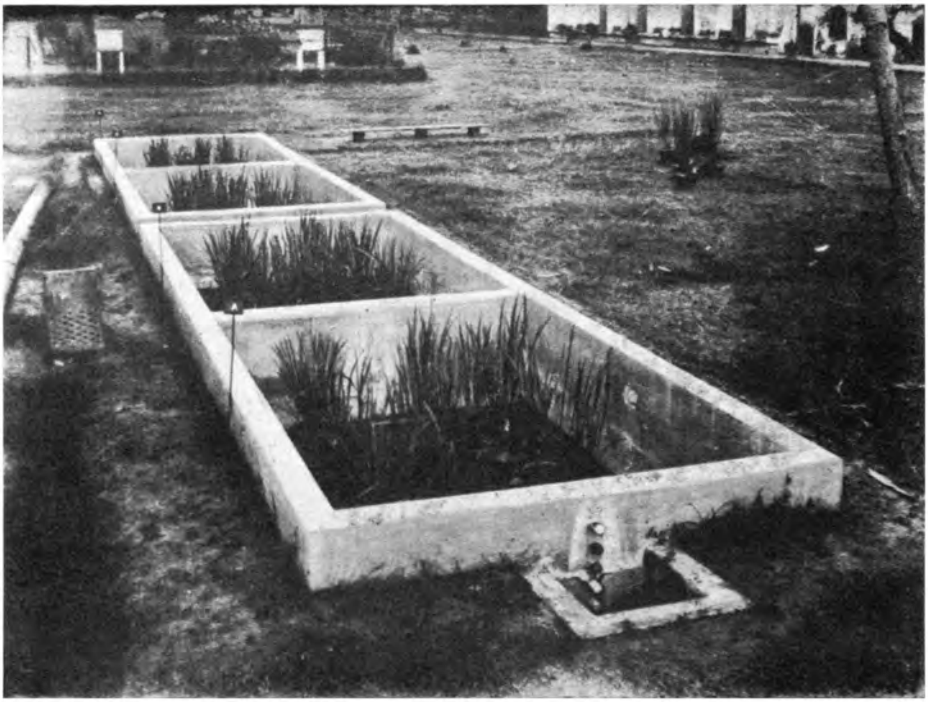

FIG. 1. Showing the general view of the experimental tanks.

Tillering.—The tillers were counted every week from the 2nd week after transplantation to the 9th week in *Kataktara* and *Bhutmuri*, and 10th week in *Bhasamanik*; the final count was made at harvest. The figures obtained for tiller numbers include the main shoot. The data are given in Table I, and graphically represented in Fig. 2. The curves show that the number of tillers steadily rises and reaches a maximum within seven or eight weeks after transplantation. This is followed by a fall to a constant number which is maintained at harvest.

TABLE I

Mean number of tillers per plant

Watering	Weeks after Transplantation									Harvest	
	2	3	4	5	6	7	8	9	10	Ripe	Unripe
					Kataktara						
A ..	2·0	3·8	5·0	6·7	7·1	7·3	7·2	7·2	..	7·2	7·2
B ..	1·3	4·7	7·2	11.0	11·0	11·7	12·2	12·2	..	12·2	7·8
C ..	1·0	2·3	4·8	9·7	10·3	10·7	10·8	10·8	..	10·8	5·6
D ..	1·0	2·0	3·5	7·7	8·1	8·2	7·8	7·8	..	7·8	5·2
					Bhutmuri						
A ..	3·0	6·4	9·3	12·9	14·7	15·0	15·0	15·2	..	14·6	9·0
B ..	2·9	9·4	15·2	19·1	19·2	19·7	19·2	19·2	..	17·8	8·8
C ..	1·7	6·4	11·3	19·8	19·9	20·3	20·6	20·2	..	18·4	6·6
D ..	1·4	4·8	9·3	17·0	17·0	17·5	16·4	16·4	..	16·4	3·8
					Bhasamanik						
A ..	3·1	6·2	9·3	14·4	18·3	18·0	17·8	17·2	17·2	17·2	0·4
B ..	2·2	5·8	12·2	20·1	20·0	20·8	19·2	18·6	18·0	15·8	1·0
C ..	1·4	4·2	8·9	16·2	16·1	17·7	17·0	16·8	16·0	15·2	0·8
D ..	1·3	3·2	7·4	14·1	14·2	14·0	12·8	12·8	12·2	11·8	0·2

In *Kataktara* tillering was maximum under 'B'; with further increase in water under 'C' and 'D', it was reduced. Tillering was minimum under 'A'. In *Bhutmuri* tillering was most rapid under 'B' up to the fourth week after which it was largest in 'C'. The maximum number of tillers in this variety was produced in 'C', but under 'D' it was reduced. Tillering was minimum in 'A'. In *Bhasamanik* tillering was maximum under 'B', * under 'C' and 'D' it was progressively reduced. Tillering under 'A' lies between 'B' and 'C'.

The nature of the effect of watering on tiller growth in all the varieties used appears to be the same. *Bhutmuri* indicates a greater affinity for water than the other two varieties, *Kataktara* and *Bhasamanik*. Singh *et al.* (1935) have observed varietal differences in the water requirement of rice.

The level of the curves shows that water standing above the soil suppresses tillering. This result corroborates the findings of Agricultural Department of

* In another paper on 'Physiological studies on the effect of varying water levels on growth of rice in relation to carbohydrate metabolism of the leaves', tillering was maximum under 'A' and not under 'B' as observed in the present paper. This difference may be due to the difference in watering under 'A' in the two experiments. The exact moisture content of the soil was not measured.

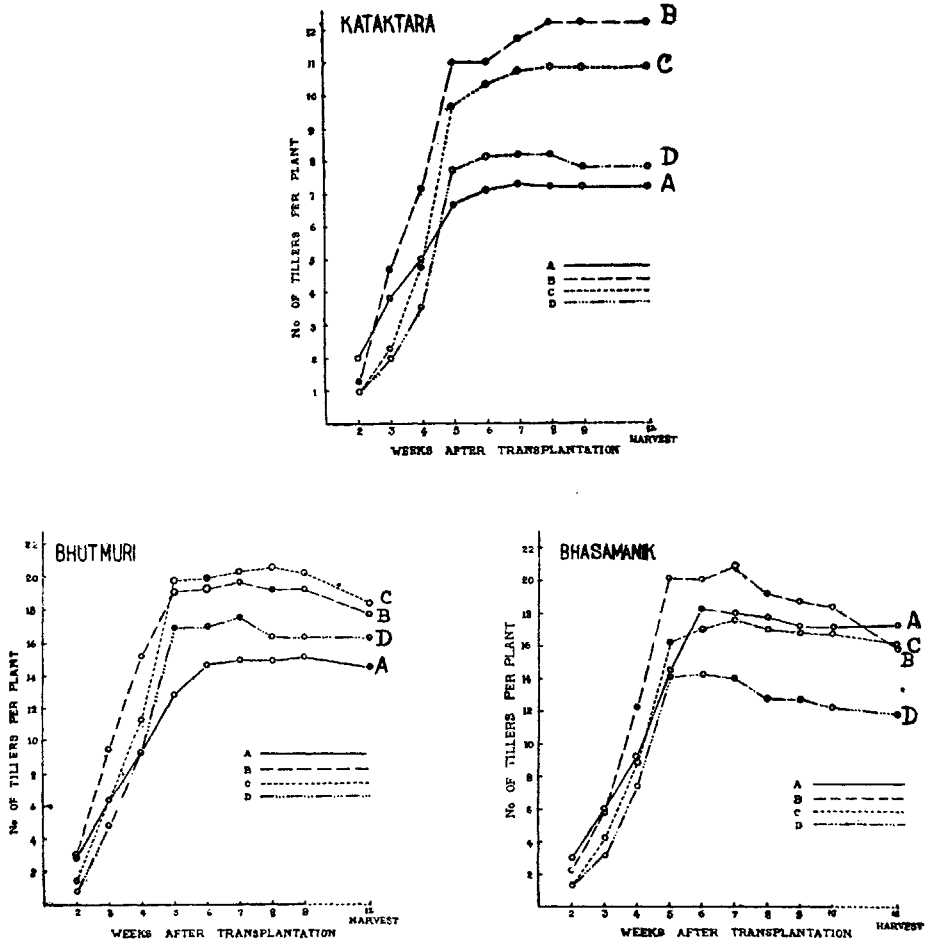

FIG. 2. Showing the effect of varying water levels on tillering in *Kataktara, Bhutmuri* and *Bhasamanik*.

Bengal (Report, 1925-26) that water standing in the field during early period of growth after transplantation suppresses tillering in rice.

In the early ripening varieties, *Kataktara* and *Bhutmuri*, tillering was minimum probably because water was limiting their rapid growth. In *Bhasamanik* which grows more slowly over a longer period, condition 'A' does not show a limiting effect to an equal extent.

With the maturation of the shoots there was a second crop of tillers from the base of the plants. In *Kataktara* and *Bhutmuri* the number of these new tillers was considerable. Immature tillers at harvest in *Bhasamanik* were very small. Watering treatments had important effects on these new tillers. The number of these new tillers was maximum under 'A', and progressively reduced under conditions of increased water supply.

Height.—Two measurements were taken; one from the surface of the soil up to the base of the uppermost leaf on the biggest shoot of the plant, and another up to the highest leaf tip. The first measurement indicated the development of the stem, while the second was the measure of the height of the plant. The data are given in Table II.

TABLE II

Plant height and stem length in centimetre

Watering	Weeks after Transplantation									Harvest
	2	3	4	5	6	7	8	9	10	
					Kataktara					
A ..	14·8	19·9	22·9	27·4	50·2	76·4	89·5	90·4	..	90·8
	62·6	66·6	74·9	82·8	91·6	109·9	120·4	110·5	..	115·7
B ..	15·4	21·0	24·1	27·7	39·9	65·5	92·3	95·7	..	94·4
	60·9	65·2	73·2	84·4	91·5	100·6	119·4	121·0	..	124·2
C ..	14·6	19·4	23·6	26·5	33·4	52·4	78·2	95·2	..	97·3
	60·7	66·0	72·1	78·8	88·1	97·9	110·7	122·0	..	124·4
D ..	14·2	20·6	24·5	28·2	34·3	51·7	73·3	94·7	..	100·5
	61·7	63·8	70·0	79·2	91·8	102·0	111·3	123·9	..	125·1
					Bhutmuri					
A ..	18·6	24·0	25·9	28·5	40·3	64·9	82·5	84·2	..	89·0
	67·3	70·2	72·4	79·4	87·0	102·0	116·4	115·8	..	108·1
B ..	13·0	23·8	27·2	28·9	36·7	61·6	83·9	95·0	..	96·3
	68·8	69·9	73·8	81·2	84·3	96·3	112·1	119·9	..	118·5
C ..	18·4	22·9	26·5	27·9	33·5	53·6	80·1	96·9	..	99·5
	69·4	69·8	72·3	77·2	83·3	93·0	108·6	120·0	..	122·4
D ..	18·1	24·2	28·2	28·9	33·8	53·7	80·1	96·6	..	101·7
	64·8	65·2	73·9	78·6	84·7	93·7	108·7	120·8	..	122·6
					Bhasamanik					
A ..	14·9	19·3	22·1	24·2	25·7	28·0	29·5	32·3	38·8	95·4
	58·5	64·2	68·6	72·9	77·9	84·8	88·7	93·9	102·3	120·3
B ..	13·9	20·2	23·2	23·9	25·9	28·9	32·7	35·1	43·2	106·6
	57·2	61·4	68·9	71·3	73·7	81·7	89·5	96·1	103·9	131·7
C ..	14·1	20·1	22·8	23·7	26·3	29·4	32·2	35·9	43·4	110·0
	58·9	62·1	70·7	73·8	77·3	85·0	93·9	100·1	105·9	135·7
D ..	15·3	21·9	24·6	25·5	27·5	30·1	32·8	35·8	43·1	113·0
	58·2	63·1	70·2	75·1	78·8	85·9	93·9	99·7	107·1	138·8

During the first six weeks after transplantation the stem grew very slowly in *Kataktara* and *Bhutmuri*, after this it elongated very rapidly up to a point after which the rate of elongation fell again. In *Bhasamanik* the slow rate of growth is prolonged corresponding to its longer growing period. During the early period when growth rate of the stem was very slow, showing very little effect of watering on the plants. But in the other varieties stem elongation started first under 'A' and it was delayed with increasing water. Finally, however, the stem length increased with increasing water level. In *Bhasamanik* the growth rate of the stem was more or less uniform up to the 10th week after which there was only one measurement at harvest. The effect of water increasing the height of the plant in this case was evident comparatively earlier.

From the data it is seen that there is no sudden rise in the case of the actual height of the plant like that in the stem. The rise is uniform. This is due to the fact that the earlier leaves are longer and the later leaves are gradually smaller. The effect of the watering treatments on the height of the plant is determined by the height of the stem. The final plant height and stem length determined at harvest are shown in Fig. 3. The effects of water level on the increase in the height of the plant and stem length are very marked. These have also been confirmed by Sen (1937) in field culture.

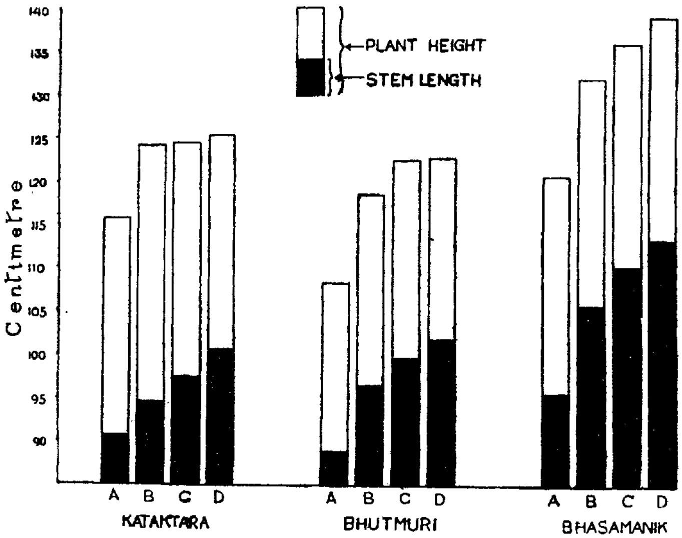

FIG. 3. Effect of varying water levels on plant height and stem length in three varieties of rice. Note increase in plant height and stem length with rise in water level.

Ear emergence.—Ears began to emerge in *Kataktara* and *Bhutmuri* seven weeks after transplantation. The data for ear emergence were taken thrice, and a final count was made at harvest. In *Bhasamanik* ears were counted only at harvest.

Flowering was most rapid under 'A' and it was increasingly delayed with increasing water level (Table III), while in the field experiment (Sen, 1937) cracked condition delayed flowering in the *aus* varieties and the process was hastened under increasing moisture conditions of the soil.

These contradictory results are due to the amount of soil moisture. In the pot culture experiment water under 'A' was limiting, thus inducing rapid flowering, while under increasing water levels the vegetative growth was prolonged. In the field soil moisture even under cracked condition was not limiting, but the comparative moisture deficiency of the soil reduced the rate of growth.

The total number of ears per plant was primarily determined by the number of shoots in a plant. In *Bhasamanik* largest number of ears was produced under 'A'. The percentage of ears produced in a plant (Table III) shows an inverse relationship to tillering in their response to watering. In *Kataktara* and *Bhasamanik* this value is minimum under 'B' where tillering is maximum.

The data for length of ears per plant are given in Table III. The length of ear was reduced under 'A' irrespective of varieties. In *Kataktara* it rose to a

TABLE III

Number and length (in cm.) of ears per plant

Watering	Weeks after Transplantation					Length of Ears
	7	8	9	Harvest	Ears as p.c. of maximum tillers	
			Kataktara			
A ..	3·6	6·8	6·8	6·8	93	24·9
B ..	0·17	6·4	10·6	10·6	87	29·8
C ..	0·0	2·4	10·0	10·0	93	27·1
D ..	0·0	1·2	7·8	7·8	95	24·6
			Bhutmuri			
A ..	1·0	8·8	13·2	13·2	87	19·1
B ..	0·0	7·8	15·2	15·2	77	22·2
C ..	0·0	4·8	16·2	16·2	79	22·8
D ..	0·0	4·0	15·0	15·0	86	20·9
			Bhasamanik			
A ..	..	..	..	17·2	94	24·9
B ..	..	..	..	14·6	73	25·1
C ..	..	..	..	14·4	81	25·7
D ..	..	..	..	11·6	82	25·8

maximum under 'B', under 'C' and 'D' it was reduced. In *Bhutmuri* length of ears under 'B' and 'C' was almost similar but maximum under 'C'; under 'D' it was reduced. In *Bhasamanik* the length of ears under 'C' and 'D' was greater than that under 'B'.

Leaf Area.—The area of the total leaf surface of the plants was determined at the time of 1st sampling, made six weeks after transplantation. The leaves were removed at their base. The length and maximum breadth of each leaf was measured directly with a metre scale. At the same time an estimation of the area of all the leaves from the three largest tillers of three of the five plants sampled was made with a planimeter. The length and breadth of each individual leaf when multiplied gave a 'leaf product' which was an estimate of the leaf area. Dividing the actual area of every planimetered leaf by the leaf product 'a factor' was obtained. The average of this factor for the plants under each treatment was employed to convert the leaf product to real leaf area. The data are presented in Table IV.

From the data it is clear that the total leaf area of the plant is determined by the number of tillers. The effect of the watering treatments on tillering is reflected on the total area of leaf surface.

The low value for leaf area in *Bhutmuri* under 'C' in spite of high figures for tiller number may be explained by the fact that under this condition tillering was lower than under 'B' up to the fourth week after transplantation; it was only after the fifth week that tillering was maximum under 'C' (Table I). A considerable number of tillers at this stage, therefore, must be very young which had produced only a few leaves.

The average area of a single leaf is also given in Table IV. In all the varieties of rice used, area of a single leaf increased with increasing water level. The effect was most clearly shown in *Bhasamanik*.

TABLE IV

Leaf area in sq. cm.

Watering	*Kataktara*		*Bhutmuri*		*Bhasamanik*	
	Average leaf area per plant	Average area of a single leaf	Average leaf area per plant	Average area of a single leaf	Average leaf area per plant	Average area of a single leaf
A ..	831·7	30·5	1,188·7	18·1	1,281·5	14·9
B ..	1,291·3	31·2	1,635·3	18·8	1,254·5	15·1
C ..	1,105·0	31·4	1,340·7	18·8	1,102·0	16·4
D ..	1,001·7	31·1	1,299·9	19·2	1,179·1	17·2

Water content.—Water content of the stem and leaf of the plant was determined at the time of 1st sampling, i.e., after six weeks of transplantation. The data are presented in Table V as percentage of dry matter. Percentage of water content in both stem and leaf increased with rise of water level.

The increase of water content of leaf from 'C' to 'D' was little, but in stem percentage of water considerably increased from 'C' to 'D'.

TABLE V

Water content of stem and leaf as percentage of dry weight

Watering	*Kataktara*		*Bhutmuri*		*Bhasamanik*	
	Stem	Leaf	Stem	Leaf	Stem	Leaf
A ..	532	236	449	253	625	269
B ..	553	289	507	264	624	298
C ..	590	322	567	272	709	305
D ..	703	320	618	286	751	306

Dry weight data.—The data for total dry weight per plant and its distribution in root, stem and leaf after six weeks of transplantation are given in Table VI and graphically represented in Fig. 5.

In all the varieties used, the total dry weight of the plant and its distribution in root, stem and leaf increases in 'B', and then falls with further rise of water level. Plants of different varieties at this stage are shown in Fig. 4. In Table VII are given the dry weight data of the plant at harvest. The total dry weight of the plant at this stage shows the same relationship as before. Dry weight of root, straw and ears also show a similar effect in *Kataktara* and *Bhutmuri*. In *Bhasamanik* the dry weight of ears under 'A' is very much reduced, as a result the dry weight of straw in this variety of rice is maximum under 'A'.

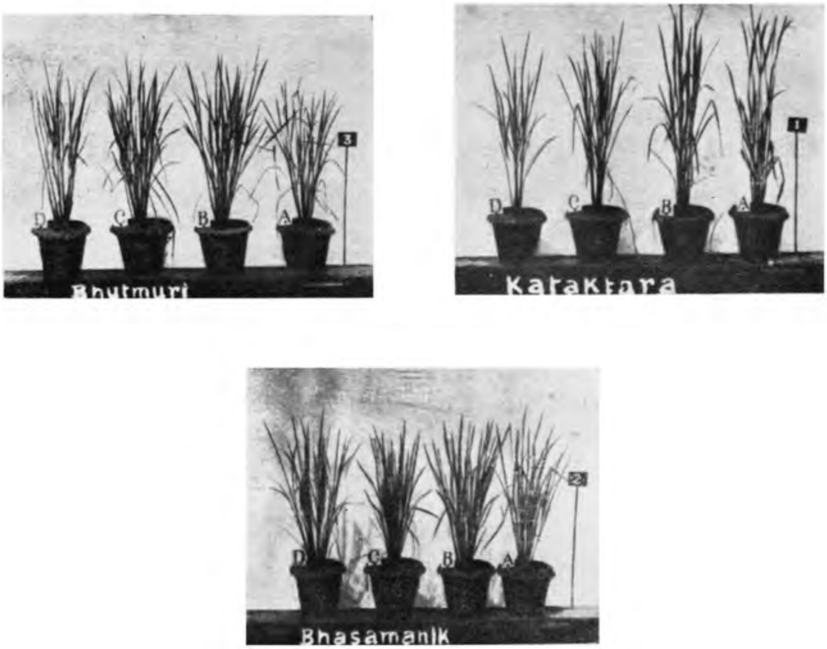

Fig. 4. Showing plants of *Bhutmuri*, *Kataktara* and *Bhasamanik* after six weeks of transplantation under different levels of watering.

TABLE VI

Dry weight in grm. per plant after six weeks of transplantation

Watering	*Kataktara*				*Bhutmuri*				*Bhasamanik*			
	Root	Stem	Leaf	Whole plant*	Root	Stem	Leaf	Whole Plant*	Root	Stem	Leaf	Whole Plant*
A ..	2·85	10·50	4·44	18·20	3·35	12·24	5·85	22·37	4·30	7·17	5·64	17·5
B ..	3·38	12·50	6·13	22·40	4·12	15·79	7·07	28·30	5·47	8·03	5·96	20·6
C ..	2·52	8·27	5·50	16·90	3·52	11·67	6·41	22·50	3·75	6·46	5·46	16·8
D ..	2·22	6·96	4·98	14·90	3·31	10·65	5·14	20·50	3·31	5·90	4·78	14·9

* The dead parts of the shoot are included in the dry weight of the whole plant.

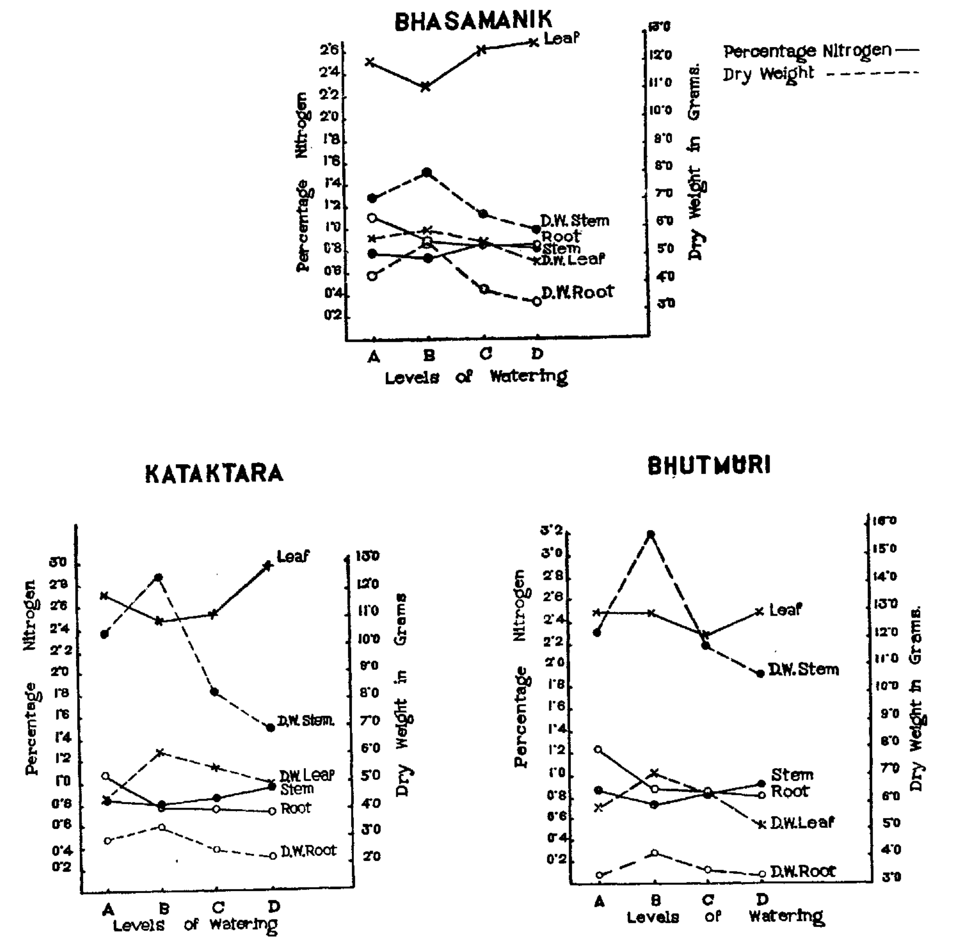

FIG. 5. Showing the effect of varying water levels on the dry weight and nitrogen content of root, stem and leaf of *Bhasamanik*, *Kataktara*, and *Bhutmuri* after six weeks of transplantation.

TABLE VII

Dry weight in gm. per plant at harvest

Watering	*Kataktara*				*Bhutmuri*				*Bhasamanik*			
	Root	Straw	Ears	Whole plant	Root	Straw	Ears	Whole plant	Root	Straw	Ears	Whole plant
A ..	1·65	18·3	21·6	41·5	1·66	23·5	24·6	48·1	8·59	66·1	29·4	104·1
B ..	3·80	27·1	28·4	59·3	2·87	30·3	29·4	62·6	10·60	62·2	40·9	113·7
C ..	2·48	22·6	24·3	49·4	2·76	27·4	27·6	57·8	9·42	58·2	39·0	106·6
D ..	1·90	18·2	21·5	41·6	2·09	25·7	26·0	53·8	7·17	50·2	35·4	92·8

The total dry weight of grains per plant and the dry weight of a single grain are presented in Table VIII. Yield of grains per plant increased in 'B', with further increase in the water level it was reduced. Single grain weight was similarly affected in *Kataktara* and *Bhutmuri*, but in *Bhasamanik* single grain weight is found to have increased with rise in water level.

Grain yield was calculated on the basis of 100 gms. dry weight of the whole plant in order to study its relation with the dry matter produced per plant under different conditions of water supply, and the data are presented in Table VIII. The effect was very little in the two varieties, *Kataktara* and *Bhutmuri*, but in the late ripening *aman* variety, *Bhasamanik*, the percentage of grain yield increased with increased soil moisture. This difference in the varieties of *aus* and *aman* paddy is possibly due to the differences in the time of their flowering. The early ripening *aus* varieties started flowering about seven weeks after transplantation, i.e., in early September when the rains were not yet over. For this reason the soil moisture under 'A' was not limiting. But in late October during the period of floral development in *Bhasamanik* rainwater was scarce, consequently soil moisture under 'A' was deficient for the development of flowers.

TABLE VIII

Grain yield of three varieties of rice

Watering	*Kataktara*			*Bhutmuri*			*Bhasamanik*		
	Grain per plant (gm.)	Single grain (mg.)	% grain to whole plant	Grain per plant (gm.)	Single grain (mg.)	% grain to whole plant	Grain per plant (gm.)	Single grain (mg.)	% grain to whole plant
A ..	20·1	16·9	48·4	22·6	18·8	46·9	19·8	14·7	19·0
B ..	26·9	17·9	45·3	27·3	20·3	43·6	34·5	17·0	30·3
C ..	23·2	17·1	46·9	25·9	18·9	44·8	32·3	17·4	30·3
D ..	20·6	16·7	49·5	24·8	19·1	46·1	30·3	17·8	32·7

In this work watering was not controlled by determining the soil moisture at regular intervals. The treatments were designed mainly for the first seven weeks after transplantation. An investigation controlling watering during the flowering period should elucidate the water relations of the plant with its floral development.

Chakladar (1946), in an investigation on the influence of soil moisture on the yield of paddy, has reported that none of the plants under 33% saturation formed seeds though some of them had flowered, while the plants under 75 and 50% saturation formed seeds showing that water is essentially necessary during the flowering stage for seed formation.

Dry weight of root in the *aus* varieties did not show any increase at harvest than that after six weeks of transplantation, on the other hand, it was very much reduced (Tables VI and VII). In the *aman* variety root increased in dry matter showing that at the time of the first sampling the plant was at an early stage of growth.

The reduction of dry matter in root was greatest under 'A' when the largest number of second crop of tillers produced. The roots translocate all their reserve materials for the development of the new shoots thus decreasing in their weight.

In 1935 the effect of varying conditions of water on growth and nitrogen content was repeated with *Bhasamanik*. Two more tanks 'E' and 'F' had been added, which had 9″ and 12″ of water respectively above the soil level in the pots. In this case four samples were taken. The first sample was taken three weeks after transplantation, the second after six, the third after nine and the fourth at harvest. To obtain the dry weights of the different parts of the plant, roots, stems, leaves, straw and grains, were dried to constant weight in a gas oven at 100 ± 1°C. The replicates were subsequently mixed, ground, and then stored in sealed bottles with proper labelling for nitrogen determinations.

The data for total dry weight per plant and its distribution in root, stem, leaf, straw and grain of *Bhasamanik* of four samples are given in Tables IX and X, and graphically represented in Fig. 6.

TABLE IX

Dry weight in gm. of root, stem and leaf of Bhasamanik *after three, six and nine weeks of transplantation (1935).*

Watering.	Root			Stem			Leaf		
	Weeks after Transplantation								
	3	6	9	3	6	9	3	6	9
A ..	0·43	1·50	3·91	0·74	3·96	11·14	0·61	3·14	6·16
B ..	0·53	3·68	5·48	0·95	6·45	12·91	0·83	3·89	5·33
C ..	0·40	2·69	5·25	0·82	4·64	9·95	0·74	2·98	4·18
D ..	0·46	2·45	3·76	0·84	4·13	8·17	0·66	2·74	3·60
E ..	0·33	2·08	3·70	0·89	3·73	7·52	0·67	2·49	3·26
F ..	0·24	1·47	2·83	0·66	2·93	6·78	0·45	2·22	2·68

TABLE X

Dry weight in gm. per plant of Bhasamanik *at harvest (1935).*

Watering	Root	Straw	Ears	Grain	Single grain (mg.)
A ..	4·13	29·00	14·99	11·48	11·75
B ..	4·86	24·84	16·18	13·65	14·60
C ..	4·10	21·17	15·29	13·19	14·79
D ..	3·49	18·76	14·53	12·40	15·21
E ..	2·80	15·12	13·14	11·78	15·34
F ..	2·10	14·45	9·74	8·56	15·10

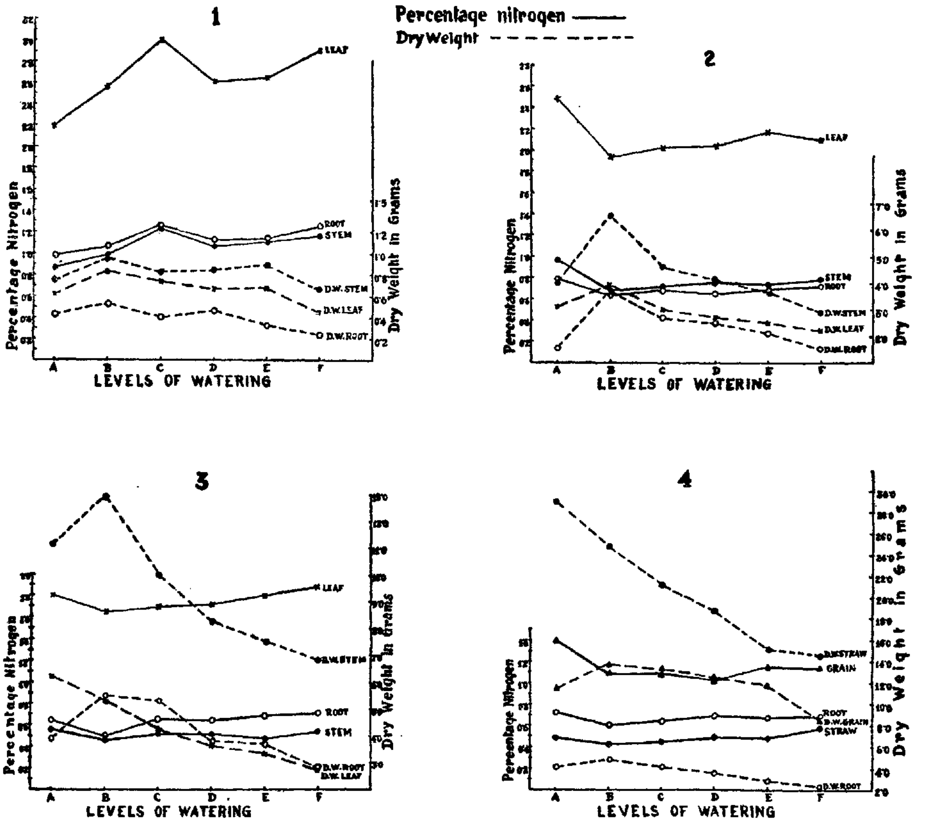

FIG. 6. Showing the effect of varying water levels on the dry weight and nitrogen content of root, stem, leaf, straw and grain of *Bhasamanik*. 1—three weeks after transplantation; 2—six weeks after transplantation; 3—nine weeks after transplantation; and 4—at harvest.

The total dry weight of the plant of first three samples and its distribution in root, stem and leaf increases in 'B', but it is falling with further rise of water level. At harvest, however, the dry weight of the straw has its maximum value in 'A', decreasing steadily with increasing the water level. The dry weight of root, ears and grains per plant has a maximum value in 'B', and then falling with increase of water level. Dry weight of a single grain increases with increase of water up to 'E' and then falling in 'F'.

NITROGEN CONTENT

In 1934 the percentage of total nitrogen in root, stem and leaf of *Kataktara*, *Bhutmuri* and *Bhasamanik* was determined after six weeks of transplantation by the usual Kjeldahl method. The previously powdered and dried material was first finely ground in a mortar, and then three samples each about 2 gms. were weighed. Two of these were taken for nitrogen estimation as replicates and the third dried to constant weight at 100°C. for finding the dry matter.

All the results were calculated on the dry weight basis and corrected for a small blank for the reagents. The agreement between replicates was very good. The nitrogen content data are presented in Table XI and graphically represented in Fig. 5.

TABLE XI

Total Nitrogen as percentage of dry weight after six weeks of transplantation (1934).

Watering	*Kataktara*			*Bhutmuri*			*Bhasamanik*		
	Root	Stem	Leaf	Root	Stem	Leaf	Root	Stem	Leaf
A ..	1·06	0·85	2·72	1·23	0·88	2·49	1·11	0·79	2·52
B ..	0·77	0·79	2·48	0·89	0·74	2·48	0·89	0·74	2·29
C ..	0·76	0·86	2·52	0·86	0·84	2·27	0·84	0·85	2·62
D ..	0·72	0·94	2·96	0·82	0·92	2·49	0·84	0·83	2·67

Percentage of nitrogen in roots of *Kataktara*, *Bhutmuri* and *Bhasamanik* is maximum in 'A', and then steadily decreases with increase in water level; while the maximum dry weight of root in these varieties is found in 'B' and then falling with increasing water levels under 'C' and 'D'. Both nitrogen content and dry weight of root are minimum in 'D', irrespective of varieties. This shows that the nitrogen content of root decreases with increase in water level.

In stem and leaf of *Kataktara*, *Bhutmuri* and *Bhasamanik* nitrogen content is maximum in 'D' and minimum in 'B', while the number of tillers, total leaf area per plant and the dry weight of stem and leaf is maximum under 'B' and gradually decreases with increase in water level. This shows an inverse relationship between tillering, total leaf area and dry weight on the one hand and nitrogen content on the other.

Again in 1935 the percentage of total nitrogen in root, stem, leaf, straw and grain of four samples of *Bhasamanik* which were taken three, six and nine weeks after transplantation and the fourth one at harvest, was estimated as before. The data are given in Tables XII and XIII and graphically represented in Fig. 6.

TABLE XII

Nitrogen content of root, stem and leaf of Bhasamanik *after three, six and nine weeks of transplantation (1935).*

Watering.	Root			Stem			Leaf		
	Weeks after Transplantation								
	3	6	9	3	6	9	3	6	9
A ..	0·99	0·79	0·65	0·86	0·96	0·56	2·19	2·49	1·80
B ..	1·06	0·63	0·50	0·99	0·67	0·47	2·55	1·93	1·64
C ..	1·26	0·69	0·65	1·24	0·71	0·52	3·01	2·02	1·69
D ..	1·13	0·65	0·64	1·06	0·75	0·51	2·61	2·04	1·71
E ..	1·14	0·69	0·69	1·11	0·74	0·48	2·65	2·18	1·80
F ..	1·25	0·71	0·71	1·16	0·78	0·54	2·92	2·10	1·89

TABLE XIII

Nitrogen content of Bhasamanik *at harvest (1935).*

Watering	Root	Straw	Grain
A ..	0·73	0·49	1·40
B ..	0·60	0·42	1·09
C ..	0·64	0·45	1·09
D ..	0·69	0·49	1·02
E ..	0·67	0·48	1·15
F ..	0·69	0·57	1·14

Percentage of nitrogen in root, stem and leaf of the first sampling which was taken three weeks after transplantation, increases generally with increase of water level. Nitrogen content of root, stem and leaf is found maximum under 'C' and minimum under 'A'. In early stages nitrogen content of root, stem and leaf seems to be accumulated under water-logged condition due to very restricted growth of the plant.

Percentage of nitrogen in roots, stems and leaves of second and third sampling which were taken after six and nine weeks of transplantation respectively, is minimum under 'B', and then gradually increases with the increase of water. The dry weight of roots, stems and leaves of second and third sampling is maximum under 'B' and then gradually decreases with increase of water level, minimum being under 'F'. Thus the percentage of nitrogen shows an inverse relation to the dry weight. The results of stem and leaf of second and third sampling confirm the previous years data (Table XI).

With advancing age of the plant there is a gradual tendency of falling of nitrogen content in root, stem and leaf in all the treatments, except in 'A' and 'B' where percentage of nitrogen in root somewhat rises again at harvest. This corresponds with the decrease of nitrogen in the stem and leaf—the soluble nitrogen being translocated into the root with the death of the upper part of the plant. This downward translocation of nitrogen is possibly related with the growth of the new tillers. The number of these new tillers was maximum under 'A', and increasingly reduced with increased water levels, as is found in Table I. Under relatively deeper water treatments no such rise of nitrogen is noticed. Percentage of nitrogen in the straw seems to be very little affected by the treatments, except under 'F' where a higher nitrogen content is found. On the other hand, the highest percentage of nitrogen in the grains is obtained under 'A'.

In root, stem and leaf, percentage of nitrogen is highest in the early stages of growth of the plant. Sen (1946) also found higher percentage of nitrogen in the earlier leaves than in the later leaves.

Discussion

The results presented in this paper show that water standing above the soil level suppresses tillering and consequently the total yield is much reduced (Tables I and VIII). Height of the plant increases as the water level rises (Table II). The mechanism of the increase cannot be precisely explained since in this study the measurement of the length of the internodes with the rise of water level has not been taken. However, it may be stated that the increase in plant height dependent on the expansion phase of the growth of the internodal cells is related to the water content of the stem. This is clearly indicated in the treatments where rise of water level has increased the water content of stem (Table V) along with plant height. In 'A' and 'B' water content is less than under 'C' and 'D'; water supply in these cases may not be available to the same extent for the elongation of the internodal cells as under standing water levels 'C' and 'D'. This would possibly explain why the individual internodes remain shorter than those where rise of water level accelerates the extension growth of the stem length. Crowther (1934) has reported increased plant height and internodal length of cotton with increased water supply. In leaves also similar relation between water content and leaf area is noted (Tables IV and V). Thoday (1910) working with Helianthus showed that the leaves expand with increase of water. In the leaves of barley similar relation has been recorded by Richards (1932).

From the nitrogen content in different parts of the paddy varieties, it is evident that there exists a close relationship between tillering, total leaf area per plant and dry weight on the one hand and nitrogen content on the other. Percentage of nitrogen in roots of *Kataktara*, *Bhutmuri* and *Bhasamanik* is maximum in 'A', and then gradually decreases with increase in water level (Table XI), while the maximum dry weight of root in these varieties is found in 'B' and then falling with increasing water levels 'C' and 'D' (Table VI). Both nitrogen content and dry weight of root are minimum in 'D' irrespective of varieties. This shows that the nitrogen content of root decreases with increase in water level. From the results, it appears that water-logged condition associated with reduced soil aeration has checked both root growth and the uptake of nitrogen, while in comparatively dry condition under 'A', in spite of maximum nitrogen content in the roots of the three varieties, the root growth decreases due to insufficient water-supply.

In stem and leaf nitrogen content is maximum in 'D' and minimum in 'B', while the number of tillers, total leaf area per plant and the dry weight of stem and leaf is maximum under 'B' and gradually decreases with increase in water level, indicating an inverse relation between tillering, total leaf area and dry weight on the one hand and nitrogen content on the other. Although percentage of nitrogen increased in stem and leaf under water-logged conditions ('C' and 'D'), plant growth as indicated by tillering is not correspondingly increased under these conditions; it is restricted by the influence of increasing water levels and therefore nitrogen not being utilized accumulates in stem and leaf. On the other hand, maximum tillering, total leaf area and dry weight of stem and leaf are found in 'B' where percentage nitrogen content is minimum, irrespective of varieties. This corresponds with the fact that the demand for nitrogen for growth and yield is greatest in 'B', consequently nitrogen content is in minimum percentage of the dry weight of the plant. In 'B' maximum plant growth and yield of the varieties may be due to better utilization of nitrogen and moisture status of the soil. Here both nitrogen and moisture content of the soil influence tillering, total leaf area and ultimately its total dry weight and grain yield, while under relatively deeper water treatments ('C' and 'D') standing water reduces meristematic activity; here factor or factors other than nitrogen are limiting the growth and yield of the plant. Under partial drought in 'A' plant growth has suffered due to insufficient water-supply rather than nitrogen as nitrogen content is not much reduced. The author (1949), in his work on the effect of varying water levels on growth of rice in relation to carbohydrate metabolism, has reported that the synthesis of sugar is not limiting the production of tillers in treatments with standing water, since sugar is in excess in the leaves under water-logged condition. Other reasons that might account for this difference in growth due to variation in water level are: (1) insufficient aeration to the submerged parts, and (2) pressure of water column acting upon the region where meristems for tillers are laid down.

Asana (1950) on growth analysis of the sugarcane crop has reported that the tillering phase was not so much affected by hot weather (high temperature and low relative humidity) as by the nitrogen supply, while in low-lying water-logged areas growth was checked due to depression in the rate of uptake of nitrogen and leaf growth. Vlamis and Davis (1944) have suggested that oxygen can be transported from the shoots to the roots by anatomical adaptation, improving thereby the growth of rice under submerged condition particularly with respect to the root system. The increased growth as they have measured by the fresh weight of roots and shoots may be due to the increased water content. In the present experiment it is seen that the water content of different parts of the rice plant increases as the water level rises (Table V), while the dry weight decreases increasingly with the rise of water level (Tables VI, VII and IX). From the results it appears that the plant growth as measured by tillering, total leaf area per plant and dry weight has suffered a lot under water-logged condition. Woodford and Gregory (1948) have studied the growth of barley plant under anaerobic conditions of the roots and concluded that the growth under anaerobic conditions can be maintained at a level as high as that with full aeration by merely increasing the nutrient concentration, for it appears that the poor growth in badly aerated soils may to a large extent be due to a starvation of the primary nutrients consequent upon a slower uptake for a given concentration of soil nutrients.

Summary

The effects of varying water levels on growth, yield and nitrogen content of three varieties of paddy are reported in this study.

Number of tillers, total leaf area, total dry matter and grain yield increase in the treatments with water up to the soil level in pots, but gradually decrease with the rise of water level. Varietal difference in the optimum water requirement is established.

Plant height and individual leaf area are found to increase with the rise of water level. Water content of stem and leaf is similarly affected, the increase being greater in the stem. The cause of the variation in plant height and individual leaf area under different water levels has been discussed.

Both nitrogen content and dry weight of root decrease with increasing water level. In stem and leaf nitrogen content, on the other hand, is high under water-logged condition, nitrogen

not being utilized accumulates. Under partial drought plant growth has suffered due to insufficient water supply rather than nitrogen as nitrogen content of stem and leaf is not much reduced. Stem and leaf nitrogen is low where water is maintained up to the soil level (puddling condition) because of its utilization for optimum growth.

The results of this experiment indicate the necessity of maintaining different water levels at different stages of growth and development. 2·3 inches of water in the field for two weeks after transplantation followed by drainage and maintenance of the soil in the puddling condition for another 5-6 weeks for *aus* and 7-8 weeks for *aman* would give optimum tillering. Standing water, however, has some beneficial effect at the time of ear emergence and grain formation.

The author expresses his grateful thanks to Dr. P. K. Sen for suggesting the problem, to Dr. S. P. Agharkar for granting facilities to conduct this work and to Dr. S. M. Sircar for many helpful criticisms and suggestions in the preparation of this paper.

References

Asana, R. D. (1950). Growth analysis of the sugarcane crop in North Bihar (India). I. Seasonal variation in growth and yield in unmanured plots. *Ann. Bot., N.S.*, **14**, 465–486.

Bengal, Department of Agriculture (1925-26). Annual Report, 1925, 26, 11.

Briggs, L. J. and Shantz, H. L. (1914). Relative water requirement of plants. *Jour. Agri. Res.*, **3**, 1–63.

Chakladar, M. N. (1946). Influence of soil moisture on the yield of paddy. *Ind. Jour. Agri. Sci.*, **16**, 152–157.

Crowther, F. (1934). Studies in growth analysis of the cotton plant under irrigation in the Sudan. I. The effects of different combinations of nitrogen applications and water supply. *Ann. Bot.*, **48**, 877–913.

Ghosh, B. N. (1949). Physiological studies on the effect of varying water levels on growth of rice in relation to carbohydrate metabolism of the leaves. *Bull. Bot. Soc., Bengal*, **3**, 1–8.

Richards, F. J. (1932). Physiological studies in plant nutrition. III. Further studies of the effect of potash deficiency on the rate of respiration in leaves of barley. *Ann. Bot.*, **46**, 367–388.

Sen, P. K. (1937). Studies in the water relations of rice. I. Effect of watering on the rate of growth and yield of four varieties of rice. *Ind. Jour. Agri. Sci.*, **7**, 89–117.

Sen, N. K. (1946). Nitrogen metabolism in rice leaves. *Jour. Ind. Bot. Soc.*, **25**, 71–75.

Singh, B. N., Singh, R. B. and Singh, K. (1935). Investigations into the water requirement of crop plants. *Proc. Ind. Acad. Sci.*, **1**, 471–495.

Thoday, D. (1910). Experimental researches on vegetable assimilation and respiration. V. A. critical examination of Sach's method for using increase of dry weight as a measure of carbon dioxide assimilation in leaves. *Proc. Roy. Soc.*, London, **82**, B1.

Vlamis, J. and Davis, A. R. (1944). Effects of oxygen tension on certain physiological responses of rice, barley and tomato. *Plant Physiology*, **19**, 33–51.

Woodford, E. K. and Gregory, F. G. (1948). Preliminary results obtained with an apparatus for the study of salt uptake and root respiration of whole plant. *Ann. Bot., N.S.*, **12**, 335–370.

Issued September 10, 1954.