INVESTIGATIONS ON THE RÔLE OF ORGANIC MATTER IN PLANT NUTRITION.

Part XI. Effect of Manuring on the Growth and Intake of Silicon by Dry and Wet Cultivated Rice.

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IT has been shown in some previous communications (Sreenivasan and Subrahmanyan, 1934 ; Bhaskaran *et al.*, 1934 ; Sundara Iyengar and Subrahmanyan, 1935) that decomposition of organic matter under conditions of swamp soil results in increased dissolution of minerals. Attention has also been drawn (Sreenivasan, 1934) to the high silicon content of the rice plant and its probable bearing on the physiology of that crop. Since the rice plant flourishes best under the conditions of the swamp soil and responds well to organic manures, it appeared probable that those two conditions are particularly favourable to both dissolution and intake of silicon by that crop. With a view to throwing further light on that aspect of the problem, the present enquiry was undertaken.

Experimental.

A number of glazed earthenware pots were prepared in the usual way, a clay soil (42 lbs.) from an adjoining area being used for filling. The treatments were as follows.—(*a*) unmanured and maintained at 60 per cent. saturation with water ; (*b*) unmanured and maintained in a puddled condition ; (*c*) manured with leaves of *Pongamia glabra* at 100 g. per pot and maintained as in (*a*) ; (*d*) manured as in (*c*) and maintained as in (*b*) ; (*e*) manured with seed-cake of *Pongamia glabra* at 70 g. per pot and maintained as in (*a*) and (*f*) manured as in (*e*) and maintained as in (*b*). Eighteen pots were allotted for each treatment. The green manure was applied in the shape of fresh, tender leaves cut into small bits while the cake was added as fine powder. In either case the manure was mixed thoroughly with the soil to a depth of about 6 inches.

The pots in series (*b*), (*d*) and (*f*) were made as above on 3rd July 1934 while those in series (*a*), (*c*) and (*e*) were made on 12th July 1934. All the pots were kept in the open and maintained under conditions which would correspond to those obtaining in the field. The drainage was rather slow in the puddled series (*b*, *d* and *f*), while the other sets of pots drained quite freely.

TABLE I.

Meteorological Observations.

	July				August				September					October			
Week ending..........	7	14	21	28	4	11	18	25	1	8	15	22	29	6	13	20	27
Maximum Temp.° (weekly averages) ..	80.2	84.7	88.0	84.1	78.0	82.4	80.6	83.5	84.6	84.6	86.8	86.1	87·8	88·8	82·0	83·0	87.7
Minimum Temp.° (weekly averages) ..	66.9	66.0	67.4	67.6	66.1	67.4	66.9	65.7	66.5	66.7	66.8	65.4	65.8	68·4	67.0	66.7	66.7
Total sunshine (from week to week, hrs.)	10.6	33.8	44.9	20.5	5.1	27.5	13.9	41.3	41.2	30.6	46.9	39.3	53·6	46·7	20.8	46.5	39.5
Total rainfall (from week to week, inches) ..	0.70	..	..	0.06	1.31	0.35	0.65	0.69	0.21	0.05	0.08	0.05	0.15	0.24	5.03	0.22	0·27
Relative humidity (weekly averages) ..	75	64	61	68	83	72	76	70	66	63	61	62	56	59	81	67	65

Paddy (Var., Adt., 3—a four month crop) was sown in separate seed pots on 12th June 1934. The seedlings were transplanted into the experimental pots on 16th July 1934 when they had attained an average height of about 6 inches. Four pairs of seedlings were transferred to each pot, the planting being done two together. When the seedlings had all become well-established in the soil (about a week after transplanting) enough water was added to the pots in series (*b*), (*d*) and (*f*) so as to keep the soil well under submergence (about 3 inches) and slow drainage allowed to take place. Water was added at frequent intervals to keep the level of submergence nearly constant. This was continued till the first week of October when grains began to form in all the cases. Pots in series (*a*), (*b*) and (*e*) were just kept moist by daily addition of water which was also stopped in the beginning of October.

Meteorological Observations.—The growing period was from 16–7–1934 to 26–10–1934; during this period systematic daily records of maximum and minimum temperature, hours of sunshine, rainfall and relative humidity were maintained. The weekly averages have been presented in Table I.

The season corresponded to the active part of the south-west monsoon and was, therefore, attended by a fair amount of rain, especially during the last stages. The majority of the days were, however, fairly bright and sunny and moderately warm. Watering was not done during periods of heavy rainfall and, at the time of harvest, the pots were practically dry.

Samples for Analysis.—At different stages of development, representative samples (8 for each treatment) of whole plant were taken by careful uprooting. They were then taken to the laboratory where they were carefully washed in running water and dried between folds of filter paper. After making the necessary determinations on the green material, the plants were divided into roots and tops and the corresponding fresh and oven-dry (100°) weights determined.

The dates of sampling at different developmental stages of the plant are given in Table II.

It was observed that the rate of growth was not the same in all the cases, being obviously due to the different treatments. Particularly was this noticeable in the case of series (*f*) treated with hongay cake and swamped, wherein there was an initial set-back, the tillers appearing long after they had done so in the other cases. This was perhaps due to the period of puddling having been insufficient and consequent persistence of toxicity for some time after transplantation (Onodera, 1923). This set-back was however only temporary: all the plants recovered fully after some time, and, indeed, as shown elsewhere, the best yields were obtained from that series.

TABLE II.

Date of sampling	Age of plant since germination (18–6–1934) days	Developmental stage (approximate)
16—7—1934	28	Seedlings (Transplantation stage)
15—8—1934	58	Beginning to tiller (Green stage)
18—9—1934	92	Mature plants (Stage of active tillering)
28—9—1934	102	Just flowering (Bloom stage)
7—10—1934	111	Panicles were out, but seeds only partially formed (Grain formation stage)
26—10—1934	130	Seeds fully formed and ripe (Harvesting stage)

Ash and Silica.—The roots were cut into very small bits while the tops were ground to pass the 40-mesh sieve. A known weight of the material in a platinum dish was first heated over a low flame and then ignited at dull red heat in a muffle furnace till almost white after which the ash weight was determined. Silica in the ash was estimated from the loss in weight after volatilisation of same with hydrofluoric acid (*A. O. A. C.*, 1930).

It was observed that in the case of root ash, a considerable amount of brick red residue was always left behind after volatilisation of silica. This was probably finely divided iron oxide which, on account of its having been strongly ignited, was not completely soluble in concentrated hydrochloric acid.

Analytical Results: Growth data.—It will be seen from a comparative study of the different tables (Tables III—VIII) that the best growth was obtained in both the manured and swamped series while the manured "dry" series came next and control (unmanured) series last. The unmanured (control) "dry" series showed particularly poor growth and root development and the plants began to dry up and even die in a few cases before the completion of the experiment. The rate of development of the plants, the roots and the total dry weight were all also in the same order as above except, as mentioned before, for an initial lag in the case of series (*f*) (cake swamped). There was steady increase in the dry weight upto the 111th day after which there was fall in all the cases. This was due to the fact that after that period

TABLE III.

Manure: Hongay Leaves—Swamped.

(Series d)

Age of plants (in days)	TOPS				ROOTS			Total dry weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	3.3 (–)	55	10.84	2·25	24	1·33	0·36	2·61	6·2
92	6·5 (2.6)	82	13·75	3·39	38	2·59	0·61	4·00	5·4
102	8.3 (4.9)	85	18·41	5·00	41	2·18	0·61	5·61	8·2
111	10·3 (8·8)	97	22 93	6·43	44	3·30	0·85	7·28	7·6
130	8.9 (8.0)	89	22·23	6·23	36	3·25	0·78	7·01	13·7

(*Figures in columns 2, 4, 5, 7, 8 and 9 represent the average of 16 plants in each series. In column 2, the bracketted figures indicate the number of earing tillers.)

TABLE IV.

Manure: Hongay Cake—Swamped.

(Series f)

Age of plants (in days)	TOPS				ROOTS			Total weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	2·0 (–)	39	7·15	1·49	19	0·80	0·21	1·70	7·0
92	3·9 (–)	58	7·83	1·89	31	1·69	0·41	2·30	4·6
102	6·8 (1·5)	62	9·98	2·40	38	..	..	..	..
111	8·9 (8·0)	86	21·34	5·84	39	3·19	0·76	6·60	7·7
130	9·9 (9·0)	80	19·55	5·65	39	2·63	0·76	6·41	15·4

(*In column 2, first figure indicates all the tillers in one plant while the bracketted figures are the number of earing tillers.)

TABLE V.

Manure : Hongay Cake—'Dry'

(Series e)

Age of plants (in days)	TOPS				ROOTS			Total dry weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	2·4 (–)	48	10·13	2·16	23	1·30	0·31	2·47	7·0
92	3·4 (1·4)	66	13·80	2·98	26	1·46	0·38	3·36	7·9
102	5·8 (2·8)	75	12·63	3·89	20	2·30	0·65	4·54	6·0
111	5·5 (4·8)	88	12·08	3·63	21	2·88	0·95	4·58	3·8
130	4·5 (3·8)	71	8·58	4·04	24	2·09	0·63	4·67	6·5

(*In column 2, first figure indicates all the tillers in one plant while the bracketted figures are the number of earing tillers.)

TABLE VI.

Manure : Hongay Leaves—'Dry'

(Series e)

Age of plants (in days)	TOPS				ROOTS			Total dry weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	3·0 (–)	46	9·74	2·39	21	1·15	0·35	2·74	6·8
92	4·9 (1·4)	69	12·38	3·48	29	1·08	0·33	3·81	10·7
102	5·3 (2·3)	71	11·58	3·08	24	2·13	0·69	3·77	4·5
111	4·9 (4·0)	77	10·03	3·08	28	2·15	0·64	3·72	4·8
130	5·1 (3·3)	69	7·28	2·90	23	2·45	0·61	3·51	4·7

(*In column 2, first figure indicates all the tillers in one plant while the bracketted figures are the number of earing tillers.)

TABLE VII.

Unmanured (Control)—Swamped.

(Series b)

Age of plants (in days)	TOPS				ROOTS			Total dry weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	2·5 (–)	42	6·69	1·64	18	1·08	0·26	1·90	6·0
92	4·1 (0·9)	63	7·94	2·09	29	2·10	0·56	2·65	3·7
102	4·0 (1·6)	74	9·65	2·68	25	1·93	0·51	3·19	5·3
111	3·8 (3·0)	77	8·19	2·19	24	1·98	0·56	2·75	3·9
130	3·6 (1·4)	64	5·78	4·44	22	1·38	0·41	4·85	5·0

(*In column 2, first figure indicates all the tillers in one plant while the bracketted figures are the number of earing tillers.)

TABLE VIII.

Unmanured (Control)—'Dry'.

(Series a)

Age of plants (in days)	TOPS				ROOTS			Total weight of plant in g.	Ratio Tops/Roots
	Tillers Number per plant	Height in cm.	Fresh weight in g.	Dry weight in g.	Length in cm.	Fresh weight in g.	Dry weight in g.		
(1)	(2)*	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
28	..	19	0·60	0·11	13	0·65	0·18	0·29	0·64
58	2·3 (–)	34	2·56	0·60	14	0·75	0·18	0·78	3·3
92	3·0 (0·8)	48	3·00	0·95	15	0·53	0·13	1·08	7·6
102	3·3 (1·1)	51	3·38	0·91	12	0·50	0·13	1·04	7·3
111	2·4 (2·0)	70	3·48	0·99	19	0·70	0·18	1·17	5·7
130	1·5 (0·8)	65	3·04	1·40	18	0·79	0·63	1·63	6·2

(*In column 2, first figure indicates all the tillers in one plant while the bracketted figures are the number of earing tillers).

a few of the leaves had dried up and withered and even dropped out sometimes. Variations in the moisture content of the roots were not very significant while in the case of the tops, it was noticed that there was a gradual rise in the percentage dry matter till the stage of grain formation after which it was practically constant (about 30 per cent.) in all the cases.

The results show in a striking manner how the wet soil conditions are favourable at all stages for the growth of the rice plant. Thus, in the manured pots the weight of straw in the dry series at any stage was often less than half what was obtained in the case of the corresponding wet treated series; while with regard to the roots, not only was the extent of root development greater in the case of the swamped and manured series but also the area over which the roots spread was very much more in those cases than in the "dry" manured ones.

Yields.—The yields of straw and of grain at harvesting stage in each of the series is given in Table IX. Results represent the average yield per plant and is the average of 48 plants in each case.

TABLE IX.

Yield (dry weight in g. per plant) at harvesting.

	Green manured swamped	Hongay cake swamped	Unmanured swamped	Green manured 'dry'	Hongay cake 'dry'	Unmanured 'dry'
Straw weight	6·45	5·61	1·55	1·78	1·86	0·88
Grain weight	4·20	3·58	0·45	1·05	1·21	0·35
$\frac{\text{Grain}}{\text{Straw}} \times 100$	63·6	63·7	29·0	59·2	29·0	39·1

It will be seen that the yield of straw in the case of dry series is only about 30-35 per cent. of that in the swamped series while the corresponding ratio in the yield of grain is also about 25-30 per cent. The percentage of moisture in the straw grown under wet conditions was slightly higher than in the other cases while it was almost constant throughout in the case of the grains.

Ash Analyses.—Tables X-XV give the ash analyses of the various parts of the plant at different stages. The percentage of ash or of silica in the roots varies irregularly in all the series and does not seem to be of any significance. Even the percentage of silica in the ash varies somewhat

TABLE X.

Green Manured—Swamped.

(*Series* d)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of		Per cent. in ash of silica	Total intake of silica per plant (in mg. average of 16 plants)
			Total ash	Silica		
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	27·4	10·02	4·10	40·93	14·9
	92	23·7	9·84	4·12	41·87	25·2
	102	28·2	13·59	5·60	41·19	34·3
	111	25·8	10·90	5·12	46·98	43·5
	130	23·8	9·40	4·02	42·77	31·1
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	20·8	17·04	10·40	61·03	234·0
	92	24·6	20·37	13·33	65·43	450·8
	102	27·2	19·52	12·91	66·15	645·5
	111	28·1	16·04	10·16	63·33	652·8
	130	28·0	16·05	10·60	66·04	660·3
Green Leaves and Stalks	111	29·5	19·66	12·10	61·55	
	130	26·4	17·80	10·19	57·23	
Panicles (immature)	(111)	54·3	15·67	13·29	84·82	
do. (with ripe seed)	(130)	83·7	11·24	8·54	76·00	

TABLE XI.

Hongay Cake—Swamped.

(*Series* f)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of		Per cent. in ash of silica	Total intake of silica per plant (in mg.) average of 16 plants)
			Total ash	Silica		
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	26·6	10·46	4·06	39·72	8·6
	92	24·4	10·42	4·42	42·42	18·2
	102	..	11·87	4·54	38·20	..
	111	23·9	12·01	5·20	43·33	39·7
	130	29·0	9·65	4·14	42·90	31·6
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	20·8	16·47	9·90	60·08	147·5
	92	24·2	20·30	12·71	62·62	239·9
	102	24·7	20·11	13·62	67·72	326·8
	111	27·4	17·40	11·22	66·01	655·0
	130	28·9	16·55	10·80	65·25	610·1
Green Leaves and Stalks	111	27·6	18·42	10·86	58·96	
	130	32·4	17·03	11·22	65·91	
Panicles (immature)	111	51·5	17·01	14·56	85·63	
do. (ripe)	130	82·1	9·12	7·15	78·39	

TABLE XII.

Green Manured—'Dry'

(*Series* c)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of		Per. cent in ash of silica	Total intake of silica per plant (in mg. average of 16 plants)
			Total ash	Silica		
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	30·4	11·02	3·92	35·57	13·7
	92	30·2	9·96	3·95	39·69	12·8
	102	32·4	9·92	3·96	39·92	27·2
	111	29·7	10·41	4·52	43·41	28·8
	130	25·0	9·01	3·74	41·52	22·9
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	24·6	16·98	10·12	59·58	241·5
	92	28·1	17·27	10·64	61·63	369·8
	102	26·5	17·60	11·23	63·78	345·1
	111	30·7	17·68	11·62	65·73	357·4
	130	39·9	17·29	10·65	61·60	308·9
Green Leaves and Stalks	111	30·8	18·64	10·68	60·01	
	130	29·5	17·96	10·40	57·89	
Panicles (immature)	111	53·7	16·22	14·04	86·56	
do. (ripe)	130	85·5	10·56	8·01	75·84	

TABLE XIII.

Hongay Cake—'Dry'.

(*Series* e)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of: Total ash	Per cent. on dry matter of: Silica	Per cent. in ash of silica	Total intake of silica per plant (in mg. average of 16 plants)
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	23·7	9·24	4·21	45·56	13·2
	92	25·8	9·87	3·86	39·11	14·5
	102	28·5	9·70	4·82	49·68	31·7
	111	33·0	10·06	4·54	45·14	43·1
	130	29·9	8·94	3·99	44·64	24·9
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	21·4	15·86	9·68	61·02	209·4
	92	21·6	17·58	11·26	64·03	336·5
	102	30·8	19·14	10·24	53·51	398·0
	111	30·0	16·81	10·80	64·24	391·4
	130	47·1	17·02	9·84	57·81	..
Green Leaves and Stalks	111	33·3	18·09	10·04	55·5	
	130	29·9	..	..	..	
Panicles (immature)	111	51·9	16·03	14·10	87·96	
do. (fully ripe)	130	79·8	9·94	7·57	76·15	

TABLE XIV.

Unmanured—Swamped.

(*Series* b)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of		Per cent. in ash of silica	Total intake of silica per plant (in mg. average of 16 plants)
			Total ash	Silica		
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	25·0	10·10	..	..	..
	92	27·0	9·76	4·12	42·22	23·2
	102	26·3	10·90	4·67	42·85	23·9
	111	28·5	9·10	4·96	54·51	27·9
	130	29·6	9·66	4·42	45·75	18·2
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	24·5	15·38	8·94	58·13	146·6
	92	26·4	17·63	10·96	62·19	229·0
	102	27·7	16·55	10·10	61·02	270·4
	111	26·7	16·24	10·86	66·91	238·4
	130	35·5	16·64	11·02	66·22	226·3
Leaves and Stalks	111	30·5	16·84	9·48	56·28	
	130	29·7	17·62	10·13	56·96	
Panicles	111	52·2	15·92	12·60	79·14	
do. (ripe)	130	83·1	11·24	8·26	73·50	

TABLE XV.

Unmanured—'Dry'.

(*Series* a)

Material analysed	Age of material (in days)	Per cent. dry matter in green sample	Per cent. on dry matter of		Per cent. in ash of silica	Total intake of silica per plant (in mg. average of 16 plants)
			Total ash	Silica		
Roots	28	26·9	11·60	4·68	40·33	8·2
	58	23·8	11·20	..	..	..
	92	24·0	9·48	4·00	42·20	5·0
	102	25·0	10·45	4·80	45·93	6·0
	111	24·7	8·96	4·23	47·21	7·4
	130	28·6	9·02	3·68	40·80	8·3
Whole Plant above Ground	28	18·8	15·22	8·97	58·93	10·1
	58	23·2	16·49	9·98	60·50	59·9
	92	31·7	17·11	11·44	66·86	108·6
	102	27·1	18·33	13·34	72·78	121·9
	111	28·3	17·18	11·82	68·84	116·8
	130	46·1	16·70	10·96	65·63	121·9
Leaves and Stalks	111	30·2	17·34	10·92	62·98	
	130	31·5	16·90	10·93	64·68	
Panicles	111	53·1	15·92	13·21	82·96	
do. (ripe)	130	81·3	13·20	9·87	74·76	

irregularly although it might be said that it tends to increase in the later stages of growth. The total intake of silicon by the roots increases with time. Silica is assimilated in quite large quantities by roots of plants grown under swamped conditions.

The variations in the ash content of the tops are not, however, so irregular as with the roots. There is gradual rise in the percentage of the ash during the first 102 days after which this falls to about the same value in all the cases. The rate of rise is greater in the case of series (*d*) and (*f*), somewhat less with (*c*) and (*e*) and least in the unmanured series (*a*) and (*b*). More or less similar variations may be said to take place in regard to the percentage of silicon in the dry matter.

The percentage of silica in the ash has been calculated and given separately as it was thought that the percentage of the various ash constituents in the dry matter is less significant on account of possible fluctuations in the total ash. These figures would show that, as the plant ages, there is a steady increase in the percentage of silica up to the period of grain formation after which it remains fairly constant. It is of interest to note that while silica in the dry matter decreases after the 102nd day it remains about the same in the ash of the dry matter after this date. This is due to the fact that in the former case the percentage of silica in the dry matter of the grains is less than in the straw while the reverse is true with regard to the composition of the ash itself.

The foregoing sets of results would indicate that paddy grown under swamped conditions appears to be very much richer in silicon than under other conditions. In fact, the total intake of silica as calculated for the different series at different stages is far more in these cases than in the others. Manured "dry" series comes next in order with regard to silica uptake while the unmanured ones rank last. The total absorption of silica attains a maximum by about the 102nd day after which it remains practically the same in each series for the rest of the life period of the crop.

With a view to finding the distribution of silica between the green leaves and stalks and the grains, the ash and silica analyses on the above ground portion of the plant was done separately in the grains and in the straw on separate samples taken on the 111th and 130th day. The grains were all immature on the first day while, on the second sampling day, they were fully ripe. The results (included in Tables X–XV) indicate that the silica in the ash of the leaves is practically the same at both the periods of sampling in all the cases, though they were somewhat less than the silica content of the leaves of corresponding samples taken on the 102nd day.

The ash of the panicles on the other hand was considerably richer in silica while the grains were yet unripe than when they were fully formed and ripe. The results would thus suggest that (*a*) the absorption of silicon from the soil ceases after the flowering stage, (*b*) there is a transference of silicon from the green leaves and stalks to the panicles during the stage of grain formation, and (*c*) during the ripening of the grain only the constituents of the grain other than silicon are transported from the stem and stalk.

Absorption of Other Minerals by the Plant.—Table XVI gives the total intake of minerals other than silicon by the plant (above ground portion) at the different stages. It would be seen that the absorption of minerals as of silicon is greatest in the swamped manured series, less with the "dry" manured series and least in the case of the unmanured series. Absorption increases as the plant ages but after the flowering period, that is, after about 102 days, the plant does not seem to take any more minerals from the soil.

TABLE XVI.

Absorption of Mineral Constituents other than Silicon.

Age of plant in days	Green manured swamped	Hongay cake swamped	Unmanured swamped	Hongay leaf 'dry'	Hongay cake 'dry'	Unmanured 'dry'
	Intake of minerals (in mg.) per plant (averages)					
28	7·04	..	..	..	..	..
58	149·4	97·8	105·5	163·8	243·8	39·0
92	238·5	143·3	139·3	230·4	175·5	53·9
102	330·5	155·8	172·5	195·9	346·0	45·5
111	377·9	366·6	117·9	186·4	218·6	53·0
130	345·5	324·8	115·1	192·6	290·0	80·4

Discussion.

The present enquiry has shown that for optimum growth, the rice plant requires swamp soil conditions and that, under such conditions, it absorbs considerable quantities of silica from the soil system. The latter observation would mean that under swamp conditions more silica is rendered soluble in the soil or available to the plant. In order to verify whether there is increased dissolution of silica under swamped soil conditions, attempts were made to follow the amount of soluble silica present in the soil system in the different series afore-mentioned at various stages together with the corresponding intake of that constituent by the plant. This could not be done as it was found that even when a soluble silicate was added to the soil it was very soon converted into insoluble forms consequent on certain interactions between the soil and the silicate (Sreenivasan, 1935). It would follow therefore that although at any one time there may not be a large quantity of soluble silica in the soil system, it does not give any indication of what might have been absorbed by the plant. In other words, the availability of silica to the plant is not measurable merely by the amount present in solution at any time.

The presence of such large quantities of silica in the rice plant under conditions of optimum growth might lead one to suppose that the supply of soluble silica is one of the most important factors governing the yield of crop. Observations have, however, been made by a number of workers in regard to the proportions of the various elements contained in plants of different species grown under the same condition and of the same species grown under different conditions and it is found that they depend upon a number of factors such as the species of plant, the type of soil, the distribution of the root system, the rainfall and general climatic conditions as well as the methods of cultivation. While therefore the amount of nutrients necessary for the optimum growth of plants at the different stages of their growth is an important factor from the standpoint of crop production, an analysis of the plant does not necessarily give any indication of the deficiencies or fertilizer needs of the soil (Salter and Ames, 1928).

The present enquiry, while providing data regarding the intake of silicon by the rice plant, does not entirely explain the significance of that element in the physiology of the plant. The fact that after 102 days there is not any further appreciable assimilation of silicon would mean that if at all silicon is an important factor in improving plant growth, it must perform its function before this period. But as to whether the increased assimilation of silicon precedes and is therefore the main factor governing the yield of paddy or whether it is only a secondary thing, can be definitely said only when observations on growth are correlated with corresponding intake of silicon at very frequent intervals of time during the life of the plant. Experiments are also necessary to show whether under conditions of dry cultivation and in the presence of free supply of soluble silica secured probably by addition of sodium silicate to the soil, the yield of paddy can be improved to the same level as when grown under swamp conditions. Trials have also to be conducted by growing paddy under a variety of conditions and at different seasons to be able to say whether or not silicon plays any important rôle in its nutrition. It is also necessary in order to know whether silicon is a "limiting factor" in paddy nutrition to carry out experiments by growing rice to maturity and harvesting stage in solution cultures with and without the addition of silica in soluble form.

There may be certain other factors which are more important from the point of the rice plant for maintenance of swamp soil conditions and this latter condition induce a greater intake of silica enabling the plant to withstand such an environment which might ordinarily be detrimental to the crop. Thus, it is well known that the rice plant assimilates nitrogen only in the form of ammonia especially in the early stages of its growth, and under swamp conditions the transformations of added nitrogen stop at ammonia stage, practically no nitrate being formed. Thus swamping might be beneficial to the crop only inasmuch as it enables intake of nitrogen as ammonia; absorption of silica then might be taking place just because it is also formed in the soil under such conditions in fairly large quantities.

Since the extent of root system of the plant was observed to vary with different treatments being most in the swamped, manured series, it is possible that greater intake of minerals including silicon in these series, may be due to this factor alone without the latter being of any direct importance in the nutrition of the plant.

As to how exactly under swamped conditions more of silicon and other minerals are brought into solution, it is still obscure; there is little doubt however that the organic acids which are formed under such conditions play some part in the dissolution of minerals.

The mode of intake of silicon by the plant is still obscure. In fact, little is known regarding the manner in which plants assimilate their nutritive elements. Since different plants are composed of different proportions of the various elements, it has been assumed by some that they exercise a "selective absorption" and that the variations in composition are due to differences in the specific absorbing powers of the roots. Others consider that this is due to a specificity of the protoplasm, which requires different proportions of materials for its development in different parts. Thus, Dastur and Malkani (1933) state that the preferential absorption of ammonium ion by the rice plant at early stages of its growth and of nitrate ions at later stages is due to differences in the permeability of the protoplasm of the plant at the different periods and in a later communication (1934), Dastur and Kalyani correlate this behaviour with the *iso*-electric point of the proteins of the protoplasm of the tissues of the rice plant. Yet another school of thought (*cf.* Davis, Hoagland and Lipman) emphasise that the difference in the extents of the root systems and the differences in the rate of production of carbon dioxide by these roots are factors which may determine, to a considerable degree, the differences in the amount of minerals absorbed by plants. It is as yet difficult to say whether the absorption of the elements of nutrition by the plants is a selective process in the strict sense of the term.

Another observation of interest that has emerged from this study is the sudden decrease or perhaps even cessation, towards the end, in the rate of absorption of the minerals by the plant. The fact that the percentage of silicon in the ash steadily increases with the age of the plant would naturally mean that the percentages of the other ash constituents decrease in the later stages of growth of the plant. Such a decreased rate of absorption of minerals during the ripening period has been reported by a few earlier workers in the case of other plants. Thus, Hornberger (1882) found in the case of corn that, when the tassels were beginning to form, there was an abrupt slowing down in the rate of absorption of the various elements. Similar observations have been made by Burd (1919) in the case of barley. It would therefore appear (Table XVI) that while the rate of absorption of elements by plants during the different stages of growth may vary considerably, in some plants, all the soil nutrients required for their further development are already accumulated in the stem at the time of flowering when their further absorption ceases almost completely.

Summary.

1. Periodical observations on rice plants grown under wet as well as dry soil conditions, with and without different organic manures, showed that (*a*) better growth and yield are obtained under swamp conditions than under "dry" ones, (*b*) there is a greater intake of minerals particularly silicon in the case of the swamped series over that in "dry" series, and (*c*) the percentage of silicon in plants grown in the swamped and manured soil is greater than in the others.

2. The significance of these observations in relation to (*a*) the possible beneficial effects of silicate fertilisation in field practice, and (*b*) the rôle of silicon in the nutrition of the rice plant have been discussed.

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