Nutrient Absorption of Rice from Media Containing Different Types of Clay Minerals Preliminary Study*

By

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Rice is not only an important staple food of Asiatic people, but also a very important food crop of the world. Many studies on the management and fertilization of rice have been carried out in Japan, India and other countries. Little is known, however, regarding the relationships between rice growth and the type of clay minerals. Experiments conducted with other crops indicate that the kind of clay mineral may markedly affect plant nutrition. It is the purpose of this study to investigate the effect of the clay minerals, montmorillonite, kaolinite, and illite on the growth and nutrient absorption by rice plants.

Experimental Methods

Kaolinite from North Carolina, bentonite from Wyoming, and illite-bearing till from Illinois were used in this study. Their cation and anion exchange capacities were determined by Mehlich's method (5). Their pH values were also determined. The results were as follows :

Clay mineral	pH	Cation exchange capacity milli-equivaents per 100g.	Anion exchange capacity milli-mols per 100g.
Kaolinite	5.2	3.5	2.0
Bentonite	8.5	120.1	3.9
Illite	8.7	30.7	2.9

As pH values show, illite and bentonite had a strong alkaline reaction. The illite contained 13.9 percent of calcium carbonate. Its cation exchange cepacity on a carbonate free base is 34.9 m. e. per 100 gms. The bentonite was a sodium saturated one. Therefore, the illite was treated with hydrochloric acid in order to remove calcium carbonate, Further, bentonite and illite were hydrogen saturated by treatment with 1/10N hydrochloric acid and subsequently washed with distilled water.

The experiments were conducted in the greenhouse. Mixtures of clay minerals and quartz sand were used as cultural media and one gallon glazed pots were used as containers. In making these mixtures, the cation exchange capacity of each pot was made equal to 2.0 m.e. per 100 gms. Four kilogramms of mixtures were put in each pot. The cation exchange capacity of the mixture in each pot was saturated to 50 per cent with Ca, Mg, and K in a proportion of Ca 60 percent, Mg 20 percent, and K 20 percent. The kaolinite contained exchangeable calcium in amount of 0.90 m. e. per 100 gms. Therefore, this calcium was taken in consideration in adding this base. 280 mgs. of nitrogen were supplied by addition of ammonium nitrate to each pot. Ten parts per million of iron citrate, 10 ppm. of manganese sulphate, 10 ppm. of zinc sulphate, 2 ppm. of borax and 2 ppm. of copper sulphate were also added to each pot. The experiment

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pots were divided into two groups ; to one group was added 0.2 gms. of P_2O_5 and to another group was added 0.1 gms. of P_2O_5 per pot. The phosphorus carrier was triple super phosphate labelled with P^{32}. All the experiments were run in triplicate.

The rice seeds of variety Zenith were obtained from the Arkansas Experiment Station. They were seeded in a bed on June 20th. Young seedlings were replanted in the pots on July 12th, and were kept in an inundated condition. On July 26th, 0.1 gms. of P_2O_5 as non-radioactive mono-calcium phosphate was applied to the pots containing the low rate of phosphorus. This made the phosphate content equal in all pots.

On August 6th, 27th and September 17th, rice plants were uprooted. Sand-clay mixtures were carefully washed away with water. The rice plants ware dried and pulverized. Nitrogen was determined by the Kjeldahl method. Radioactivity of P^{32} was measured. Oven-dry plant material was wet ashed with nitric, sulfuric, and perchloric acids, and the residue was taken up in dilute hydrochloric acid. Phosphorus was determined colorimetrically by the ammonium vanadate and ammonium molybdate method, potassium with a flame photometer, calcium by potassium permanganate titration, and magnesium colorimetrically using thiazol yellow.

Experimental Results

Growth and development :

The data on growth of the rice are shown in Table 1.

Kaolinite 1 P. means that one-half of the phosphorus was applied before planting and one-half was added as a supplemental application two weeks after transplanting.

Kaolinite 2 P. means that the total amount of phosphorus was added as a single pre-planting application.

The number of tillers in the pots containing kaolinite and bentonite showed no change in the three dates but decreased slightly in the latest stage. This is attributed to the fact that some tillers died. In the pots containing illite tillering increased with time. This is associated with poor growth at the earliest stage which will be further discussed later in this paper.

Table 1. Size and Development of Rice on Various Dates

Clay mineral and treatment	August 6	August 27	September 71
Number of tillers, per pot			
Kaolinite 1 P.	14	11	12
Kaolinite 2 P.	13	13	11
Bentonite 1 P.	14	16	13
Bentonite 2 P.	15	14	14
Illite 1 P.	8	9	10
Illite 2 P.	12	12	10
Length of above-ground portions, cms.			
Kaolinite 1 P.	68	70	69
Kaolinite 2 P.	67	72	70
Bentonite 1 P.	74	74	68
Bentonite 2 P.	72	71	68
Illite 1 P.	70	71	79
Illite 2 P.	67	65	79
Weight of aboveground portions,* gms.			
Kaolinite 1 P.	4.6	8.7	14.3
Kaolinite 2 P.	3.9	9.9	13.2
Bentonite 1 P.	5.8	13.6	15.5
Bentonite 2 P.	6.1	11.8	19.0
Illite 1 P.	2.8	8.1	14.2
Illite 2 P.	3.5	8.6	14.1
Weight of roots,* gms.			
Kaolinite 1 P.	1.3	5.9	9.8
Kaolinite 2 P.	1.1	6.1	8.0
Bentonite 1 P.	1.0	5.6	7.3
Bentonite 2 P.	1.1	5.5	7.3
Illite 1 P.	0.5	3.7	6.7
Illite 2 P.	0.9	3.7	6.8

* Values represent oven dry weight.

Chemical analyses :

The results of nitrogen analyses are shown in Table 2.

From these experimental results, no remarkable differences in plant composition were apparent between series 1 P. and 2 P. of each clay mineral.

In the above-ground plant portions, the percentage of nitrogen was highest on August 6. On August 27, the percentage decreased remarkably and decreased further on September 17. The percentage of nitrogen was, in general, highest in illite and lowest in kaolinite. The percentage in the roots was lower than that in the above-ground portions but both showed the same

Table 2. Nitrogen Content of Rice as Influenced by the Nature of the Clay Mineral in Quartz-clay Mixtures

Clay Mineral and Treatment	August 6		August 27		Sptember 17	
	N %	N mg.	N %	N mg.	N %	N mg.
			Above-ground portion			
Kaolinite 1 P.	1.96	90.2	0.88	76.6	0.58	82.9
Kaolinite 2 P.	2.58	100.6	0.80	79.2	0.58	76.6
Bentonite 1 P.	2.74	158.9	1.12	152.3	0.70	108.5
Bentonite 2 P.	2.84	173.2	1.12	132.1	0.74	140.6
Illite 1 P.	2.80	78.4	1.48	119.9	0.70	99.4
Illite 2 P.	2.68	93.8	1.52	132.2	0.72	101.5
			Root			
Kaolinite 1 P.	1.42	18.5	0.54	31.8	0.34	33.3
Kaolinite 2 P.	1.62	17.8	0.60	36.3	0.46	36.8
Bentonite 1 P.	1.86	18.6	0.82	45.9	0.78	56.9
Bentonite 2 P.	1.76	19.4	0.84	46.2	0.60	43.8
Illite 1 P.	1.90	9.5	0.70	25.9	0.44	29.5
Illite 2 P.	1.98	17.8	0.96	35.5	0.46	31.3
			Whole plant			
Kaolinite 1 P.		108.7		108.4		116.2
Kaolinite 2 P.		118.4		115.8		113.4
Bentonite 1 P.		177.5		198.4		165.4
Bentonite 2 P.		192.6		178.3		184.4
Illite 1 P.		87.9		145.8		128.9
Illite 2 P.		111.6		167.9		132.8

trend with time. In kaolinite and bentonite, the amount of absorbed nitrogen in the above-ground portion was highest on August 6, and lowest on August 27 or on September 17. However, in illite the highest was shown on August 27 and the lowest on August 6.

The amount of nitrogen in the roots was less than in the above-ground portions. They increased with growth in general. Exceptions were found on bentonite 2 P. and illite 2 P. which showed the highest values on August 27.

The nitrogen content of the whole plant was highest in kaolinite and lowest in bentonite. No remarkable change in the nitrogen in the three stages occurred, but the nitrogen content of the plants in illite increased considerably on August 27 and decreased on September 27.

The analytical data on phosphorus are shown in Table 3.

In the above-ground portions, the percentage of phosphorus in the rice plants decreased with growth. The value was highest in bentonite, intermediate in kaolinite, and lowest in illite. In the roots, illite showed the highest value throughout the period among the three clay minerals and showed its maximum on August 27. In bentonite and kaolinite, the maximum phosphorus percentage in the rice roots was found on August 6.

The amount of phosphorus absorbed by the above-ground portions and by the roots increased with growth. In the roots there was less phosphorus than in the above-ground portions, especially much less on August 6. On August 27 and September 17, the amount of phosphorus in roots in illite were much greater than those in kaolinite and bentonite.

The phosphorus abosrbed by the whole plant increased with growth. Rice plants growing in bentonite showed the highest values throughout the experiment. The total absorption of phosphorus by plants in illite and kaolinite was almost equal on August 6 and August 27, but the amount in illite was higher than that of kaolinite on September 17.

In the phosphorus analyses, radioactivity of

Table 3. Phosphorus Content of Rice as Influenced by the Nature of the Clay Mineral in Quartz-clay Mixtures

Clay Mineral and Treatment	August 6		August 27		Septmber 17	
	P_2O_5 %	P_2O_5 mg.	P_2O_5 %	P_2O_5 mg.	P_2O_5 %	P_2O_5 mg.
			Above-ground portion			
Kaolinite 1 P.	0.800	36.8	0.782	68.2	0.564	80.6
Kaolinite 2 P.	0.880	34.3	0.773	76.5	0.600	73.9
Bentonite 1 P.	1.128	65.4	0.698	94.9	0.682	105.8
Bentonite 2 P.	1.371	83.6	0.946	111.6	0.644	122.4
Illite 1 P.	1.028	28.8	0.681	55.2	0.532	75.6
Illite 2 P.	0.817	28.6	0.624	54.3	0.535	75.4
			Root			
Kaolinite 1 P.	0.316	4.1	0.188	11.1	0.166	16.3
Kaolinite 2 P.	0.468	5.1	0.189	11.5	0.216	17.2
Bentonite 1 P.	0.436	4.4	0.215	12.0	0.235	17.1
Bentonite 2 P.	0.556	6.1	0.283	15.6	0.302	22.0
Illite 1 P.	0.930	4.7	1.064	39.4	0.527	35.3
Illite 2 P.	0.790	7.1	0.909	33.6	0.582	39.6
			Whole plant			
Kaolinite 1 P.		40.9		79.1		96.9
Kaolinite 2 P.		69.8		88.0		91.1
Bentonite 1 P.		69.8		106.9		122.9
Bentonite 2 P.		89.7		127.2		144.4
Illite 1 P.		33.5		94.4		110.9
Illite 2 P.		35.7		87.9		115.0

Table 4. Proportion of Phosphorus in the Rice Plants Absorbed from that Applied Basically and Supplementally to Quartz-clay Mineral Mixtures.

Clay Mineral and Treatment	August 6		August 27		September 17	
	P(B) %	P(S) %	P(B) %	P(S) %	P(B) %	P(S) %
			Above-ground portion			
Kaolinite	63	37	58	42	53	47
Bentonite	57	43	69	31	53	47
Illite	55	45	59	41	47	53
			Root			
Kaolinite	66	34	68	32	37	63
Bentonite	68	32	66	34	48	52
Illite	42	58	23	77	34	66

P(B) stands for proportion of phosphorus which was absorbed from the basic application.
P(S) stands for proportion of phosphorus which was absorbed from the supplemental application.

P^{32} was determined. From the results obtained, the proportion of absorbed phosphorus which was applied as a basic application and absorbed phosphorus added as a supplemental application was calculated as shown in Table 4.

In general, the proportion of phosphorus absorption was a little higher from the basic application than from the supplemental application. However, a reverse result was found in the roots growing in illite throughout the experiment, and for the above ground portion of the plants in illite and even the roots of plants in kaolinite and bentonite on the last date, September 17.

The potassium analyses are shown in Table 5.

On August 6, the above-groud portion of the plants showed almost the same percentage of K_2O when grown in each clay mineral. The percentages decreased with growth. Plants grown in kaolinite showed the highest value, followed by illite, and bentonite the lowest value. The potassium percentages in the roots was much less than the percentage in the above-ground portions. In the root, illite gave the highest value, followed by kaolinite and bentonite showed the lowest value. The percentages of K_2O in the roots also decreased with growth.

The amount of potassium absorbed by the whole plant was much higher in the above-ground portion than in the root. Potassium was higher in the whole plants on bentonite than on kaolinite and illite on August 6. However, on August 27, those on kaolinite showed a marked high value. The amount of potassium in plants grown on each mineral decreased on September 17. At this stage the plants in kaolinite showed the highest amount, followed by illite, with bentonite the lowest.

The results of the calcium and magnesium analyses are shown in Table 6 and 7.

The percentage of calcium in plants growing in quartz-clay mixtures was a little higher in illite than in kaolinite or bentonite. The percentage in the above-ground portion was higher than that in the root except on August 27. On September 17, the percentage of calcium was considerably higher than the percentage in the two earlier stages. The calcium content of the roots showed the same trend as the above-ground portions in the percent of calcium. The calcium content of the whole plant increased with growth.

The percent of magnesium in the above-ground portions showed almost no change or decreased slightly with growth, but in the root, it decreased. The magesium content of the whole plant increased with growth.

Tabe 5. Potassium Content of Rice as Influenced by the Nature of the Clay Mineral in Quartz-clay Mitures

Clay Mineral and Treatment	August 6		August 27		September 17	
	K_2O %	K_2O mg.	K_2O %	K_2O mg.	K_2O %	K_2O mg.
			Above-ground portion			
Kaolinite 1 P.	3.85	177.1	2.41	209.7	1.34	192.2
Kaolinite 2 P.	3.02	117.8	2.40	237.6	1.37	180.6
Bentonite 1 P.	3.40	197.2	1.67	227.1	1.00	154.4
Bentonite 2 P.	3.12	190.3	1.55	182.9	0.84	159.6
Illite 1 P.	3.06	85.7	2.16	175.0	1.20	170.4
Illite 2 P.	3.16	110.6	2.08	181.0	1.21	170.8
			Root			
Kaolinite 1 P.	0.85	7.5	0.46	27.1	0.32	31.8
Kaolinite 2 P.	0.77	8.5	0.53	32.2	0.29	23.0
Bentonite 1 P.	0.31	3.1	0.37	20.7	0.18	13.1
Bentonite 2 P.	0.49	5.4	0.42	23.1	0.29	21.0
Illite 1 P.	1.00	5.0	0.76	28.1	0.38	25.7
Illite 2 P.	1.15	10.4	0.61	22.6	0.30	20.4
			Whole plant			
Kaolinite 1 P.		194.6		236.1		224.0
Kaolinite 2 P.		126.3		269.9		203.6
Bentonite 1 P.		200.3		247.8		167.5
Bentonite 2 P.		195.7		206.0		180.6
Illite 1 P.		90.7		203.1		196.1
Illite 2 P.		121.0		203.6		191.2

Table 6. Calcium Content of Rice as Influenced by the Nature of the Clay Mineral in Quartz-clay Mixtures

Clay Mineral and Treatment	August 6		August 27		Septemqer 17	
	CaO %	CaO mg.	CaO %	CaO mg.	CaO %	CaO mg.
			Above-ground portion			
Kaolinite 1 P.	0.29	13.3	0.18	15.7	0.64	92.5
Kaolinite 2 P.	0.39	15.2	0.19	18.8	0.54	71.8
Bentonite 1 P.	0.31	18.0	0.19	24.5	0.63	98.0
Bentonite 2 P.	0.29	17.7	0.18	21.2	0.64	122.1
Illite 1 P.	0.29	8.1	0.31	25.1	0.72	102.3
Illite 2 P.	0.34	11.9	0.21	18.3	0.69	97.4
			Root			
Kaolinite 1 P.	0.15	2.0	0.28	16.5	0.22	21.6
Kaolinite 2 P.	0.15	1.7	0.19	11.6	0.22	17.6
Bentonite 1 P.	0.22	2.2	0.26	14.6	0.25	18.2
Bentonite 2 P.	0.20	2.2	0.28	15.4	0.32	22.4
Illite 1 P.	0.24	1.2	0.41	15.2	0.26	17.7
Illite 2 P.	0.26	2.3	0.35	13.0	0.16	11.0
			Whole plant			
Kaolinite 1 P.		15.3		32.2		114.1
Kaolinite 2 P.		16.9		30.4		89.4
Bentonite 1 P.		20.2		39.1		116.2
Bentonite 2 P.		19.9		36.6		145.5
Illite 1 P.		9.3		40.3		120.0
Illite 2 P.		14.2		31.3		108.4

Table 7. Magnesium Content of Rice as Influeneed by the Nature of the Clay Mineral in Quartz-clay Mixtures

Clay mineral and Treatment	August 6		August 27		September 17	
	MgO %	MgO mg.	MgO %	MgO mg.	MgO %	MgO mg.
			Above-ground portion			
Kaolinite 1 P.	0.41	18.9	0.59	55.4	0.50	70.9
Kaolinite 2 P.	0.46	17.9	0.56	55.4	0.50	66.5
Bentonite 1 P.	0.41	23.8	0.56	55.8	0.36	56.1
Bentonite 2 P.	0.56	34.2	0.41	48.3	0.28	53.0
Illite 1 P.	0.61	17.1	0.59	47.8	0.48	68.4
Illite 2 P.	0.67	23.5	0.56	48.7	0.54	75.8
			Root			
Kaolinite 1 P.	0.36	4.7	0.31	18.3	0.19	18.2
Kaolinite 2 P.	0.58	6.4	0.30	18.3	0.18	14.0
Bentonite 1 P.	0.51	5.1	0.18	10.1	0.16	11.3
Bentonite 2 P.	0.66	7.3	0.14	7.7	0.16	11.3
Illite 1 P.	0.51	2.6	0.43	15.9	0.24	16.3
Illite 2 P.	0.59	5.3	0.31	11.5	0.19	12.6
			Whole plant			
Kaolinite 1 P.		23.6		69.6		89.1
Kaolinite 2 P.		24.3		73.7		79.5
Bentonite 1 P.		28.9		65.9		67.4
Bentonite 2 P.		41.5		56.0		64.3
Illite 1 P.		19.7		63.7		84.7
Illite 2 P.		28.8		60.2		88.4

Upon comparing the magnesium and calcium content on August 6 and 27, it can be noted that the magnesium content of the plants was higher than their calcium content in the three clay minerals, but on September 17, their calcium content was higher than magnesium.

Discussion

The percentage of nitrogen decreased with growth, but the total absorbed nitrogen showed no remarkable change except for the plants grown in illite. Usually the nitorgen absorption by rice increases with growth. The results indicate that an insufficient amount of nitrogen was used in this experiment. In illite, the growth in the early stage was not good. The reason became clear when the rice was uprooted. The illite-sand mixture contained easily reduceable iron-sulphur compounds. Ferric iron was reduced to ferrous iron, and at the same, hydrogen sulphide formed. This retarded early growth was overcome some in the later stages. The absorbed nitrogen was highest in bentonite and lowest in kaolinite.

The percentage phosphorus content of rice plants decreased but the total absorbed phosphorus increased with growth. This trend is only natural. However, the percentage and the absorbed amount in above-ground portion were highest in bentonite, while in the root the highest phosphorus percent was obtained with illite, and the total absorbed phosphorus was highest in bentonite. Anion exchange capacity of each series of pots was as follows : Kaolinite 34. 4, bentonite 1. 9, illite 5. 6 millimols. Therefore, it seems that phosphorus is fixed to a great degree in kaolinite, and, accordingly, the absorption of phosphorus was lowest in kaolinite. Until August 27, phosphorus was absorbed in equal amounts by rice grown in kaolinite and illite. On September 17, the amount in kaolinite was the lowest, although much higher than the amount which would be anticipated from the anion exchange capacity. Namely, the ratio of anion exchange capacity is ; kaolinite 100 ; illite 16 ; bentonite 6 ; and the ratio of the amount of absorbed phosphorus on September 17 is ; kaolinite 63 ; illite 80 ; bentonite 100.

It is generally believed that in rice growing, supplimental application of phosphorus fertilizer is useless. This was not true in this experiment. Total P absorbed was not different in 1P. and 2P. The phosphorus applied as a basic application was absorbed only to a slightly greater extent than the phosphorus of a supplimental application in general. In fact, the analysis of the roots of plants grown in illite shows that it absorbed much more phosphorus of the supplemental application than that of the basic application. As the writer mentioned, the root growth in illite was damaged by some toxic substances. It is not sure, however, whether or not this peculiar behavior of illite root was due to reduceble compounds.

The potassium percentage of rice plants decreased with growth, with bentonite showing the lowest value both in the above-ground portions and the roots. The total amount of absorbed potassium was highest on August 6 in bentonite. Plants grown in kaolinite showed the highest value on August 27 and September 17, while bentonite showed the lowest value on September 17. These differences may be attributed to the difference in potassium fixing power of the crystal lattice of clay mineral. It is known that the potassium fixing power of 1 : 1 type clay mineral is weaker than that of 2 : 1 type clay mineral (3). Decrease in the potassium content of plants in the later stages of growth has been acknowledged in many experiments.

It is an interesting fact that in the early stages of growth of rice the amount of absorbed calcium was less than that of magnesium, while in the later stages the relation was reversed in the three clay minerals. It has been reported that some crops absorb calcium more easily from kaolinite than from bentonite and illite (1, 2, 4, 6). The results in this study do not necessarily coincide with this concept. Further study seems to be necessary in order to clarify this point.

Summary and Conclusion

Nutrient absorption of rice was studied using various kinds of clay mineral-quartz sand mixtures, whose cation exchange capacities were made equal. The amounts of nutrients added to each were equal. The total absorbed nitrogen was highest in the plants grown in bentonite and lowest in those grown in kaolinite.

Total absorbed phosphorus was highest in bentonite and lowest in kaolinite, but fhis difference was much less than the variation which was anticipated from the difference of anion and cation exchange capacities of the mineral mixtures.

Phophorus which was added as a supplimental application in the early stage of growth was absorbed to a large extent by rice.

In kaolinite the total amount of potassium absorption was much higher than in plants grown in bentonite and illite. Differences in the lattice structure of the clay mineral may account for this variation in uptake of potassium. Absorption of calcium and magnesium increased with growth. In the early stage, the amount of calcium was less than that of magnesium, however, in the later stages, more calcium was absorbed by rice than was magnesium.

In this experiment, some fundamental relations between nutrient absorption of rice and clay minerals were found.

Literature Cited

1) ALLAWAY, W. H. Soil Sci. **59,** 207, 1945.
2) CHU, T. S. and TURK, L. M. Mich. State Col. Tech. Bul. 214, 1949.
3) DE TURK, E. E. Soil Sci. Soc. Amer. Proc. **8,** 46, 1943.
4) MEHLICH, A. and REED, J. F. Soil Sci. Soc. Amer. Proc. **11,** 201, 1947.
5) MEHLICH, A. Soil Sci. **66,** 429, 1948.
6) MILES, I. E. Soil Sci. **65,** 97, 1948.

摘　　要

森田修二：種々の粘土鉱物と水稲の養分吸収に就て

種々の粘土鉱物に石英砂を混合してカチオン置換容量を一定とし添加養分量も等量として，之等に水稲を栽培し養分の吸収を研究した．

吸収された全窒素量はベントナイト区の植物に於て最高で，カオリナイト区の植物に於て最低であつた．

吸収された全燐量はベントナイト区に於て最高，カオリナイト区に於て最低であつた．しかし此の差は粘土鉱物石英砂混合物のアニオン置換容量から予想されるよりも遙かに小であつた．初期に於て追肥として加へた燐は水稲によつて多量に吸収された．

カオリナイト区の植物によつて吸収された全加里量はベントナイト区，イライト区の植物による吸収量よりも遙かに大であつた．此の吸収量の相違は粘土鉱物の結晶格子の構造の差異に基くのであろう．

水稲による石灰，苦土の吸収は生長と共に増加した．生育初期に於ては吸収された石灰の量は苦土の量よりも小であつたが，生育の後期では吸収された石灰量は苦土量よりも大であつた．