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Mineral-Deficiency Symptoms Displayed by Rice Plants Grown Under Controlled Conditions in the Greenhouse[1]

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ABSTRACT

Deficiency symptoms were induced by the omission of macro- and micronutrient elements on rice plants of the Sinaloa variety grown in solution culture in the greenhouse. The elements included in the study were N, P, K, Ca, Mg, S, Fe, Mn and B. The omission of N, K and Fe from the nutrient medium resulted in the poorest top growth of plants. The lowest values of either fresh or dry weight of roots were caused by lack of K. Omission of Ca, S, Mg, B and Mn treatments also caused the development of poor root systems. Lack of P was the least detrimental. Except for S and Fe, the concentration of the particular missing element in the leaf tissues was lower in plants from each deficiency treatment than in the control plants. Leaf analysis indicates that the absence of one element from the nutrient medium could cause either a reduction or an increase of other related elements in the leaf tissue.

INTRODUCTION

Rice (*Oryza sativa L.*) was probably introduced into Puerto Rico from the Dominican Republic early in the 16th century. The cereal soon became our most important staple. However, in 1911, 126,901,195 lb (5,768,236 kg) valued at $1.8 million were imported from the United States[3]. At present we are importing more than $30 million in rice.

Rice is still planted by a handful of highland farmers as a subsistence crop.

Very little information is available in Puerto Rico about the fertilization of this crop. Probably, new difficulties will be encountered by the potential rice farmers, at least for a few years. In the long run, however, the continuous cropping of the land to this cereal may lead to nutrient deficiencies, especially with more than one crop per year on the same land. Anticipating this possibility, major as well as minor element deficiencies, were induced.

MATERIALS AND METHODS

The elements included in the study were N, P, K, Ca, Mg, S, Fe, Mn, and B. A full nutrient treatment was included for comparative purposes.

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[3]Carrol, A., 1911. Register of Porto Rico, Imp. del Gobierno, San Juan.

The deficiencies were developed by the solution culture method as follows: 30 10-liter earthenware, glazed, round bottom, self-drained crocks were thoroughly washed and filled with distilled water. PVC (polyvinyl chloride) covers were used on top of the crocks for holding the plants upright and suspending the roots in the nutrient solutions. Covers also helped to reduce contamination of solutions by dust. Two holes were cut into each cover to insert a plastic tube 6.5 cm high by 7.5 cm wide and the aerating capillary tube. The plastic tube sections were covered on the lower end with a piece of a wide mesh Saran fabric, which was fastened to the tube with rubber bands. The tubes thus fixed were inserted halfway into the bigger hole in the center of the cover. To prevent these from sinking, three nails were driven, at right angles, on the outside. The nails were set equidistant one from the other and rested flat on the plastic covers. Mechanical aeration of the nutrient solutions was provided by air pumped through rubber, glass and capillary Pyrex tubing.

Fifty rice seeds of cultivar Sinaloa were planted in each plastic tube section underlaid by the Saran fabric. At first, the seedlings were supplied with distilled water only up to a level which would soak the rice seeds completely. One month later the differential treatments were started.

Table 1 shows the composition of the nutrient solutions used in the study. The various solutions were supplied at half-strength for 3 weeks and then at full-strength for the duration of the study.

Composite samples of leaves from the different treatments were gathered for the corresponding chemical analyses. The deficiency symptoms were recorded as they appeared. The fresh and dry weights of the plants were also recorded.

RESULTS AND DISCUSSION

GROWTH

Top

Table 2 shows the influence exerted by the various nutrient deficiencies upon the fresh and dry weights of shoots and roots, as well as the top-root ratios and relative decrease in fresh and dry weight of the plants. Except for the minus Ca, the complete treatment produced the greatest increase in fresh and dry weight, while the omission of N from the nutrient medium brought about the poorest growth. The growth reduction induced by the lack of N relative to that of the full nutrient plants was 75%. The minus K and minus Fe treatments ranked next to N deficiency in reducing either the fresh or dry weight. These two deficiencies caused a reduction in growth of 68 and 52%, respectively. The growth of plants as affected by the other deficiencies, although lower than that exhibited by plants in the complete nutrient treatments, was not as drastically curtailed; the relative decrease in growth was 15 to 20%.

TABLE 1.—*Composition of nutrient solution used in the rice nutrient deficiency experiment*

Treatment	Partial volume-molecular concentration of —						
	$Ca(NO_3)_2$	$MgSO_4$	KH_2PO_4	$CaCL_2$	NaH_2PO_4	$NaNO_3$	KNO_3
Complete	0.009	0.0045	0.0045				
Minus N	–	.0045	.0045	0.009			
Minus P	.009	.0045	–				
Minus K	.009	.0045	–		0.0045		
Minus Ca	–	.0045	.0045			0.0045	0.0045
Minus Mg	.009	–	.0045		.0045		
Minus S	.009	–	.0045				
Minus Fe	.009	.0045	.0045				
Minus Mn	.009	.0045	.0045				
Minus B	.009	.0045	.0045				

TABLE 2.—*Effect of the various mineral deficiencies in the fresh and dry weights of rice plants*

Deficiency	Shoot	Root	Total (shoot and root)	Top: root ratios	Relative decrease in fresh and dry weight
	G	*G*	*G*		%
			Fresh weights		
Minus N	42.0	24.0	66	1.75:1	75
Minus P	137.0	92.0	229	1.49:1	19
Minus K	54.0	17.0	71	3.17:1	68
Minus Mg	138.0	72.0	210	1.91:1	18
Minus Ca	219.0	42.0	261	5.21:1	+1
Minus S	130.0	48.0	178	2.71:1	23
Minus Fe	81.0	21.0	102	3.86:1	52
Minus Mn	144.0	68.0	212	2.12:1	15
Minus B	135.0	51.0	186	2.64:1	20
Complete	169.0	104.0	273	1.62:1	0
			Dry weights		
Minus N	9	2	11	4.5:1	79
Minus P	30	10	40	3.0:1	15
Minus K	12	2	14	6.0:1	84
Minus Mg	26	5	31	5.2:1	31
Minus Ca	44	4	48	11.0:1	60
Minus S	25	3	28	8.3:1	54
Minus Fe	15	2	17	7.5:1	80
Minus Mn	27	5	32	5.4:1	34
Minus B	27	4	31	6.75:1	51
Complete	35	7	42	5.0:1	0

Root

According to table 2, the complete treatment produced the greatest fresh weight, while the minus P induced the highest dry weight. On the other hand, the lowest values of both fresh and dry weights was caused by the lack of K in the growing media. This lack of K was followed closely by the absence of N. The root growth attained by plants lacking Fe was seemingly affected. The minus Ca, S, Mg, B and Mn treatments also caused the development of poor root systems. The omission of P exerted the least detrimental effect upon root growth. This lack of P resulted in the second largest root system of all. The difference in fresh weight between this and the complete treatment was only 15.2%.

Ranked in decreasing order, the adverse effects of the omission of each mineral element on the growth of the rice plants was as follows:

Tops—N K Fe S B P Mg Mn C Ca
Roots—N K Fe S Mg Mn B P C Ca
Total—N K Fe S B Mn Mg P Ca C

Top-root ratios

Table 2 shows the top-root ratios induced by the various treatments. Results show that the narrowest ratio between the aerial and root portions of plants was that developed under lack of P. Apparently the absence of P from the nutrient medium did not interfere much with the general growth and development. Similarly, the minus N, the minus Mg and the complete treatment also had narrow top-root ratios. Lack of K, Ca and Fe in the nutrient solution produced, on the contrary, the highest top-root growth relationship. This was especially true of the minus Ca treatment, in which the top-root ratio of the Ca-deficient plants was about three times that of the complete treatment. Apparently K, Ca and Fe are needed by rice plants to insure an abundant and well developed root system. Intermediate to the above mentioned ratios were the minus S, the minus Mn and the minus B treatments.

LEAF ANALYSES

Table 3 gives the results of the leaf analyses of the rice plants submitted to the various deficiency treatments.

Nitrogen

The lack of N produced the lowest leaf-N content. Aside from the N, P and Ca treatments, the leaf-N in the remaining treatments was higher than that of the complete solution. The highest leaf-N was found when Fe was omitted from the feeding medium.

TABLE 3.—*Chemical composition of leaf tissue from rice plants as affected by the omission of nutrient elements from the solution*

Treatment	N	P	K	Ca	Mg	S	Fe	Mn	B
	%	%	%	%	%	%	*p/m*	*p/m*	*p/m*
Complete	2.22	0.63	1.94	0.45	0.91	0.37	5,639	683	31
Minus N	1.01	0.39	2.07	0.37	0.71	0.24	2,529	1,077	42
Minus P	1.70	0.07	3.82	0.34	0.42	0.26	4,618	704	49
Minus K	2.59	1.18	0.73	0.95	1.09	0.38	591	435	22
Minus Ca	1.95	0.40	3.85	0.06	0.49	0.33	2,889	342	34
Minus Mg	2.62	0.75	2.35	0.80	0.40	0.41	2,255	490	36
Minus S	2.62	0.40	1.69	0.59	1.20	0.34	3,866	329	43
Minus Fe	2.93	0.97	3.76	0.59	1.03	0.38	2,980	768	38
Minus Mn	2.39	0.51	2.86	0.43	0.98	0.32	8,055	160	36
Minus B	2.48	0.52	1.93	0.44	1.11	0.36	2,943	575	15

Phosphorus

The lowest leaf-P values were found in the minus P treatment. When N was omitted the P content of leaves dropped sharply as compared to those of complete and other treatments. The leaf-N values of the minus Ca, S, Mn, and B deficiencies were also lower than those of the control. The highest P accumulation occurred in leaf tissues of the minus K plants in which contents of this element almost doubled that of the full nutrient. Fe-and Mg-deficient plants also showed a high P content.

Potassium

The leaf-K values were lowest in the minus K treatment. These values were about 2.6 times lower than those in the control. K tended to accumulate at relatively high levels in the absence of P, Ca, Mg, Fe, and Mn. The K present in the foliage of otherwise treated plants was similar to that of the complete.

Calcium

Leaf-Ca was present in negligible amounts when this nutrient element was omitted. The highest amounts of Ca were detected in the minus K and Mg deficiencies. Such values were a little lower with lack of N and P than in the control. However, those for the minus Fe and sulfur-starved plants were slightly higher.

Magnesium

Leaf-Mg was lowest in the minus Mg treatment. Mg was also present in low amounts in the P, N and Ca deficient plants. The highest level of Mg was detected in plants lacking S. Leaf-Mg was somewhat higher in the minus K, Fe, and B than in plants receiving full nutrient treatment.

Sulfur

The leaf-S value of plants under the minus S treatment was about the same as that of plants in the complete solution. However, there was a big contrast between the former in growth, appearance and chemical composition. This may suggest that the absence of an element is liable to cause a detrimental effect without being critically deficient in the plant.

Except for the minus N- and minus P-plants, the leaf-S values of the remaining deficiency treatments were more or less similar to that of plants in the full nutrient medium.

Iron

The lowest leaf-Fe was present in the minus K plants. Although the Fe content of plants lacking this element was considerably less than that of the full nutrient treatment, it amounted to almost five times that of the minus K plants. Apparently, the presence of K is essential for the absorption and utilization of Fe by the rice plant. Slightly lower leaf-Fe was found in the minus N, Ca and Mg treatments.

Even though the omission of Fe did not cause the lowest-Fe content of the treated plants, the content was low enough to induce characteristic symptoms of Fe deficiency. The absence of Mg showed the highest level of Fe among the various treatments. Leaf-Fe in this treatment was 1.43 and 3.7 times higher than the complete and the minus Fe treatments, respectively.

Manganese

Leaf-Mn was lowest in the minus Mn treatment. On the contrary, N starved plants had the highest leaf-Mn. Those lacking Fe and P followed. Other leaf-Mn values were somewhat lower than that of the complete medium.

Boron

Lack of B induced the lowest leaf-B content, which was about half that of the complete treatment. The B content of the leaf tissue was also low

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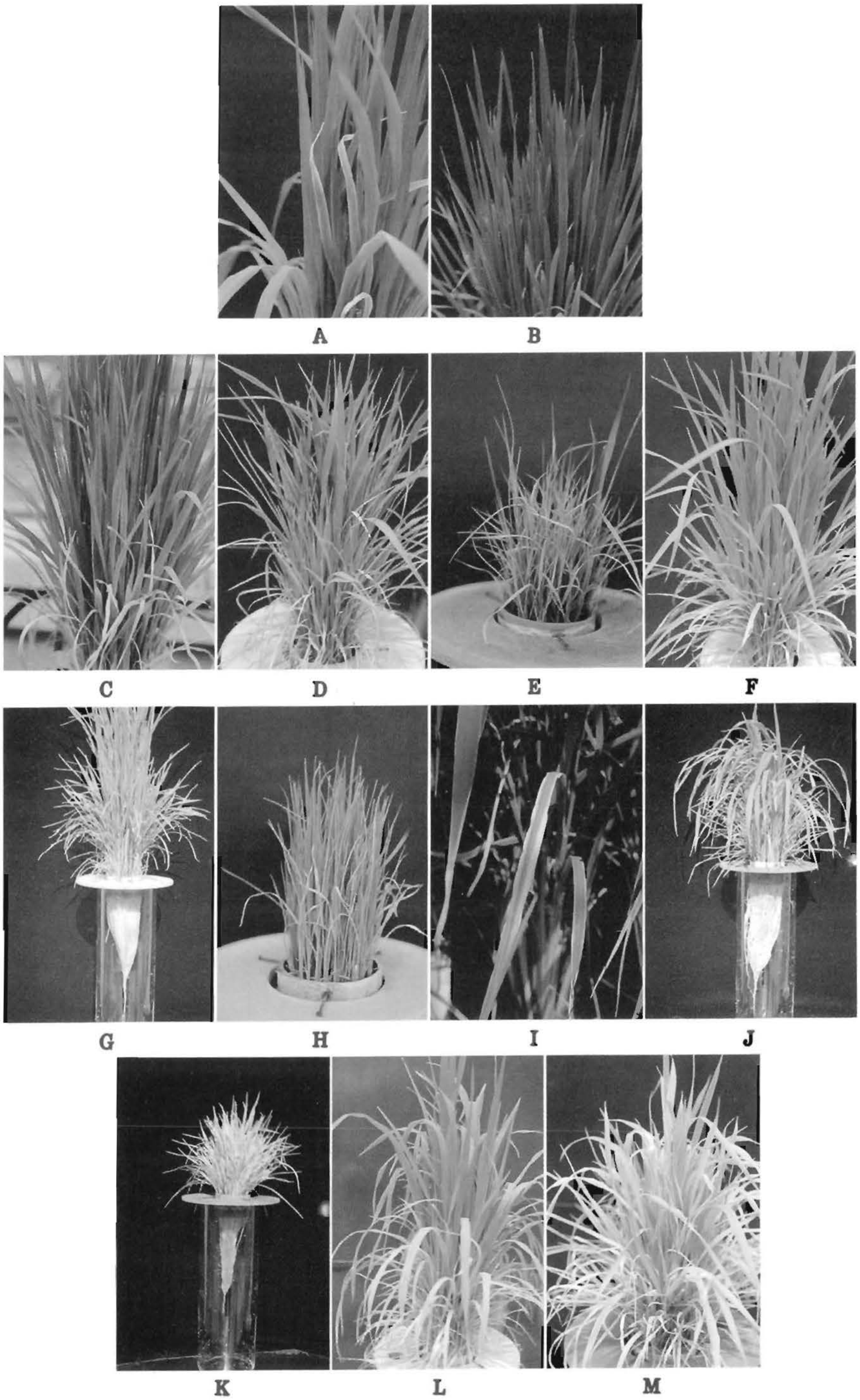
PLATE I.—A—The minus N plants made the least growth. Besides, their stiff, upright growth gave them a needle case appearance as shown by photo. B—First sign of P deficiency appeared as a deep brown discoloration of leaf-tips simulating lady's fingernails. C—Tip necrosis in the minus P plants increased in size extending downward through the lamina. D—Potassium deficiency was characterized by yellowing, tip burning and scorching of leaves. E—Ragged appearance shown by minus K plants at the end of experiment. F—Calcium deficiency was characterized by yellowing and dying back of older leaves. G—Lack of Ca produced a high top-root ratio. H—First symptoms of Mg starvation appeared in the form of whitish colored tip burn. I—As Mg depletion continued the tip burned condition extended downward along the margins leaving a definite green section through the center portion of affected leaves. J—A bunchy type of growth developed by rice plants lacking S. K—Elimination of Fe from nutrient solution drastically reduced the fresh weight of plants. L—Lack of Fe culminated in the affected plants turning almost white in color. M—Symptoms displayed by Mn deficient plants were characterized by an interval chlorosis.



A B C D E F G H I J K L M

in K deficient plants, while in the minus P, N and S it was somewhat higher than in the full nutrient treatment.

VISUAL DEFICIENCY SYMPTOMS

Nitrogen

N deficiency symptoms appeared first. Lack of N had a severe effect upon growth and development (table 2). Those plants grew the least. Their reduced size, and stiff, upright type of growth gave them a needle-case appearance. Figure A shows the dwarfing effect of the N deficiency. There was a sharp contrast between the minus N and the normal, sound plant in this respect. The latter exhibited luxuriant growth as the long, tender, arching leaves show.

The deficiency was also characterized by a change of color and die-back of leaves. The typical yellowing induced by the restriction of N started on the lower leaves. The first symptom consisted of fading of the deep green color. As the deficiency became more acute, leaves went from pale green to yellowish-green until a totally yellow stage was reached. Soon after the onset of the yellow stage leaves started to die-back. By the end of the experiment many were completely dry.

Phosphorus

Severe deficiency symptoms attributable to lack of P took some time to become evident. At first, there was very little difference in the general appearance and development among plants from minus P and those from the complete nutrient solution. However, when plants were harvestted at the end of the study, almost all leaves were showing clear signs of P malnutrition. The first sign was a discoloration of the leaf-tip. As the deficiency advanced, the discoloration changed to a deep brown color similar to a lady's fingernail (fig. B). Later on, this tip necrosis extended downward throughout the lamina (fig. C). As in the case of the minus N plants, there was no bending or arching of leaves.

Potassium

K deficiency symptoms were the second to appear. Plants with no K were nearly as affected in their top and root growth as the minus N. N and K deficiencies coincided also in a diminution in the rate of growth of young plants when the first symptom appeared. The first deficiency symptom was the yellowing of the leaves. In a more advanced stage the tips and margins of the older leaves became yellow, then brown and finally died out, with the characteristic scorching, the common and universal symptom of K malnutrition of cereals (fig. D). By the end of the experiment a considerable number of leaves had rolled in from the margins developing a tubular form. Figure E shows an advanced stage of K deficiency.

Calcium

In the absence of Ca, no definite symptoms were evident, except for the yellowing and dying of the older leaves of affected plants (fig. F). Although the top growth of the minus Ca plants exceeded that of the complete treatment, the root system was about 60% smaller (fig. G), which may indicate that in rice Ca is essential for root development rather than for top growth.

Magnesium

Mg deficiency symptoms were also slow to develop, but by the termination of the investigation all plants showed them. They were first seen in the older leaves. The first symptoms of Mg starvation appeared as a whitish colored tip burn (fig. H). With the continued depletion of Mg, the tip burn condition extended downwards along the margins leaving a definite green section throughout the center portion of the affected lamina. With the intensification of the deficiency, the whole lamina died. (fig. I).

Sulfur

S deficiency symptoms appeared early in the growing cycle. The outstanding symptom was a solid yellowing of plants, including both the old and younger leaves. Another symptom is the bunchy type of growth. This was probably because the stalks were short for the size of the leaves (fig. J).

Iron

Besides the characteristic chlorosis induced by the omission of Fe, this deficiency had a very drastic effect upon the general growth and development of the plants. In fact, the lack of Fe reduced fresh weight to 52% of the full nutrient treatment (fig. K). Apparently, Fe is greatly needed for healthy growth and development of the rice plant.

The chlorosis shown by the minus Fe plants started in the younger leaves, but as the older ones died the whole plant showed the symptoms. The deficiency progressed until the affected plants turned almost white (fig. L). The ill effects of the lack of Fe culminated in the disintegration of the leaf tissue.

Manganese

Symptoms of Mn deficiency were not as severe as symptoms in plants lacking Fe. These appeared first in the older leaves as an interveinal chlorosis; i.e., the parenchymatous tissue between the parallel veins of the leaves turned yellow but the veins remained green (fig. M). The Mn deficient plants also were somewhat bunchy.

Boron

The suppression of B from the nutrient solution did not induce any particular symptom other than the fading of the color and a reduction of the fresh and dry weight of both the top and root systems.

RESUMEN

Para inducir carencias nutricionales, se cultivaron plantas de arroz de la variedad Sinaloa en el invernadero en soluciones nutritivas. Cada solución carecía de uno de los siguientes elementos: N, P, K, Mg, Ca, S, Fe, Mn o B. La falta de N, K y Fe redujo el crecimiento de los tallos y hojas. En cambio, la falta de K aminoró drásticamente el desarrollo del sistema radical, siendo los pesos fresco y seco los más bajos de todos. La falta de Ca, S, Mg, B y Mn también afectó adversamente el crecimiento de las raíces. En ese sentido, la falta de P fue la menos perjudicial al arroz. Con excepción del S y el Fe, las concentraciones de los elementos omitidos fueron, invariablemente, más bajas que en las plantas testigo. Por otra parte, el análisis químico del follaje reveló que la ausencia de un elemento afectó el contenido en otro directamente relacionado con aquél en la nutrición mineral del arroz. Las plantas sometidas a casi todos los tratamientos mostraron síntomas carenciales.