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# Effect of nutrient solution pH and N-Sources ( $\text{NH}_4/\text{NO}_3$ ) on the growth and elemental content of rice plants

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## SUMMARY

Rice plants were grown in nutrient solution for a period of one month at pH values ranging from 3.5 to 7.5, containing two sources of nitrogen. Maximum dry matter production occurred at pH 5 to 6 with  $\text{NH}_4^+\text{-N}$  and pH 4 to 5 with  $\text{NO}_3^-\text{-N}$ , but substantial reductions in the growth of tops and roots were observed at pH values of 3.5 and 7.5, with both N-sources. At the lowest pH, leaves and roots were short and unhealthy under both N-applications, while at the highest pH, leaves were chlorotic having discoloured brown roots. The concentrations of N, K, Mg and Mn in plant tops generally increased with increasing pH and were higher with  $\text{NO}_3^-\text{-N}$  than with  $\text{NH}_4^+\text{-N}$ . The effect of pH on the concentration of P and Ca under the  $\text{NH}_4^+$ -treatment was insignificant, while their concentrations increased in plant tops with increasing pH under  $\text{NO}_3^-$ -treatment. Iron concentration in plant tops decreased with increase in solution pH. In roots, Fe and Mn concentrations increased with increasing pH and were greater with  $\text{NO}_3^-\text{-N}$  than with  $\text{NH}_4^+\text{-N}$ . The results suggest that a solution pH of 5.0 to 6.0 is reasonably good for the normal growth and nutrient uptake by rice plants with  $\text{NH}_4^+$  and  $\text{NO}_3^-$  sources of nitrogen.

**Additional key words :** *Hydroponics, rice nutrition.*

## RÉSUMÉ

*Effet du pH de la solution nutritive et de la source d'azote sur la croissance et la teneur du riz en divers éléments.*

Des plants de riz sont cultivés pendant un mois sur des solutions nutritives dont le pH varie de 3,5 à 7,5 en présence de deux sources d'azote. La production maximale de matière sèche est obtenue pour des pH compris entre 5 et 6 en présence d'azote ammoniacal, entre 4 et 5 en présence d'azote nitrique. Des réductions importantes de croissance des parties aériennes et des racines sont observées avec les deux sources azotées pour les pH 3,5 et 7,5. Au pH le plus bas, les feuilles et les racines sont courtes et chétives en présence des deux formes azotées, tandis qu'au pH le plus élevé, les feuilles sont chlorotiques et les racines sont brunes. Les teneurs en N, K, Mg et Mn des parties apicales aériennes augmentent généralement avec le pH et sont plus fortes avec l'azote nitrique qu'avec l'azote ammoniacal. L'effet du pH sur les teneurs en P et en Ca est faible dans le traitement ammoniacal ; elles augmentent avec le pH dans les parties apicales dans le traitement nitrique. La teneur en fer diminue dans les parties apicales lorsqu'augmente le pH. Dans les racines, les teneurs en Fe et en Mn augmentent avec le pH et sont plus élevées avec l'azote nitrique qu'avec l'azote ammoniacal. Ces résultats suggèrent que des pH de 5 à 6 assurent au riz une croissance et une absorption minérale normales avec les deux sources azotées.

**Mots clés additionnels :** *Culture hydroponique, nutrition minérale du riz.*

## I. INTRODUCTION

Solution culture is a widely and frequently used technique for growing plants without soil, providing for a considerable degree of control of the elemental environment surrounding the roots. The determination of the essential elements required by plants was discovered using solution culture techniques. Solution culture experiments offer a means of studying direct effects of pH on the growth and development of plants.

The pH of the nutrient solution will affect the availability of certain elements, particularly the micronutrients, stimulating excessive uptake at a low pH, and resulting in removal from the nutrient solution by precipitation at high pH (ANDREW, 1976 ; ISLAM *et al.*, 1980 ; JONES, 1982). The pH of the nutrient solution is thought to be best when kept between 6.0 and 6.5, although most nutrient solutions when constituted will have a pH between 5.0 and 6.0. It is fairly well known that if the pH of nutrient solution drops below 5.0 or goes over 7.0, plant

growth can be significantly reduced (JONES, 1982). In an interesting experiment, IKEDA & OSAWA (1981) found that N uptake, from either the  $\text{NO}_3^-$  or  $\text{NH}_4^+$  form for 20 plant species in a nutrient solution ranging in pH from 5.0 to 7.0, showed some degree of N form preference at certain nutrient solution pHs. In the present study, rice plants were grown in nutrient solution under glasshouse conditions at variable pH and with two separate forms of nitrogen ( $\text{NH}_4^+$  or  $\text{NO}_3^-$ ) to determine the effects of pH and N-sources on the growth and chemical composition of rice plants. An excess pH level of 7.5 was also included to examine the possible ill-effects of this pH level on the growth parameters of rice plants.

## II. MATERIALS AND METHODS

Rice caryopses (*Oryza sativa* L. cv. 'N-sail') were soaked over-night in distilled water. The caryopses were then put into a tray on a filter paper sheet and kept in the dark for a few days. After germination the tray was put into natural light in a glasshouse. Ten-days old rice seedlings raised in a tray in a glasshouse were transferred to plastic pots, one seedling in each containing 1 800 ml modified HOAGLAND & ARNON (1950) nutrient solution (Table 1). The pH of the nutrient solution was maintained at  $\text{pH } 6.0 \pm 0.1$ . The plants were grown for 14 days before the following treatments were imposed: two N-sources applied separately at 2.7 mM each as  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{NaNO}_3$  and five pH values, 3.5, 4.0, 5.0, 6.0 and 7.5. The pH values were maintained after every 2 days by adding appropriate amounts of diluted NaOH or  $\text{H}_2\text{SO}_4$ . Very little variation in the pH values of the nutrient solution was noticed. Each treatment was replicated three times. The plants were then allowed to grow in a glasshouse in natural sunlight. To ensure an adequate supply of all the essential plant nutrients, the nutrient solution was completely renewed every 3rd day and the pots were not aerated. Symptoms of disorders such as chlorosis and short growth were noticed in the plants growing at the lowest and at the highest pH levels under both N sources. One month after imposing the treatments, the plants were harvested, the tops and roots were separated, washed with water and blotted dry. Dry weight of tops and

roots were obtained after drying in an oven at  $70^\circ\text{C}$  for 24 h.

One gram portions of plant material were digested in a mixture of nitric, perchloric and sulphuric acids and determinations of N, P, K, Ca, Mg, Fe and Mn were made from the digest. Total P was determined colorimetrically using the vanadomolybdo yellow colour method (JACKSON, 1958). Nitrogen was determined by the micro-Kjeldahl method, K and Ca were estimated by flame photometry and Mg by the EDTA method (JACKSON, 1958). Iron and Mn were determined by the phenanthroline and periodate methods, respectively (JACKSON, 1958).

## III. RESULTS AND DISCUSSION

Solution pH and N-sources had large effects on the growth of rice plants. With  $\text{NH}_4^+$  at pH 3.5 and 4.0, the rice leaves showed symptoms similar to mild nitrogen deficiency (SPRAGUE, 1964) and the plants were short and unhealthy. At pH 5.0 and 6.0, the plants were normal and healthy but at pH 7.5, they were light in colour. With  $\text{NO}_3^-$  at pH 3.5 and 4.0, the plants were slightly stunted but looked healthier than with  $\text{NH}_4^+$ . At pH values 5.0 and 6.0, the plants were generally normal in growth and at pH 7.5, chlorosis developed on plant leaves.

Dry weight of tops with  $\text{NH}_4^+$  was highest at pH 6.0, whereas with  $\text{NO}_3^-$  it was at pH 5.0. With  $\text{NO}_3^-$ , top dry weight was least at pH 7.5, with  $\text{NH}_4^+$  at pH 3.5. Damaging effects of solution pH on root growth were observed at pH 3.5 and 4.0 with both N-sources. The roots were short, fewer in number and discoloured brown. Lateral root growth appeared inhibited. At pH 5.0 and 6.0, root growth appeared to be healthy and normal. Again at pH 7.5, root growth was markedly damaged.

Short term studies have shown that, at low pH, ion transport may be impaired, especially at low Ca concentration (JACOBSON *et al.*, 1960). Longer term studies on several plant species have shown that prolonged exposure of roots to low pH leads to suppression of lateral root development and in extreme cases, to death of the root tips (ARNON & JOHNSON, 1942; SMITH, 1971). In the present study, the plants showed these symptoms at pH 3.5 and 4.0. Relatively coarse, discoloured roots occurred at low pH contrasting markedly with the fine profusely branched and symptom free roots present at pH 5.0 and 6.0 with both N-sources.

Analysis of plant tops and roots showed that pH had very large effects on the chemical composition of rice plants. Increasing solution pH from 3.5 to 6.0 substantially increased the concentration of N, K, Mg, Mn and decreased that of Fe in plant tops under the application of both N-sources (Table 2). The effect of pH on the concentration of P and Ca under the  $\text{NH}_4^+$ -treatment was insignificant, while their concentration increased in plant tops with increasing pH under  $\text{NO}_3^-$ -treatment. It was also observed that the concentrations of these nutrients in plant tops were higher with  $\text{NO}_3^-$  than with  $\text{NH}_4^+$ . Several short-term studies have shown large effects of pH on the rate of uptake of various cations. Thus large decreases in the rate of absorption of K (JACOBSON

TABLE 1  
Chemical composition of the nutrient solution.  
Composition de la solution nutritive.

Elément	Level (mM/l)	Salts used
Potassium	2.0	$\text{K}_2\text{SO}_4$
Calcium	1.5	$\text{CaCl}_2$
Phosphorus	1.0	$\text{KH}_2\text{PO}_4$
Magnesium	1.0	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$
Sulphur	—	The above salts
Iron	0.1	Fe-EDTA
Boron	0.03	$\text{H}_3\text{BO}_3$
Manganese	0.02	$\text{MnSO}_4$
Copper	0.001	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
Zinc	0.001	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$
Molybdenum	0.002	$\text{MoO}_3$

TABLE 2

*Dry weight and mineral content of tops of rice grown at different pH with two sources of nitrogen.*

*Matière sèche et teneur en éléments minéraux des parties aériennes apicales de riz cultivés à différents pH en présence de deux sources d'azote.*

pH	Dry wt. s/pot.	Nutrient content (% dry wt.)					µg/g dry wt.	
		N	P	K	Ca	Mg	Fe	Mn
NH <sub>4</sub> <sup>+</sup> -N								
3.5	2.51	2.08	0.17	2.44	0.23	0.16	277	79
4.0	7.63	2.56	0.19	3.63	0.25	0.17	220	87
5.0	8.34	2.76	0.20	3.95	0.27	0.24	202	463
6.0	9.45	2.65	0.21	4.08	0.27	0.24	162	618
7.5	3.75	2.49	0.22	4.23	0.32	0.35	45	689
Mean	6.33	2.51	0.20	3.67	0.27	0.23	181	367
LSD 5 %	0.10	0.08	NS	0.08	NS	0.05	11.34	9.18
LSD 1 %	0.14	0.12	NS	0.11	NS	0.07	16.12	13.04
NO <sub>3</sub> <sup>-</sup> -N								
3.5	3.45	2.15	0.14	3.21	0.21	0.17	188	49
4.0	8.72	2.66	0.19	3.81	0.33	0.13	182	298
5.0	8.93	3.15	0.20	4.04	0.36	0.16	166	837
6.0	5.49	2.88	0.20	4.85	0.34	0.28	95	1 019
7.5	1.93	2.20	0.24	4.85	0.33	0.44	36	1 383
Mean	5.70	2.61	0.19	4.15	0.31	0.24	133	717
LSD 5 %	0.79	0.06	0.05	0.08	0.06	0.04	10.77	8.50
LSD 1 %	1.38	0.09	NS	0.12	0.09	0.05	15.31	12.08

*et al.*, 1960), Ca (MAAS, 1969), Mg (CROOKE, 1980 ; MAAS & OGATA, 1971) and Cu (BOWEN, 1969 ; ROBSON & LONERAGAN, 1970), with decreasing pH have been recorded on several plant species. In the present study, P concentration increased in plant tops with increase in pH under both N-sources (Table 2). However, P concentration at pH 3.5 and 4.0 under both N-sources were below the concentration generally considered adequate for normal plant growth (Table 2). Adequate P levels as reported for other crops are 0.20 to 0.40 % (CHAPMAN 1967) and 0.25 to 0.40 % (JONES, 1972). No P deficiency symptom was recorded in any part of the plants in spite of lower P concentration in the plants at low pH values. Nitrogen concentration in the plant tops increased with increasing pH up to 5.0 and then decreased with further pH increases under both N-sources (Tabl. 2). The plant N concentration at all pH values, except in the case of the lowest was considered optimum for the normal growth of the plant (JONES, 1972). N concentration in plant tops at pH 3.5 was clearly in the deficient range, at both N-treatments. The reason for the decline in plant N concentration at low pH in the plants is not clear. BASSIONI (1971) reported that nitrate uptake by excised barley roots was less at pH 4 than at pH 6. In more recent work, RAO & RAINS (1976) reported higher rates of nitrate absorption in short-term uptake experiments with barley roots at pH 4.0 than at pH 5.7 or 8.5. In the present study, yields of rice plants were markedly reduced at pH 3.5 under both N-sources. Similarly, substantial yield reductions occurred in the region of pH 7.5. Rice plants reached or closely approached maximum yield at pH 5.0 with NO<sub>3</sub><sup>-</sup> and at pH 6.0 with NH<sub>4</sub><sup>+</sup> and significant negative growth responses to increasing pH were observed above this pH value (fig. 1-2).

Dry matter yield of shoot  
(g/pot)

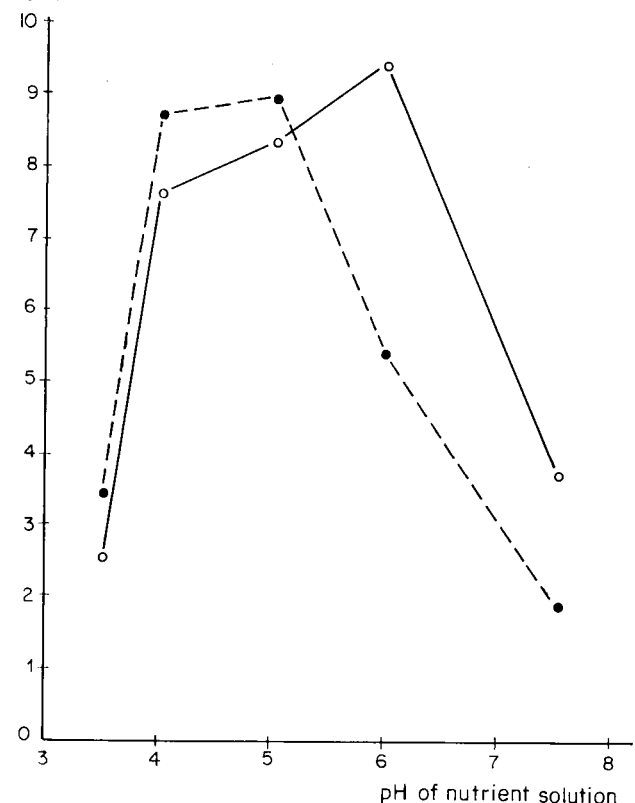


Figure 1

*Effects of solution pH and N-sources on growth of rice shoot.*

*Effet du pH de la solution et de la source azotée sur la croissance des parties aériennes de riz.*

○—○ Data for NH<sub>4</sub><sup>+</sup>-N

●---● Data for NO<sub>3</sub><sup>-</sup>-N

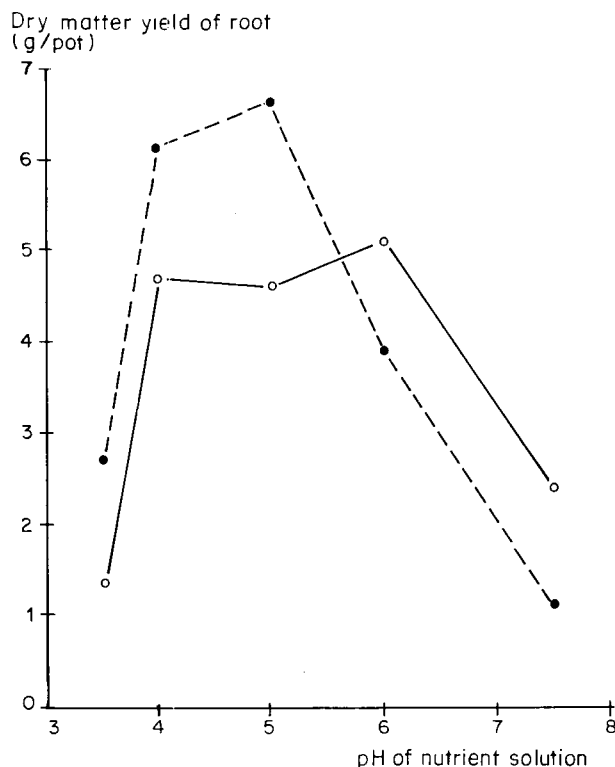


Figure 2

Effects of solution pH and N-sources on growth of rice root.

Effet du pH de la solution et de la source azotée sur la croissance des racines de riz.

○—○ Data for NH<sub>4</sub><sup>+</sup>-N

●---● Data for NO<sub>3</sub><sup>-</sup>-N

Potassium concentration increased in plant tops with increasing pH at both N-sources and the ranges considered to be adequate for healthy plant growth (CHAPMAN, 1967 ; JONES, 1972). With increasing pH

the Ca concentration in plant tops increased with NO<sub>3</sub><sup>-</sup>-N, while pH had no significant effect on Ca uptake with NH<sub>4</sub><sup>+</sup>-N (Tabl. 2). However, the ranges were well above the concentration generally considered adequate for plant growth (JONES, 1972). Magnesium concentration progressively increased in plant tops with increasing pH values at both N-sources. However, Mg concentrations at pH values 3.5 and 4.0 were so low as to be either deficient or marginally limiting for plant growth (JOHANNESON, 1951). Adequate Mg levels reported by CHAPMAN (1967) and JONES (1972) are 0.17 % and 0.2 to 0.40 % respectively.

Manganese concentrations in plant tops increased with increasing pH and concentrations at pH 3.5 with both N-sources (79 and 49 µg/dry wt.) were in the ranges considered to be adequate for plant growth (JONES, 1972). Increasing the solution pH from 3.5 to 7.5 caused substantial reductions in Fe concentration in tops of rice (Table 2) and the Fe concentration at the highest pH was in the range considered to be inadequate for normal plant growth (JONES, 1972). Poor iron nutrition depressed the growth of rice at pH 7.5, despite the use of Fe-EDTA as an iron source. In the present study, when rice plants were subjected to a high solution pH, the new leaves became chlorotic particularly with NO<sub>3</sub><sup>-</sup> nitrogen. The appearance of iron deficiency in plant leaves at high pH can be explained by the low solubility of iron in the rooting medium by fast oxidation of ferrous-Fe and immobilization in the roots.

It was observed from table 3 that in plant roots, iron and manganese contents increased with increase in pH and were higher with NO<sub>3</sub><sup>-</sup> than with NH<sub>4</sub><sup>+</sup>. The greater Fe and Mn retentions by plant roots at high pH may be related to the faster oxidation of Fe

TABLE 3

Dry weight and mineral content of roots of rice grown at different pH with two sources of nitrogen.

Matière sèche et teneur en éléments minéraux des racines de riz cultivées à différents pH en présence de deux sources d'azote.

pH	Dry wt. root s/pot.	Nutrient content (% dry wt.)					µg/g dry wt.	
		N	P	K	Ca	Mg	Fe	Mn
NH <sub>4</sub> <sup>+</sup> -N								
3.5	1.32	1.21	0.13	0.71	0.19	0.11	560	25
4.0	4.71	1.34	0.21	2.19	0.21	0.11	680	35
5.0	4.64	1.56	0.29	2.89	0.23	0.11	1 180	210
6.0	5.18	2.11	0.32	1.55	0.24	0.18	1 750	575
7.5	2.43	1.95	0.43	1.41	0.28	0.25	1 810	2 300
Mean	3.65	1.63	0.27	1.75	0.23	0.15	1 196	629
LSD 5 %	0.06	0.06	0.05	0.06	0.05	0.04	10.96	10.20
LSD 1 %	0.08	0.09	0.07	0.08	NS	0.05	15.57	14.50
NO <sub>3</sub> <sup>-</sup> -N								
3.5	2.72	1.39	0.14	0.85	0.15	0.11	700	40
4.0	6.13	1.69	0.27	2.58	0.24	0.11	1 410	90
5.0	6.65	1.83	0.33	2.69	0.28	0.17	1 620	290
6.0	3.91	2.15	0.41	1.73	0.27	0.19	1 830	2 375
7.5	1.17	2.01	0.37	1.52	0.38	0.23	1 840	6 135
Mean	4.11	1.81	0.30	1.87	0.26	0.16	1 480	1 786
LSD 5 %	0.07	0.08	0.03	0.09	0.04	0.05	9.10	7.72
LSD 1 %	0.10	0.11	0.05	0.13	0.06	0.07	12.94	10.98

and Mn to higher unavailable forms. Phosphorus, calcium and magnesium contents also increased with increase in pH values. Nitrogen content increased with increase in pH up to pH 6, while potassium up to pH 5 and then tended to decrease under both N-sources. The results also indicate that rice plants grown at high pH values especially with  $\text{NO}_3^-$ , suffer from chlorosis, indicating that at a high pH more iron immobilized at the root surface and does not translocate to the upper growing part of the plants. The findings of several workers (TANAKA & YOSHIDA, 1970 ; KANWAR & RANDHAWA, 1974) have revealed that iron deficiency on plant leaves occurs at high pH soils.

The results presented above clearly show that pH is an important factor affecting growth and influencing the concentrations of N, P, K, Ca, Mg, Fe and Mn by plant tops in solution culture using two sources of nitrogen. The results suggest that a solution pH of 5.0 to 6.0 in the presence of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  sources is reasonably good for normal plant growth and for availability and translocation of the nutrient elements from roots to tops of rice plants. Damaging effects of solution pH on root growth was observed at pH values 3.5 and 7.5 of the culture solution.

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