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著者	FUJIWARA Akio, IIDA Shuji
journal or publication title	Tohoku journal of agricultural research
volume	13
number	3
page range	273-285
year	1962-10-06
URL	http://hdl.handle.net/10097/29398

BIOCHEMICAL AND NUTRITIONAL STUDIES ON POTASSIUM. IV.

GROWTH OF RICE PLANT INFLUENCED BY THE ENVIRONMENTAL POTASSIUM AND MAGNESIUM CONCENTRATION

By

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(*Received, May 31, 1962*)

Introduction

The authors attempted to give an explanation with regard to the biochemical and nutritional function of potassium from the stand point of mineral nutrition of higher plants. Previously we (9) reported on the contents of minerals and organic substances in the rice plant and barley, which were cultivated under various environmental concentrations of potassium in the nutrient solution. The results obtained were that the outer potassium concentration affected directly the inner potassium content, moreover, the contents of other minerals were also considerably affected by the simple variation of the outer potassium level only, that means it was impossible to clarify the biochemical influences of potassium on the higher plant only by shifting the potassium level of vital plants. The same fact was found with other mineral elements, therefore, this is considered as the most fundamental problem in the research of mineral nutrition.

On the other hand as to the elements such as magnesium, calcium, and some minor elements, the deficient symptoms are observed remarkably and immediately after the removal of the elements from the culture media, therefore the roles of these elements may be judged from the specific phenomena of the deficient symptoms. Potassium deficiency symptoms did not appear so drastic immediately after the elimination of this element, and varied according to the concentration of the other cations, especially nitrogen, calcium, magnesium, iron and so on (1~3). The usual nature of potassium in the plant seems to be that it can be distributed most widely and is easily movable among the other cations. In these experiments it was designed to examine the effect of potassium on the growth, yield and comparative contents of minerals in relation to the difference of the nutritional balances of magnesium and potassium.

Thus, rice plants were carefully raised by the solution culture and also in an alluvial paddy soil, then sampled at various stages of growth to investigate the problems discussed above. The authors express their hearty gratitude to Kali-Kenkyukai, for the funds of research.

Experiment and Results

1. *The growth of the rice plant by solution culture*

Rice plant seedlings (Norin 16) were transplanted late in June with the plots having the combination of five levels of environmental concentration in potassium and magnesium. Two Wagner pots were used for a plot and per pot ten plants were cultured with the nutrient solution shown in Table 1. For the first ten days the culture solution was applied at half concentration. The growth status of each plot are shown in Table 2. As to the length of the plants, the differences among each treatment were little at the early tillering stages (early July), but at the end of the tillering stage (late July), better growth was obtained in high magnesium and potassium plots, and in magnesium for the plots more than 60 ppm concentration series, the length of the plant no more increased. At this stage magnesium deficiency symptom was revealed in magnesium 0 ppm

Table 1. Composition of nutrient

Nutritional composition of solution culture

N	$(NH_4)_2SO_4$	50 ppm
P_2O_5	$(NH_4)H_2PO_4$	32
K_2O	K_2SO_4	0, 5, 10, 30, 60
MgO	$MgSO_4 \cdot 7H_2O$	0, 5, 10, 30, 60
CaO	$CaCl_2 \cdot 2H_2O$	20
Fe_2O_3	$FeCl_3 \cdot 6H_2O$	4
MnO	$MnCl_2 \cdot 4H_2O$	2

Application in soil culture

N	$(NH_4)_2SO_4$	0.3 g/pot
P_2O_5	$NaH_2PO_4 \cdot 12H_2O$	0.3
K_2O	K_2SO_4	0, 0.1, 0.4, 0.8
MgO	$MgSO_4 \cdot 7H_2O$	0, 0.1, 0.4, 0.8

Table 2. Growth status of water culture

treatment		Length of plant (cm) (Jul. 10)	Length of plant (cm) (Jul. 30)	Length of plant (cm) (Aug. 7)	Dry weight of products (g) (Aug. 7)
Mg_0	K_0	39.0	38.0	40.5	2.0
	K_5	41.5	43.0	46.0	2.8
	K_{10}	42.0	48.0	49.5	2.7
	K_{30}	52.0	57.0	48.0	3.3
	K_{60}	53.5	56.0	51.5	3.4
Mg_5	K_0	39.0	45.0	45.0	2.3
	K_5	47.5	45.0	45.0	5.0
	K_{10}	52.0	51.5	49.5	6.5
	K_{30}	50.5	58.0	48.5	7.7
	K_{60}	56.5	57.5	47.0	8.5
Mg_{10}	K_0	39.5	41.5	45.0	2.6
	K_5	46.5	43.5	45.5	4.4
	K_{10}	51.5	55.0	50.5	6.7
	K_{30}	52.0	56.0	63.5	8.2
	K_{60}	53.5	58.0	57.5	7.5
Mg_{30}	K_0	45.0	46.0	47.5	2.5
	K_5	48.0	49.5	51.0	6.0
	K_{10}	51.5	51.0	53.5	6.6
	K_{30}	52.0	57.0	62.5	7.6
	K_{60}	51.5	56.5	57.0	8.6
Mg_{60}	K_0	46.0	43.5	46.0	3.5
	K_5	46.0	44.5	46.0	6.0
	K_{10}	47.5	49.5	49.5	6.6
	K_{30}	45.5	56.0	63.5	8.7
	K_{60}	48.5	57.5	58.5	9.6

Table 3. Chlorophyll content

treatment	K_0	K_5	K_{10}	K_{30}	K_{60}
Mg_0	236	202	195	212	187
Mg_5	345	375	330	340	320
Mg_{10}	380	360	355	365	360
Mg_{30}	370	355	363	380	370
Mg_{60}	—	—	—	—	—

Leaf blades (fresh weight 3.0 g) were extracted with 85% acetone (60 ml). Chlorophyll colour density was measured by the Klett Summerson Photoelectric colorimeter.

series, namely the yellowing phenomena of the leaves from the tip, so the chlorophyll content was measured (Table 3). Higher potassium plot combined with lower magnesium level contained a less amount of chlorophyll. The manifestation of the magnesum deficiency symptom was a little different for the upper leaves and lower leaves, especially magnesium deficient upper leaves became long and slender, on the contrary the lower leaves showed short and withering tendency.

When the rice plant showed the maximum growth in top length, that is towards the first of August, the highest growth was obtained at magnesium 30 ppm and potassium 30 or 60 ppm concentration plots, and the dry weight of the plants were especially low in magnesium and potassium 0 ppm series, increasing the environmental condition of both cations to some extent, the yields rose gradually (Table 2). Heading date was generally at the last of August except for the magnesium and potassium 0 ppm series, and harvest time at the middle of October.

2. *Yields of straws and ears at the harvest time*

Straw weights at the harvest time of each treatment showed a different tendency compared with the total dry matter yield before heading, namely more than magnesium 10 ppm concentration, no more increased straw yields were observed and in some cases it rather decreased slightly, on the other hand potassium promoted the yields up to 30 ppm concentration and increased straw weight at 60 ppm concentration was hardly observed. From the above results higher environmental concentration of magnesium and potassium was required for better growth until the heading stage, however at a later stage lower concentration ranges were rather better for normal growth. The antagonism between magnesium and potassium, has long been discussed according to the results of the straw yield, but in this case the antagonism between magnesium and potassium could not be considered as a serious problem. For example in 0 ppm or 5 ppm concentration of magnesium deficient series, the tendency of the straw yields was almost similar to magnesium rich series combined with the various potassium levels, and the magnesium deficient plot with high potassium concentration was extremely low in the yields of straws (Fig. 1).

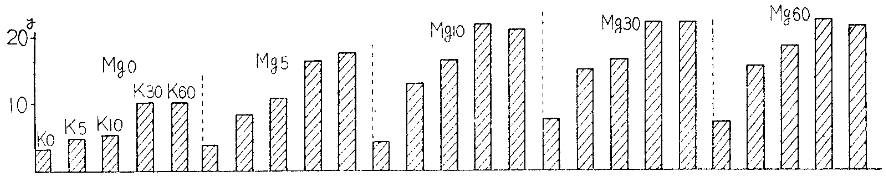

Fig. 1. Dry weight of straws at harvest time (Oct. 10, six plants)

The trends of ear yields in each plot were quite different from the tendency of the straw products, namely more than magnesium 10 ppm concentration, ear weight clearly decreased, and in the potassium series up to 30 ppm concentration yields increased rapidly, but above that concentration yields did not vary so remarkably (Fig. 2).

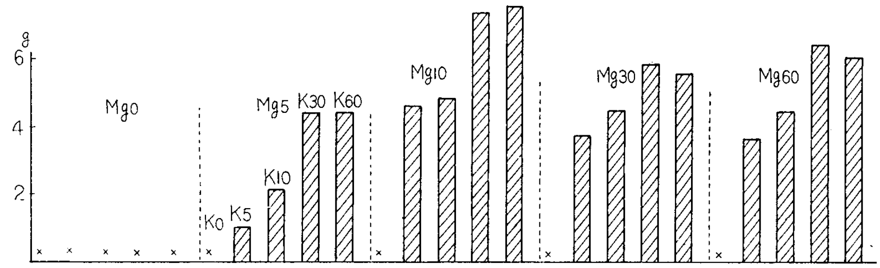

Fig. 2. Dry weight of ears (Oct. 10, six plants)

It would be difficult to conclude how the best environmental nutrition ranges on the rice plant growth and the yields from the treatmentd varied with the concentration of two cations of magnesium and potassium. Without trying the combination plots with the various levels of the other cations and anions, the balance of the nutritions or cation levels should be investigated further from the stand point of suitable dressings.

Considering the above results, the most suitable environmental concentration of magnesium and potassium varied with the growth stages, namely in the former high and in latter comparatively low concentration was found to be suitable, but high magnesium concentration resulted in lower ear yields.

3. *Mineral content in the leaf blades, leaf sheaths and ears*

Recently many investigations about the cation antagonism were made(4~8), and the antagonism between the magnesium and potassium (3) proved to be a large problem for the practical agronomy. To make clear the influences of the combination of two environmental cations levels to the mineral in the higher plant, the content of potassium, magnesium, calcium and phosphorus were determined, that is potassium and calcium were analysed by the flame photometer, phosphorus by Allen's method, and magnesium by titan yellow method. The samples were analysed at the primordial stage of ear, and at the harvest time, being divided into the leaf blades, leaf sheaths and ears.

Potassium content in the leaf blades was increased remarkably according to the rice of external potassium up to 30 ppm concentration, whereas above 30 ppm it hardly increased. In the stems and leaf sheaths, however, potassium absorption was stimulated until the potassium 60 ppm outer concentration, and it was observed that potassium was absorbed more highly in lower magnesium concentration series than in higher, and the antagonism and alteration of mineral content were conspicuous in stems and leaf sheaths than in leaf blades, and it may be also suggested that potassium was maintained at the optimum concentration in leaf blades and reserved or stored in the stems and leaf sheaths (Fig. 3).

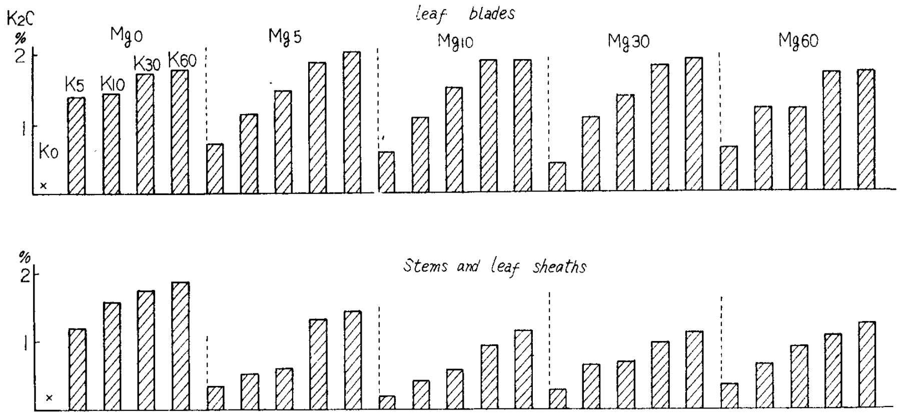

Fig. 3. Potassium content in leaf blades, stems and leaf sheaths (Aug. 7, % dry weight)

Calcium absorption was affected strongly according to the change of outer magnesium and potassium concentration, namely at the lower magnesium concentration series calcium was highly taken-in both with potassium, and at higher magnesium concentration antagonistically to potassium. Calcium content varied widely in the stems and leaf sheaths in comparison with the leaf blades (Fig. 4).

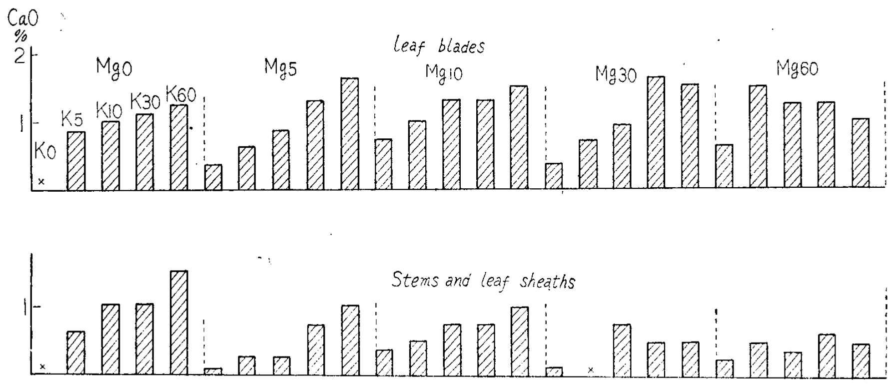

Fig. 4. Calcium content in leaf blades, stems and leaf sheaths (Aug. 7, % dry weight)

The magnesium content increased according to the elevation of magnesium concentration in the culture solution and in this respect magnesium differed from potassium. The antagonistic tendency between magnesium and potassium was hardly observed at low magnesium concentration, but more than 30 ppm magnesium acts as an antagonist to potassium. Previously it has been proved that the antagonism took place clearly under magnesium poor and potassium rich conditions. In fact the antagonism between both ions was observed under higher magnesium condition, and in case of soil culture, it could not be clearly shown that the conclusion was in accord with the case of water culture. As to the magnesium content in the parts of the rice plant, it may be concluded to be similar to potassium and calcium, that magnesium was maintained at the optimum concentration in the leaf blades, reserved or stored in stems and leaf sheaths (Fig. 5).

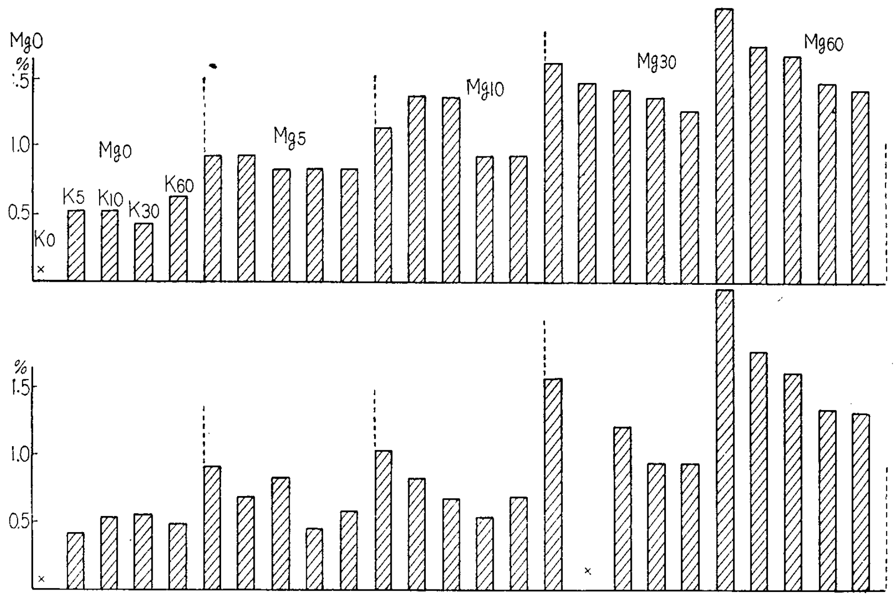

Fig. 5. Magnesium content in leaf blades, stems and leaf sheaths (Aug. 7, % dry weight)

Phosphorus absorption was scarcely influenced by the various magnesium and potassium concentrations. However it was checked weakly at higher concentration as similar to cations and phosphorus content was maintained more constant in the leaf blades than in the other parts (Fig. 6).

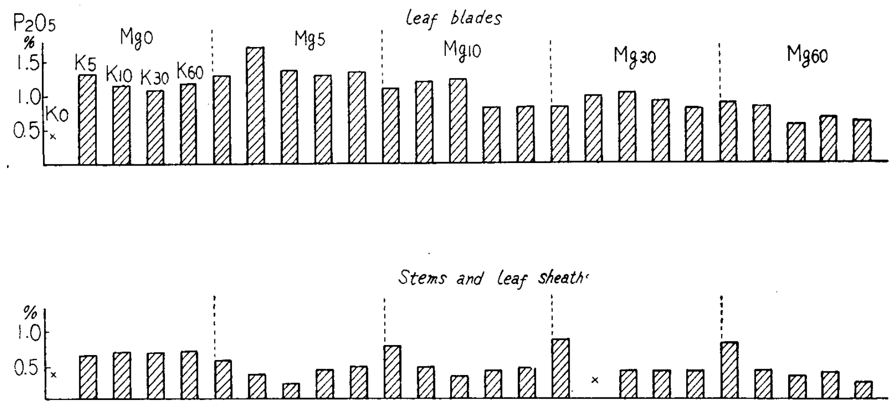

Fig. 6. Phosphorus content in leaf blades, stems and leaf sheaths (Aug. 7, % dry weight)

The tendency of each mineral content at harvest time resembled that of the primordial stage of the ear, on the contrary the difference between mineral content in the leaf blades and stems or leaf sheaths was hardly detected, it may be considered for this reason that the vital function was weakened by finishing the maturing and drying up of the leaves.

Potassium and phosphorus content in the ears was not changed by the treatments of the nutritional level, but calcium was changed a little antagonistically with potassium. Magnesium absorption on the other hand was highly related to the environmental magnesium concentration. Comparing with the magnesium content and ears yield, the latter would be depressed on account of the excess magnesium absorption (Fig. 7, Fig. 8, Table 4).

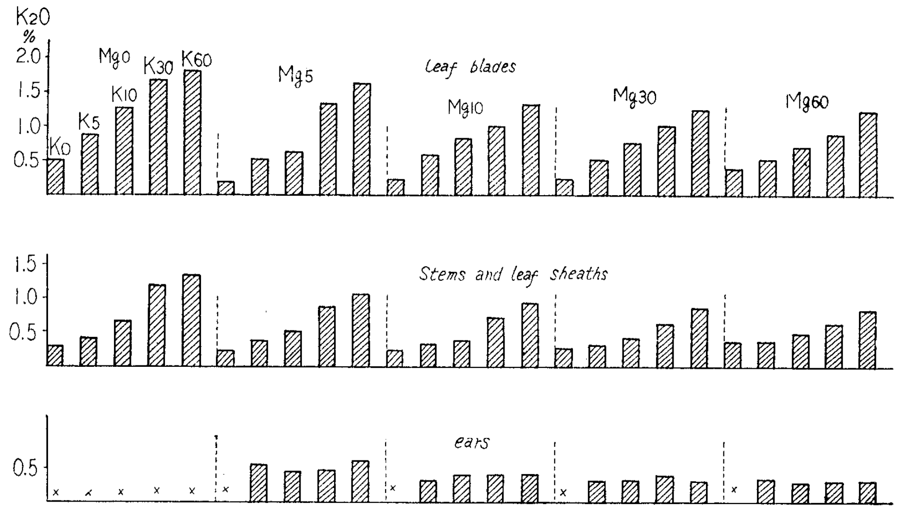

Fig. 7. Potassium content at harvest time (% dry weight)

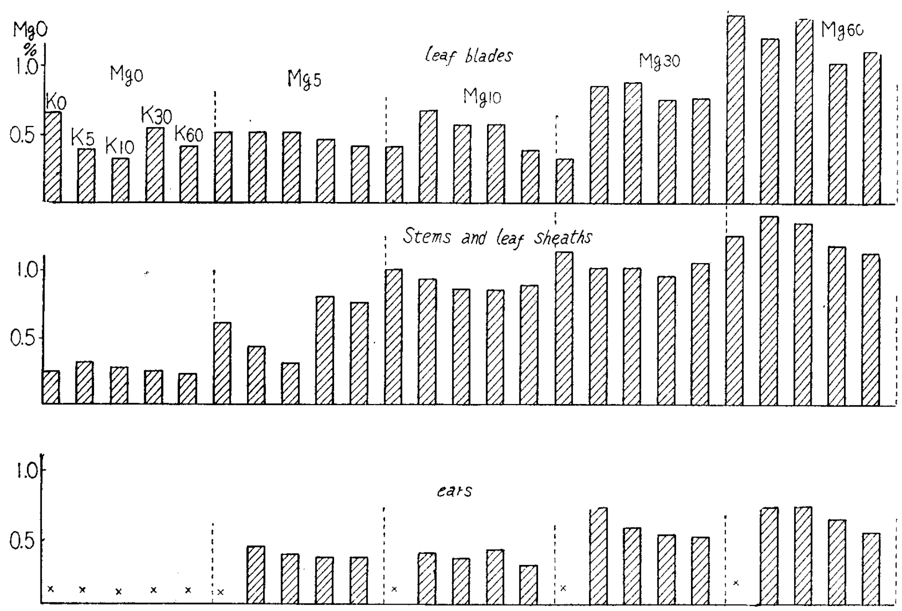

Fig. 8. Magnesium content at harvest time (% dry weight)

Table 4. Calcium and phosphorus content at harvest time

Treatment	Ca			P		
	Leaf blades	Stems and leaf sheaths	Ears	Leaf blades	Stems and leaf sheaths	Ears
Mg_0 K_0	0.30	1.25	—	0.87	0.55	—
K_5	0.95	1.55	—	0.75	0.55	—
K_{10}	1.87	1.25	—	0.75	0.50	—
K_{30}	2.20	1.88	—	0.65	0.55	—
K_{60}	3.10	1.92	—	0.73	0.45	—
Mg_5 K_0	0.30	0.63	—	0.50	0.55	—
K_5	0.65	0.60	0.90	0.60	0.40	0.27
K_{10}	0.95	1.25	0.62	0.56	0.40	0.32
K_{30}	1.55	1.87	0.62	0.50	0.43	0.30
K_{60}	3.15	2.19	0.60	0.55	0.54	0.35
Mg_{10} K_0	0.32	0.87	—	0.45	0.40	—
K_5	0.62	1.22	0.65	0.54	0.35	0.83
K_{10}	0.32	1.25	0.65	0.50	0.35	0.40
K_{30}	0.95	1.57	0.65	0.54	0.45	0.30
K_{60}	1.25	1.90	0.33	0.55	0.43	0.32
Mg_{30} K_0	0.30	0.30	—	0.45	0.50	—
K_5	0.30	0.30	1.25	0.58	0.35	0.42
K_{10}	0.93	0.90	0.95	0.55	0.37	0.35
K_{30}	1.55	1.55	0.95	0.60	0.50	0.45
K_{60}	1.70	1.70	0.65	0.55	0.48	0.35
Mg_{60} K_0	0.55	0.65	—	0.58	0.50	—
K_5	0.55	0.65	0.92	0.54	0.50	0.40
K_{10}	0.55	0.65	0.95	0.65	0.50	0.35
K_{30}	0.55	1.25	0.95	0.60	0.45	0.40
K_{60}	1.70	1.57	0.65	0.66	0.45	0.40

4. *Growth of the rice plant cultivated in the soil by treatment of various magnesium and potassium levels.*

In relation to solution culture, further investigations were made by soil culture using the alluvial paddy soil. The cultivation in the soil would be quite different from that in water, as humus and colloidal clay minerals in some soil conditions adsorb a part of the applied fertilizer and also soil microorganisms take up temporarily these elements, so mineral concentration of the soil solution did not remain so constant as in the case of the solution culture, moreover the outer conditions of the roots was also different from that of the solution culture.

The fertilizer applications were made by the following schemes as shown in Table 1, in 16 plots combined with four levels of magnesium and potassium. Four rice plant seedlings (Norin 16) were transplanted in each pot, two pots for a plot, and cultivated as usual and carefully.

As shown in Table 5 the growth status of each treatment, namely the length of plant was gradually increased according to the rise of potassium application up to 0.4 g per pot, but more than 0.4 g did not vary largely. On the contrary the effects on the length of the plants by the increasing addition of magnesium was observed up to 0.1 g application, and with higher application of magnesium,

Table 5. Growth status of soil culture

Treatment	Jul. 10		Aug. 12		
	Length of plant	No. of tillers	Length of plant	No. of tillers	Dry weight of product
Mg_0 K_0	55.0(cm)	43	70.5(cm)	38	23(g)
〃 K_1	54.5	43	72.0	43	23
〃 K_2	58.5	51	78.0	39	26
〃 K_3	56.0	51	78.5	37	27
Mg_1 K_0	53.0	45	72.0	45	22
〃 K_1	56.0	43	73.5	38	27
〃 K_2	61.5	43	79.5	36	29
〃 K_3	59.0	49	77.5	36	28
Mg_2 K_0	49.5	40	70.5	39	19
〃 K_1	56.5	40	72.0	40	25
〃 K_2	59.5	43	77.0	43	27
〃 K_3	58.0	43	76.5	40	27
Mg_3 K_0	47.5	39	66.0	40	20
〃 K_1	51.5	43	66.5	42	15
〃 K_2	57.0	45	73.5	43	25
〃 K_3	55.0	43	72.0	40	26

the growth was retarded and the length of the plants remained low. then the light brown spots of about 2 mm in diameter perhaps because of the excess magnesium absorption were observed on the leaf blades. As it drew near the later stage, the growth was more extremely depressed, and this clear phenomenon was observed particularly under the circumstance of higher magnesium and lower potassium dressing and with the increasing potassium application, this symptom reduced gradually.

No constant tendency was shown about the tillering number among the treatments. The yields in each plot at the growing stage showed the similar trends as the length of the plant, and better products were found at comparatively low magnesium and higher potassium application, which accord with the results of solution culture.

Ears and straw yields shown in Table 6 were almost similar to the results of the solution culture. In this case higher magnesium application at lower

Table 6. Yields at harvest time (Nov. 29)

Treatment		No. of ears	Dry weight of ears	Dry weight of straws
Mg_0	K_0	38	38.0	40.0
	K_1	42	34.0	39.0
	K_2	37	38.0	40.0
	K_3	36	39.0	39.0
Mg_1	K_0	43	32.5	36.5
	K_1	37	38.0	36.5
	K_2	35	38.0	39.0
	K_3	35	37.5	40.0
Mg_2	K_0	33	24.5	35.0
	K_1	39	38.5	37.0
	K_2	41	39.0	42.0
	K_3	37	34.0	42.0
Mg_3	K_0	37	14.0	25.5
	K_1	40	21.5	34.5
	K_2	40	28.5	43.0
	K_3	38	30.0	42.0

g per pot

Table 7. Minerals content at the pre-heading stage (Aug. 4)

treament		K	Ca	Mg	P	N
Mg_0	K_0	0.73	0.63	0.23	0.32	1.85
	K_1	0.85	0.63	0.23	0.34	1.85
	K_2	1.16	0.83	0.24	0.38	1.82
	K_3	1.39	0.95	0.30	0.29	1.73
Mg_1	K_0	0.71	0.70	0.28	0.35	1.83
	K_1	0.73	0.58	0.25	0.37	1.84
	K_2	1.70	1.30	0.21	0.33	1.80
	K_3	1.97	1.38	0.25	0.31	1.73
Mg_2	K_0	0.56	0.45	0.24	0.36	1.88
	K_1	0.68	0.63	0.30	0.36	1.86
	K_2	1.49	1.13	0.27	0.32	1.81
	K_3	1.85	1.38	0.26	0.27	1.75
Mg_3	K_0	0.42	0.43	0.38	0.36	1.92
	K_1	0.42	0.45	0.40	0.41	1.83
	K_2	1.18	1.00	0.33	0.29	1.76
	K_3	1.33	0.88	0.31	0.31	1.75

% dry weight

potassium level caused the decrease of both ears and straw yields to an extent, so it may be concluded that excess magnesium which might act as an antagonist to the potassium, suppressed the rice plant growth and the maturing. Individual mineral content at growing and harvest time also is similar to the results of solution cluture, as shown in Table 7, which shows clearly the influence by the treatment.

As this experiment was planned to know the nutritional specificity and the application method in both solution and soil culture, almost similar results were obtained.

Summary

1. Rice plants (Norin 16) were cultivated with the combination of the several levels of the potassium and magnesium concentration, using 1/5000 a Wagner pot in which nutritional solution or alluvial soil were filled. The growth status, yields and mineral content of the leaf blades, leaf sheaths, and ears were examined from the stand point of the cation balance of mineral or dressing method, therefore the following results were obtained.

2. The most suitable concentration ranges for the rice plant growth differed according to the growth stages, namely at the growing up stage the higher concentration was suitable, but at the heading stage the lower was suitable, and this tendency was observed remarkably with respect to magnesium.

3. The antagonism between potassium and magnesium seems to be remarkable at the higher magnesium concentration.

4. Mineral content such as potassium, calcium magnesium and phosphorus varied strikingly in the leaf sheaths and stems compared with the leaf blades, by the change treatments of two nutritional levels. From this fact it may be suggested that the mineral content of the leaf maintained the optimum by leaf sheaths and stems, that is, leaf sheaths and stems act as reservoir of these elements.

5. Potassium content of the ears was hardly varied by the outer conditions, on the contrary magnesium content varied widely. Sometimes because of high magnesium absorption, the ears yields decreased.

6. Calcium absorption in leaf blades, stems and ears were influenced by the surrounding potassium and magnesium treatments, and were promoted by potassium at the lower magnesium level.

7. Phosphorus absorption was scarcely varied by the environmental magnesium and potassium treatment.

8. Results of the soil culture using the alluvial paddy soil were almost in accordance with those of solution culture.

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