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Growth Response of Several Forages to Potassium Level in Water Culture

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칼륨水準에 따른 數種 牧草의 生育反應

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摘 要

칼륨施用水準과 生育段階 및 草種에 따른 牧草의 生育과 칼륨 및 마그네슘含量의 差異를 알아보기 위해 두가지의 水耕栽培實驗을 실시했다.

먼저 生育段階의 진행에 따른 牧草의 收量 및 無機物含量의 變化를 禾本科牧草 3種類를 사용하여, 牧草가 發芽한 후 15日부터 55日까지 조사했는데 그 結果는 (1) 發芽後 25日경 牧草의 生草收量 및 칼슘含量이 빠르게 增加했으며 (2) 이탈리안 라이그라스에서 칼륨含量이 가장 높고 마그네슘含量이 낮았으며, 톨 페스큐는 그와 반대였고, 오차드그라스의 두 無機物含量은 이탈리안 라이그라스와 톨 페스큐의 중간이었다 (실험 1). 다음으로 칼륨水準에 따른 生育反應의 變化를 알아보기 위해 禾本科牧草와 荳科牧草를 각각 3種類씩 이용하여 5ppm에서 1,000ppm까지의 溶液中 칼륨(K_2O)濃度에서, 발아후 30日까지 시험재배한 結果는 (3) 용액중 칼륨水準의 증가에 따라 牧草의 칼륨含量은 增加를, 마그네슘含量은 減少를 보였다. 칼륨함량의 增加는 오차드그라스와 이탈리안 라이그라스에서 그 變化 範圍가 넓었으나 알팔파와 톨 페스큐에서는 좁았고, 마그네슘含量의 減少에서 이탈리안 라이그라스와 오차드그라스는 칼륨水準이 25~50ppm인 용액에서 감소가 뚜렷했으나 荳科牧草와 톨 페스큐는 1,000ppm까지 漸進的인 감소를 보였다. (4) 용액중 칼륨水準이 5ppm에서 25ppm 또는 50ppm으로 높아질 때 牧草의 生草收量, 水分含量 및 칼륨含量의 증가가 뚜렷했으며 (5) 牧草內의 水分을 기준으로 계산된 칼륨濃度(牧草水分中 칼륨濃度)는, 용액중 칼륨수준이 5ppm에서 50ppm으로 높아질 때 禾本科牧草에서 이탈리안 라이그라스는 2.6배로 오차드그라스는 2.5배로 큰 증가를 보였으나, 荳科牧草는 1,000ppm 수준까지 점진적으로 증가했다.

以上의 結果로부터, 放牧地에 있어서도 生育時期와 土壤中 칼륨水準의 두가지의 要因이 동시에 작용할 때, 牧草의 水分含量, 마그네슘含量 및 牧草水分中 칼륨濃度의 급격한 變化를 가져오게 되는데 이러한 변화를 겪고 있는 牧草(특히 禾本科인 이탈리안 라이그라스와 오차드그라스)의 水分은, 放牧牛에 대해 毒性物質로 作用하여 그라스테타니(低마그네슘血症)를 일으킬 수 있는 것으로 생각되어졌다.

I. INTRODUCTION

Potassium behavior in grazing pasture and meadow was investigated in the previous report (Kim *et al.*, 1988 a) and it was known from the results that the response of forage to potassium appeared more clearly in simplified condition such as meadow than the complicated system as grazing pasture. But it was difficult to know the real response of forage to the element in both meadow and grazing pasture,

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because there appeared many plants of different growing stages in different populations season by season (Bates, 1971). And it was observed that there are seasonal and monthly changes of potassium and magnesium contents of forages grown in grazing pasture and in meadow (Metson *et al.*, 1966; Metson and Saunders, 1978).

Therefore, it was required to investigate the influence of potassium fertilization on the plant growth and mineral contents of forages under a controlled condition such as water culture. Solution culture techniques are often used to simulate situations which occur when plants are growing in the field, though there might be a difference between performance on the model experimental system and on soil media (Asher and Edwards, 1983). Response of orchardgrass to potassium in water culture was investigated previously (Kim *et al.*, 1987).

In the present report, two experiments were carried out with the purposes of knowing the differences of response among forage species to potassium level in culture solution and investigating possible relation of the responses with occurrence of grass tetany (hypomagnesaemic) on grazing pasture (Grunes *et al.*, 1970;Underwood, 1981). It is known that most of potassium is water soluble (Kim *et al.*, 1990 b), so K concentration of forage on a tissue water basis (Sugiyama *et al.*, 1985) might be a useful term for the purposes of the present research.

II. MATERIALS AND METHODS

1. Five harvests with three *gramineous* forages on a potassium(K) level (Experiment 1)

These experiments were carried out on the Farm of Nagoya University, which is situated in the central part of Japan.

Two large plastic containers (width, 50 X 150cm; depth, 25cm; capacity, 180 liters) were used for the first water culture experiment. The composition of the basal media was NH_4NO_3 95.3mg, $NH_4H_2PO_4$ 126.5mg, $Ca(NO_3)_2$ 146.4mg, $CaCl_2 \cdot 2H_2O$ 97.8mg, $MgSO_4 \cdot 7H_2O$ 229.2mg and NaEDTA. Fe 13.1mg/liter. Potassium level of the culture was made to 100 ppm by applying K_2SO_4 to the container. Tap water containing 3.6-4.2ppm K_2O was used for the culture solution and for the supplement of water loss through transevaporation during the growth period of the forage. After the culture solution was prepared, a formed styrol plate (50 X 150cm, 3cm depth) with 18 drilled holes (8cm in diameter) was floated in each container. A half gram each of orchardgrass (*Dactylis glomerata* Linn. var. Aonami), Italian ryegrass (*Lolium multiflorum* Lamark var. Mass;4n) and tall fescue (*Festuca arundinacea* Schreb. var. Ky 31) seeds were sown in a plastic cup filled with vermiculite (8 cm in diameter).

Water culture was carried out under an aerated condition in a glass-house from April 15 to June 10, 1985. The samplings of the forage were made 5 times at intervals of 10 days from May 1. The renewal of culture solution was not performed throughout the experimental period, because the total amount of minerals in each container was markedly larger than that absorbed by the forages. At harvest, the forages were cut 3cm above the upper edge of the forages. The residual part containing the 3cm stubble was regarded as the root (underground) parts.

2. One harvest with six forages under different K levels (Experiment 2)

Six large plastic containers (capacity, 180 liters) were used for the second water culture experiment. Potassium(K_2O)' levels in the culture solution were kept at 5, 25, 50, 100, 300 and 1000 ppm by applying K_2SO_4 to each container. The forage species were Italian ryegrass, orchardgrass, tall fescue, alfalfa (*Medicago sativa* Linn.), red clover (*Trifolium pratense* Linn.) and white clover (*Trifolium repens* Linn.). A half gram each of *gramineous* forage (Italian ryegrass, orchardgrass and tall fescue) and 0.2 gram each of *leguminous* forage (alfalfa, red clover and white clover) seeds were sown in a piastic cup filled with ve-

Table 1. Fresh weight of top and root parts of 3 *gramineous* forages grown on water culture[1]

(g FW/pot)

Forage species	Plant part	Days after germination 15	25	35	45	55
Italian ryegrass	Top	38[2]	172	512	635	963
	Root	12	43	92	205	582
	Top+Root	50	215	604	840	1,545
Orchardgrass	Top	12.0	77	169	248	292
	Root	5.5	21	41	149	242
	Top+Root	17.5	98	210	397	534
Tall fescue	Top	1.2	9.5	32.0	44	47
	Root	0.9	3.7	7.0	24	62
	Top+Root	2.1	13.2	39.0	68	109

1) Mean value of 3 replicates
2) Mean value of 2 replicates.

rmiculite (8cm in diameter). Immediately after the root tip reached the bottom of the cup, the cup was firmly inserted into each of the 3 holes in each styrol plate. Water culture experiment was carried out from October 1 to 30, 1985, and supplementation of water loss were done at 7day intervals.

Analyses of water and mineral contents of forage; Forage samples were weighed for fresh yield, and oven-dried at 85 C for the calculation of water content, then milled for mineral contents of forages. Determination of mineral contents of forages were carried out by flame photometry for K, and atomic absorption spectrophotometry for magnesium (Mg). And K concentration of forage on a tissue water basis was calculated as follows;(K content) x (Dry matter content)/(Water content) of the forages.

Statistical analyses; Comparisons among means of treatment were performed by using both the analysis of variance and Duncan's multiple range test at 5% significance level (Cho and Lee, 1979).

III. RESULTS AND DISCUSSION

1. Time course of growth, K and Mg contents of the *gramineous* forage (Experiment 1)

Table 1 shows the fresh yield of top and root parts of the three *gramineous* forages grown under wa-

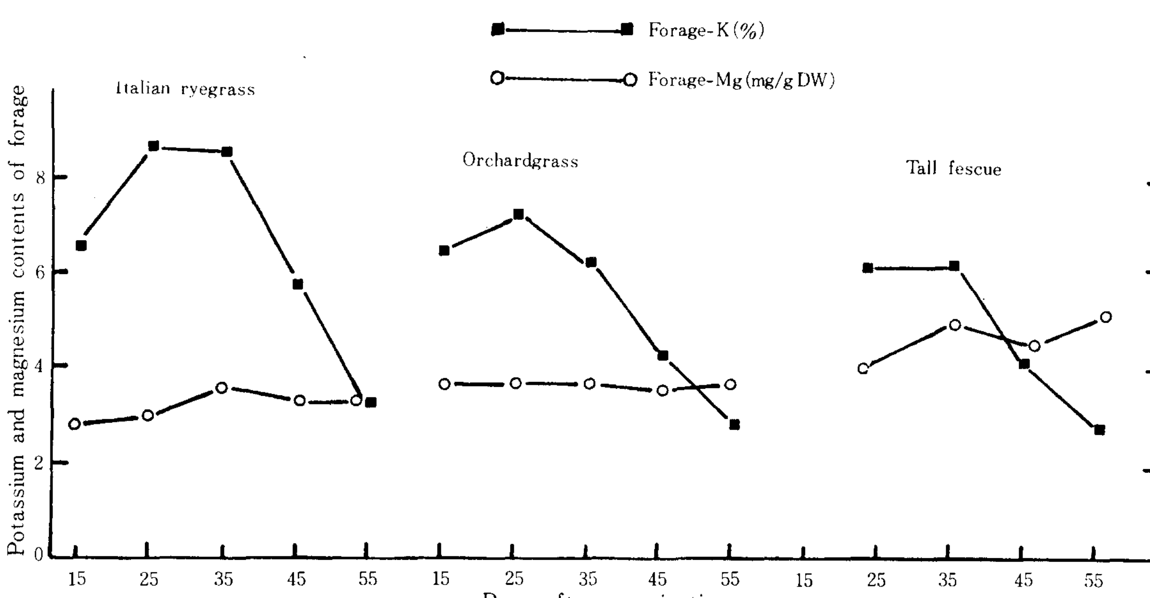

Fig. 1. Time course of potassium and magnesium contents of 3 *gramineous* forages grown on water culture.

Note ; mean value of 3 replicates.

ter culture condition. The increasing tendency of forage yield remained strong up to 35 days after germination on all the forage species. Within species there were significant differences of fresh yield, and Italian ryegrass was the highest and tall fescue was the lowest in the fresh yields of top and root throughout the experimental period. At 25 days after germination, fresh weight of top part as well as the sum of top and root parts of the forages increased significantly on a basis of the ratio between the weights at the present and the previous sampling date.

Figure 1 shows the time course of K and Mg contents of the *gramineous* forages grown on water culture. The K and Mg contents of tall fescue at 15 days after germination were not determined because of little forage yield. Potassium contents of the three forage species reached maximum at 25 days after germination, and then decreased gradually to less than a half of those at 15 or 25 days. But Mg content did not vary with time, although increasing tendencies were observed till 35 days after germination on Italian ryegrass and tall fescue. Italian ryegrass was the highest in K content but the lowest in Mg content among the three forages, while tall fescue showed the opposite result to it till 35 days after germination. Orchardgrass was intermediate of the two forage species. And this tendency among the three forages was similar to the results from the grazing pasture and meadow experiment (Kim *et al.*, 1990 a).

These results of Table 1 and Figure 1 Showed that both fresh yield and K content of the forages increased significantly at 25 days after germination and then, K content decreased significantly while fresh yield increased in a small extents. Though Mg content did not vary significantly, it increased at later stage of this experiment. At present, it is necessary to investigate in detail the changes of K, Mg contents and fresh yield of forages on such a critical growing period in Experiment 1. Therefore, Experiment 2 was carried out under the condition of different K levels and forages were harvested at the growing period of 30 days after germination.

2. Effects of K on the fresh yield and water, K and Mg contents of the forage (Experiment 2)

Table 2 shows the effect of K level on the fresh yield and water content of the top part of the six forages grown on water culture condition. Though no determination was made at 0 ppm K_2O, fresh yield of the forages were significantly increased with the increase of the application levels of K up to 25 or 50ppm. Being similar to the result from orchardgrass experiment (Kim *et al.*, 1987), Further application over 300ppm was not effective in the present experiment, either. That is, application of K_2O over 300 ppm retarded the fresh yield of orchardgrass, tall fescue and alfalfa. Water contents of the six forages were significantly increased at the level of 25ppm. However, in higher level than 100ppm, the content of the forages tended to decrease again with the increase of K level in the culture solution. Though the correlation coefficients were not shown in the table, changes of water content of the forages except Italian ryegrass have close relations with those of fresh yield ($P<0.05$). The decreases of water content in higher K levels were similar to the result obtained by Jungk (1970) who experimented with petunia plant (*petunia multiflora*). Water content differed among forage species, and Italian ryegrass was the highest and showed 91.5-92.3%.

Table 3 shows the effect of K level in the culture solution on K and Mg contents of the forages. The mineral contents of the *gramineous* forages at the K_2O level of 100ppm were similar to the contents of the same forage species at 25-35 days after germination of Experiment 1 (Fig. 1). Though, tall fescue and alfalfa contained more than 3% at the K_2O level of 5ppm, the other forages being lowest in applied level of K and in yield contained K less than 3% of their dry weight. The results suggested that the forages should contain more than 3% of K for their favorable growth. The K contents of forages generally increased with the increase of K level in culture solu-

Table 2. Effect of potassium level on the fresh yield and water content of the six forages grown on water culture[1,2)]

(g FW/pot, %)[3)]

Species	Items	K_2O level in solution (ppm)					
		5	25	50	100	300	1000
Italian ryegrass	Fresh yield	80 ± 4^{a}	99 ± 3^{ab}	108 ± 4^{b}	108 ± 18^{b}	101 ± 22^{ab}	112 ± 4^{b}
	Water content	91.5 ± 0.3^{a}	92.1 ± 0.1^{bcd}	92.3 ± 0.2^{d}	92.2 ± 0.1^{cd}	91.8 ± 0.3^{abc}	91.7 ± 0.1^{ab}
Orchardgrass	Fresh yield	28 ± 4^{a}	38 ± 8^{ab}	42 ± 1^{b}	43 ± 8^{b}	26 ± 10^{a}	29 ± 1^{a} [4]
	Water content	87.4 ± 0.2^{a}	89.5 ± 0.3^{cd}	89.2 ± 0.3^{c}	89.9 ± 0.1^{d}	89.3 ± 0.5^{c}	88.5 ± 0.3^{b}
Tall fescue	Fresh yield	35 ± 6^{a}	45 ± 4^{bc}	48 ± 3^{bc}	50 ± 2^{c}	42 ± 6^{ab}	41 ± 2^{ab}
	Water content	89.6 ± 0.1^{a}	90.4 ± 0.3^{b}	89.9 ± 0.1^{ab}	90.2 ± 0.0^{b}	90.0 ± 0.5^{ab}	89.9 ± 0.3^{ab}
Alfalfa	Fresh yield	26 ± 7^{a}	36 ± 4^{ab}	40 ± 6^{b}	43 ± 3^{b}	45 ± 6^{b}	30 ± 6^{a} [4]
	Water content	88.6 ± 0.7^{a}	90.4 ± 0.2^{c}	90.0 ± 0.1^{bc}	89.9 ± 0.1^{bc}	89.5 ± 0.1^{b}	88.2 ± 0.2^{a}
Red clover	Fresh yield	18 ± 8^{a}	28 ± 1^{b}	32 ± 4^{b}	31 ± 2^{b}	32 ± 4^{b}	33 ± 4^{b}
	Water content	87.1 ± 1.0^{a}	90.4 ± 0.4^{b}	89.9 ± 0.2^{b}	90.1 ± 0.2^{b}	89.7 ± 0.3^{b}	89.6 ± 0.2^{b}
White clover	Fresh yield	28 ± 3^{a}	42 ± 6^{b}	44 ± 1^{b}	48 ± 4^{b}	43 ± 14^{b}	47 ± 4^{b}
	Water content	89.0 ± 0.3^{a}	91.0 ± 0.2^{bc}	91.4 ± 0.4^{cd}	91.6 ± 0.2^{d}	91.1 ± 0.2^{bcd}	90.8 ± 0.4^{b}

1) Mean ± S. D. of 3 replicates.
2) Values in the same row with the same letter are not significantly different ($P>0.05$).
3) FW ; fresh weight. 4) Mean ± S. D. of 2 replicates.

tion. And K contents of the sixs forages increased significantly at lower levels of K_2O (5ppm to 50 ppm), where fresh yield increased significantly (Table 2). The highest K contents of Italian ryegrass and orchardgrass were more than 3 times (2.9 to 9.3 % and 2.2 to 7.7%, respectively) of the lowest values. The K content of alfalfa increased in the narrowest range (from 3.9 to 6.8%) and that of tall fescue in secondary narrow range (from 3.2 to 7.6%) among the forages. From the results, it was clear that response of forage K content to K level differed among the forage species.

In all the species, Mg content became lower with the increase of K in the culture solution, and the decrease was significant in the range from 5 to 25ppm or 50ppm K_2O, where K content of the forages increased continuously. Though the coefficients were not shown in the Table, there were significantly negative relations between K and Mg contents on all the forage species ($P<0.01$). In higher K levels than 50ppm, however, significant decreases of Mg content were not shown in Italian ryegrass and orchardgrass, while the content of the *leguminous* forages and tall fescue decreased. The Mg contents of red clover, tall fescue and alfalfa decreased in wider range; 7.8 to 2.7 mg for red clover, 7.0 to 4.8mg for tall fescue and 3.5 to 1.7mg/g DW for alfalfa, respectively.

When the fresh yield of forage was still in a small quantity, the K content of the forage might not increase even at high level of K in culture solution (Fig. 1). And if the K level in culture solution in Experiment 1 was 5ppm or 25ppm, rapid increase of fresh yield of forage might not occur even at 25 days after germination. Therefore, the extent of the increases of fresh yield or K content of forage depended both on the growing period (Fig. 1) and on the K level in culture solution (Table 3). And abrupt changes of growth response to K level in the range from 5ppm to 25ppm or 50ppm (Table 2, Table 3) were similar to those on a grazing pasture, where grass tetany (hypomagnesaemic) occurred during period of rapid plant growth, rapid increases of mois-

Table 3. Effect of potassium level on magnesium and potassium contents of the six forages grown on water culture[1,2)]

(mg Mg/g DW, mg K/g DW)[3)]

Species	Element	K_2O level in solution (ppm)					
		5	25	50	100	300	1000
Italian ryegrass	Plant-Mg	4.0±0.2[a]	3.6±0.5[a]	3.1±0.0[b]	3.1±0.2[b]	3.2±0.1[b]	2.8±0.1[b]
	Plant-K	29±2[a]	56±4[b]	83±4[c]	85±2[c]	90±3[d]	93±2[d]
Orchardgrass	Plant-Mg	4.5±0.4[a]	3.6±0.3[b]	3.5±0.2[b]	3.5±0.2[b]	3.6±0.1[b]	3.4±0.1[b 4)]
	Plant-K	22±2[a]	45±4[b]	67±3[c]	79±7[e]	70±1[cd]	77±0[de 4)]
Tall fescue	Plant-Mg	7.0±0.3[a]	5.4±0.2[b]	5.0±0.1[bcd]	4.9±0.1[cd]	5.3±0.4[bc]	4.8±0.1[d]
	Plant-K	32±3[a]	53±1[b]	65±1[c]	68±2[c]	68±2[c]	76±3[d]
Alfalfa	Plant-Mg	3.5±0.3[a]	2.5±0.0[b]	2.4±0.1[bc]	2.2±0.1[c]	2.1±0.2[c]	1.7±0.0[d]
	Plant-K	39±4[a]	58±4[b]	65±3[c]	67±5[c]	68±2[c]	68±2[c 4)]
Red clover	Plant-Mg	7.8±0.7[a]	4.6±0.2[b]	4.3±0.2[bc]	3.9±0.2[cd]	3.6±0.1[d]	2.7±0.1[e]
	Plant-K	27±2[a]	48±0[b]	57±2[c]	61±0[c]	67±3[d]	73±6[e]
White clover	Plant-Mg	3.2±0.2[a]	3.0±0.2[a]	2.8±0.0[b]	2.8±0.1[b]	2.6±0.1[b]	2.1±0.1[c]
	Plant-K	25±1[a]	52±3[b]	59±1[c]	66±0[d]	64±1[d]	71±2[e]

1) Mean ± S.D. of 3 replicates.
2) Values in the same row with the same letter are not significantly different ($P>0.05$).
3) DW; dry weight.
4) Mean ± S.D. of 2 replicates.

ture and K contents of winter wheat (*Triticum aestivum* Linn.) and rye (*Secale cereasle* Linn.) (Bohmanm *et al.*, 1983).

Figure 2 shows the relationships between K level in culture solution and K concentration of several forages on a tissue water basis. Because the K concentration (tissue water) was calculated from the values of K content on a dry matter basis (Table 3) and water content of the forages (Table 2), there were significantly positive relations between the K concentration (Tissue water) and K content of the forages ($P<0.001$). And the K concentration increased with the increase of the K_2O level.

The pattern of K concentration (tissue water) with the K_2O level was different among forage species. The K concentration of *gramineous* forages increased rapidly in lower K_2O levels than 100ppm. And the K concentration of forage at 50ppm level was higher than that at 5ppm level, especially for Italian ryegrass and orchardgrass with the value of 2.6times and 2.5times, respectively. However, the K concentration of *leguminous* forages increased gradually up to the level of 1000ppm. And the ratio between the K concentrations at 5ppm and 50ppm level was 1.6 for red clover and 1.5 for alfalfa, respectively.

Kim *et al.* (1988 b) reported that the value of subtracting urinary K excretion from K intake (K intake-Urinary K) had a significantly negative relation with serum Mg concentration in goats, while the value of K intake itself did not have any relation with serum Mg concentration. From the previous animal experiment, it is suggested that the increase of the (K intake-Urinary K) in ruminants depends upon such a rapid change of the K concentration (tissue water). Growth response to K level of *gramineous* forages at such a growing period as 25 days after germination (Fig. 1) will be more significant with rapid changes of Mg content and K concentration (Tissue water) as shown in the ranges of 5ppm to 50ppm (Table 3, Fig. 2). If such critical conditions occurred simultaneously to forages on a grazing pasture, plant water especially in Italian ryegrass and orchardgrass can function as toxic material to grazing ruminants, possible with the decrease of serum Mg concentration. Therefore, it is considered that K fertilization in the spring season to *gramineous* forages have to be limited for preventing from the rapid increase of the K concentration (tissue water) of the forages. Furthermore, it is necessary to investigate the change of K concentration (tissue water) of the forages grown under the condition of meadow or grazing pasture.

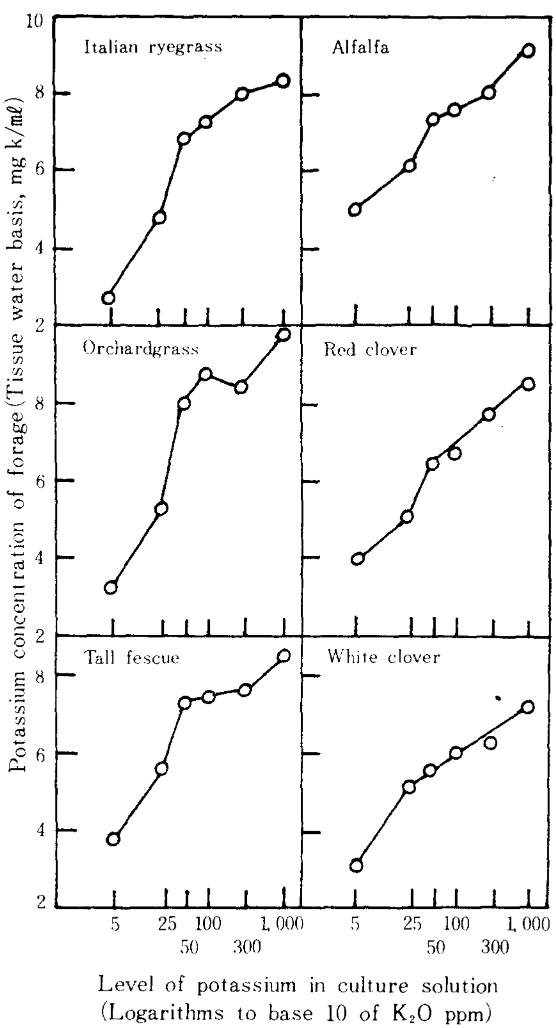

Fig. 2. Relationships between potassium level in culture solution and potassium concen tration (mg/ml tissue water) of several forages.

In conclusion, (1) growth response of forages to K level were different among growing periods, (2) growth respnse of *gramineous* forages to K level were different from that of *leguminous* forages. That is, on Italian ryegrass and orchardgrass the K concentration (tissue water) increased rapidly and Mg content of the forages decreased in comparatively lower K levels (ranges of 5ppm-50ppm) in culture solution. On the contrary, the K concentration (tisue water) of *leguminous* forages increased gradually up to the highest K level (1000ppm).

Ⅳ. SUMMARY

In the present report, two experiments were carried out with the purposes of knowing the differences of response among forage species to growing period and potassium level in culture solution, and investigating possible relation of the responses with occurence of grass tetany on grazing pasture.

The results were as follows; (1) At 25 days after germination, fresh weight of top part as well as the sum of top and root parts of the forages increased rapidly. (2) Italian ryegrass was the highest in potassium (K) content but the lowest in magnesium(Mg) content among the three *gramineous* forages, while tall fescue showed the opposite result to it. And orchardgrass was intermediate of the two forage species (Experiment 1). (3) The K contents of forages generally increased, while Mg content became lower with the increase of K level in culture solution. The highest K contents of Italian ryegrass and orchardgrass were more than 3 times of the lowest values. The K contents of alfalfa and tall fescue increased in the narrower range. The decreases of Mg content of Italian ryegrass and orchardgrass were significant in the ranges of 5ppm to 25 or 50ppm K_2O, while the content of the *leguminous* forages and tall fescue decreased up to 1000 level. (4) Fresh yield, water content and K content of the forages were significantly increased with the increase of K_2O application levels up to 25 or 50ppm. (5) The K concentration of forage on a tissue water basis was higher at

50ppm than that at 5ppm K_2O level, especially for Italian ryegrass and orchardgrass with the value of 2.6times and 2.5times, respectively. However, the K concentration (tissue water) of *leguminous* forages increased gradually up to the level of 1000ppm (Experiment 2).

It is suggested from the results that rapid changes of water content, Mg content and K concentration (tissue water) may occur to forage on a grazing pasture, when both growing period and K level in the soil affect the changes simultaneously. Under such conditions, plant water especially in Italian ryegrass and orchardgrass can function as toxic material to grazing ruminants.

V. REFERENCES

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