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The Early Growth in Sorghum Plant under Combined Treatments of Soil Moisture and Calcium Phosphate Application

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Introduction

Phosphorus as well as nitrogen and potassium is essential to normal growth of plant[9]. While the relationship between the amount of phosphorus application and crop growth has been discussed in a lot of reports[1,5,8], it has become clear that the quantitative response of crop growth to the amount of phosphorus application is dependent on the kind of crop[1], and on edaphic factors, such as P-fixing capacity and soil pH, *etc.*[8].

On the other hand, the author pointed out in the previous paper[11] that the quantitative relationship between the amount of ammonium sulfate application and the growth increment in the young sorghum plants varied considerably, depending on soil moisture content, and that the influences of the combined treatments of soil moisture and ammonium sulfate application upon the early growth in sorghum plants were noted to be consisting not only of the independent effects of soil moisture and ammonium sulfate application but also of the interactive effect of those two factors.

"How do the combined conditions of soil moisture and phosphatic fertilizer application affect crop growth ? " In order to get an answer to this question, the present experiment was carried out. And, the quantitative relationships between the soil moisture ratio and the amount of calcium phosphate application, and the early growth increment in sorghum plants were researched. The effects of soil moisture and calcium phosphate application upon evapotranspiration, transpiration and water use efficiency were also discussed.

Materials and Methods

The experiment was carried out in the vinyl plastic hothouse in the Experimental Farm of the Faculty of Agriculture, Kagoshima University, from 20 May to 18 June, 1987. Forty eight grains of the sorghum (*Sorghum bicolor* (L.) MOENCH, cv. Sorghum-Sudan Hybrid) were sown, on 20 May, in 13 litter seedling culture boxes filled with a uniform soil of 8.34 kg of dried soil that was passed through a sieve of 5 mm across.

At the beginning of the treatments (29 May), the soil moisture ratio in each seedling culture box was kept in about 20%. Twenty five treatments were imposed on the plants. The entire amounts of ammonium nitrate, calcium phosphate and potassium chloride were applied as basal dressing on 29 May. Although ammonium nitrate and potassium chloride were applied at 0.84 g/pot of N_2 and K_2O basis in all the treatments, the amount of calcium phosphate application was parceled out into the five steps, that is, 0, 0.82, 1.64, 3.28 and 6.56 g/pot of calcium dihydrogenphosphate monohydrate

$(Ca(H_2PO_4)_2H_2O)$, in accordance with those treatments. At the same time, 10g/pot of calcium carbonate was applied in all the treatments. The soil moisture treatments were also parceled out into the five steps, that is, 16, 24, 32, 40, and 48%. Soil moisture control was carried out by a gravimetric method, and the amount of water supplied in order to keep the soil moisture condition constant was sprinkled on the soil surface every day. However, because the soil moisture conditions changed gradually with the increases in evapotranspiration and plant weight, the soil moisture ratio used in this paper was the mean value noted during the treatments. The outline of treatments used is shown in Table 1.

On 18 June, 20 days after the beginning of the treatments, forty eight plants with no applications were harvested from each plot. These plants were separated into leaf blades, leaf sheaths and culms, and roots, and were dried at 80℃ for 72 hours to get dry weight.

Evapotranspiration in each plot was assessed by accumulating the total amount of water supplied during the treatments and the increased total fresh weight.

Table 1. Outline of the experiment.

f g	A		B		C		D		E	
1	14.0	0	11.2	0.82	11.1	1.64	14.3	3.28	14.1	6.56
2	20.1	0	19.0	0.82	19.0	1.64	19.0	3.28	18.5	6.56
3	25.7	0	25.6	0.82	25.4	1.64	24.9	3.28	24.5	6.56
4	32.9	0	32.1	0.82	31.9	1.64	31.4	3.28	30.5	6.56
5	39.9	0	39.2	0.82	38.4	1.64	38.3	3.28	37.3	6.56

Note : f and g indicate the mean soil moisture ratio (%) during the treatments and the amount of calcium phosphate application (g/pot), respectively.

Results

1. Relationships between growth increment, and the soil moisture ratio and the amount of calcium phosphate application

Fig. 1 shows the relationship between the soil moisture ratio and the total dry matter weight. Although the total dry matter weight tended to increase hyperbolically with an increase in the soil moisture ratio in all the calcium phosphate application plots, the promotive effect of soil moisture-increase upon the increased total dry matter weight increased considerably, depending on the amount of calcium phosphate application. The relationship of this kind was also observed in both top and root dry weights, although the promotive effect of soil moisture-increase was more conspicuous in the top dry weight than in the root dry weight. The ratio of top to root dry weight (T/R ratio) tended to increase with an increase in the soil moisture ratio (Fig.2).

The relationship between the amount of calcium phosphate application and total dry matter weight is shown in Fig.3. The result showed that the total dry matter weight increased with an increase in the soil moisture ratio, it also showed that the total dry matter weight tended to increase hyperbolically with an increase in the amount of calcium phosphate application, though the calcium phosphate application under dry condition less than 20% in soil moisture ratio increased the total dry matter weight a little. The relationship of this kind was also observed in the relationship between the amount of calcium phosphate application and top dry weight. On the other hand, the response of root

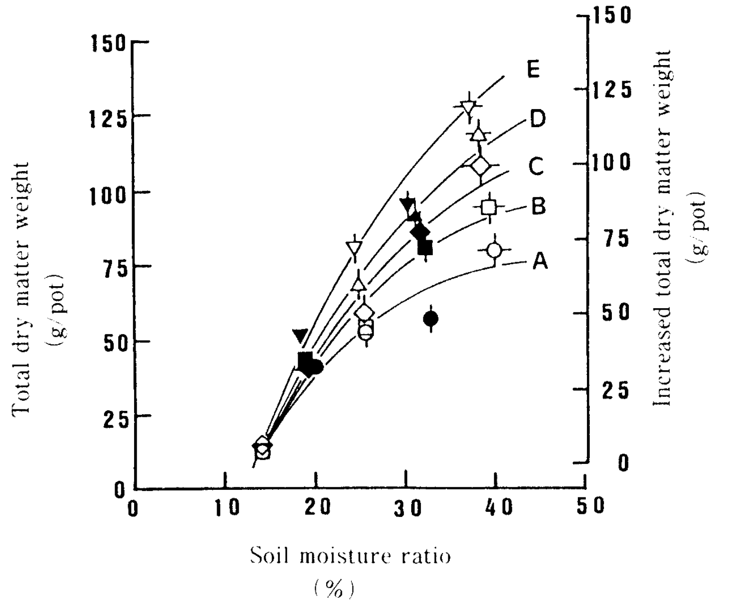

Fig. 1. Relationship between the soil moisture ratio and increased total dry matter weight.
○, ●, ○, ● and -○- indicate that the amount of calcium phosphate application and the mean soil moisture ratio during the treatments were 0 g/pot, and 14.0, 20.1, 25.7, 32.9 and 39.9%, respectively. □, ■, □, ■ and -□- indicate that the amount of calcium phosphate application and the mean soil moisture ratio during the treatments were 0.82 g/pot, and 14.2, 19.0, 25.6, 32.1 and 39.2%, respectively. ◇, ◆, ◇, ◆ and -◇- indicate that the amount of calcium phosphate application and the mean soil moisture ratio during the treatments were 1.64 g/pot, and 14.1, 19.0, 25.4, 31.9 and 38.4%, respectively. △, ▲, △, ▲ and △ indicate that the amount of calcium phosphate application and the mean soil moisture ratio during the treatments were 3.28 g/pot, and 14.3, 19.0, 24.9, 31.4 and 38.3%, respectively. ▽, ▼, ▽, ▼ and ▽ indicate that the amount of calcium phosphate application and the mean soil moisture ratio during the treatments were 6.56 g/pot, and 14.1, 18.5, 24.5, 30.5 and 37.3%, respectively. A, B, C, D and E are the same as those in Table 1.

weight to calcium phosphate application was considerably slower. In result, the T/R ratio tended to increase with an increase in the amount of calcium phosphate application (Fig.4).

2. Influences of soil moisture and calcium phosphate application upon the relationship between increased total dry matter weight and evapotranspiration

Fig. 5 shows the relationship between the increased total dry matter weight and evapotranspiration. Evapotranspiration increased in proportion to the increased total dry matter weight in all soil moisture plots, though the intercept varied with the soil moisture condition. Evaporation separated from evapotranspiration in the same method as that adopted in the previous paper[11] increased directly with an increase in the soil moisture ratio until it became constant at about 10.4 kg/pot under soil moisture conditions greater than 28% (Fig.6). On the other hand, transpiration increased in proportion to the increased total dry matter weight, independently of soil moisture ratio and calcium phosphate application (Fig.7). That is, the water use efficiency (increased total dry matter weight/transpiration) was kept at about 11 mg/g, within the limits of soil moisture and the amount of calcium phosphate application, examined in the present experiment.

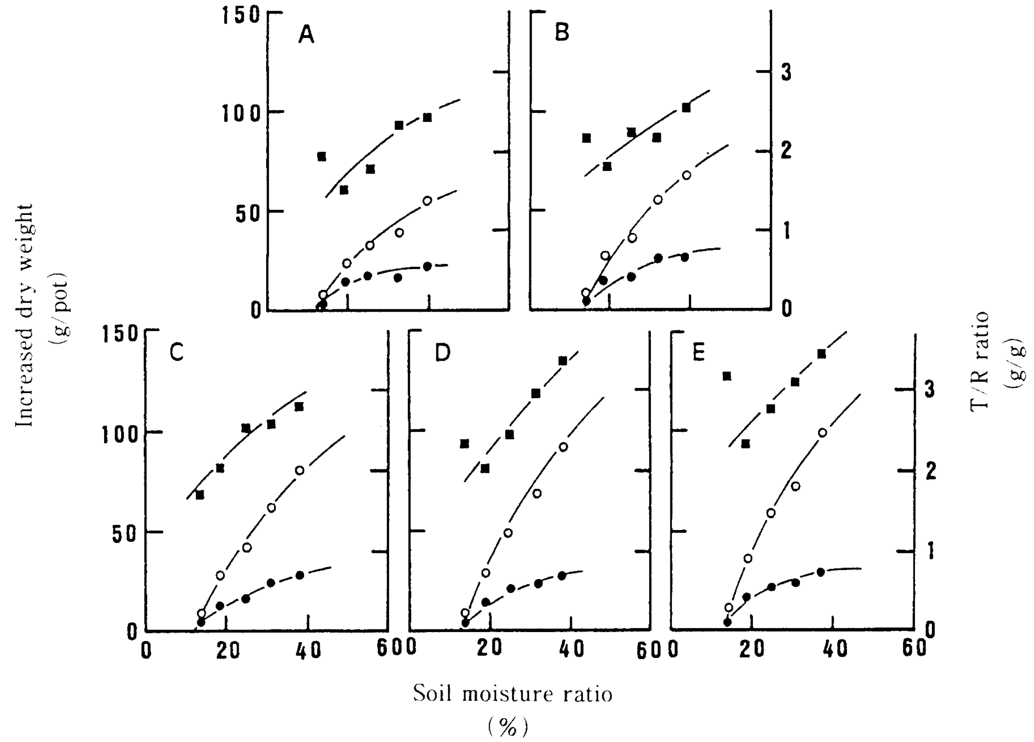

Fig. 2. Relationships between the soil moisture ratio and increased top and root dry weights and top/root ratio (T/R ratio).
○, ● and ■ indicate increased top and root dry weights and T/R ratio, respectively. A, B, C, D and E are the same as those shown in Table 1.

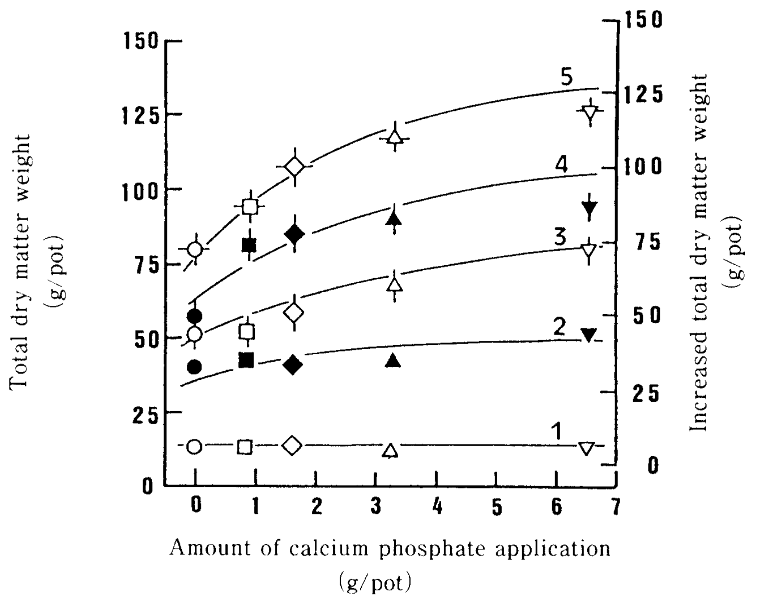

Fig. 3. Relationship between the amount of calcium phosphate application and the increased total dry matter weight.
Symbols are the same as those shown in Fig. 1. 1, 2, 3, 4 and 5 are the same as those shown in Table 1.

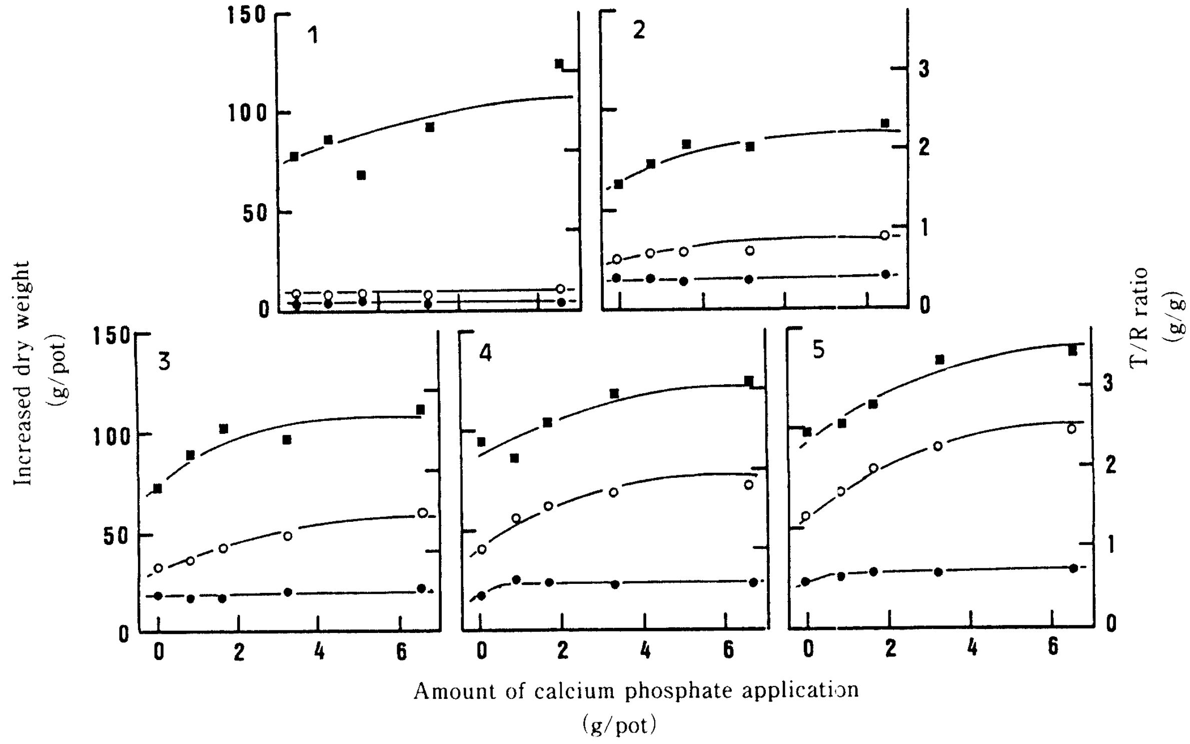

Fig. 4. Relationships between the amount of calcium phosphate application and the increased top and root dry weights and top/root ratio (T/R ratio).
Symbols are the same as those shown in Fig. 2. 1, 2, 3, 4 and 5 are the same as those shown in Table 1.

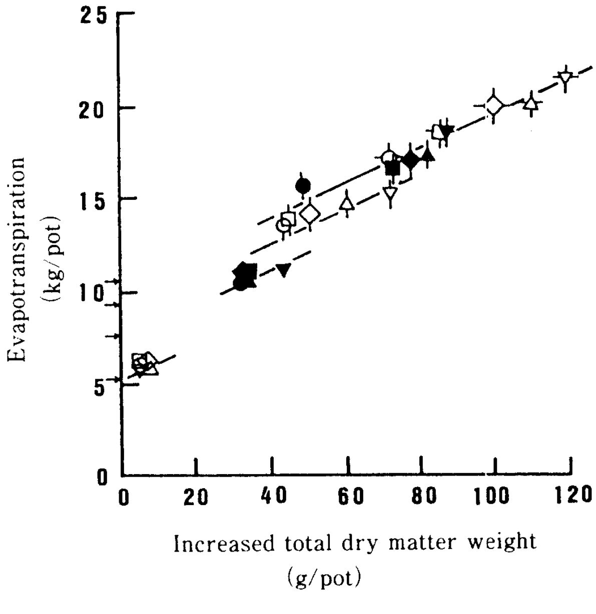

Fig. 5. Relationship between the increased total dry matter weight and evapotranspiration.
Symbols are the same as those shown in Fig. 1. Arrow in the margin indicates "unavailable evapotranspiration" in each soil moisture plot.

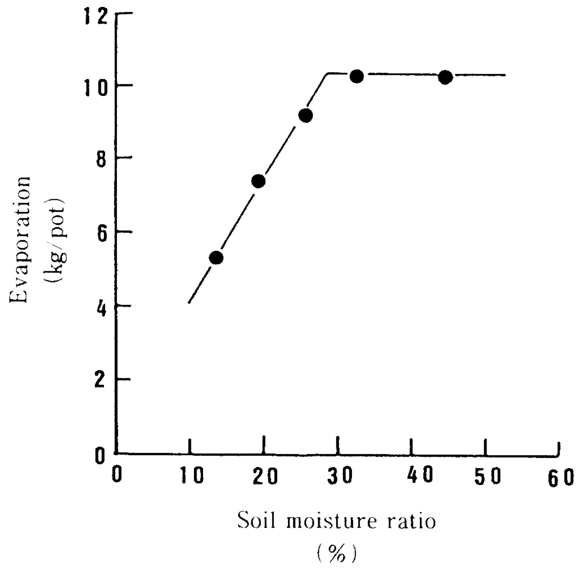

Fig. 6. Relationship between the soil moisture ratio and evaporation*1.
*1 : "Unavailable evapotranspiration" was regarded as nearly equal evaporation.

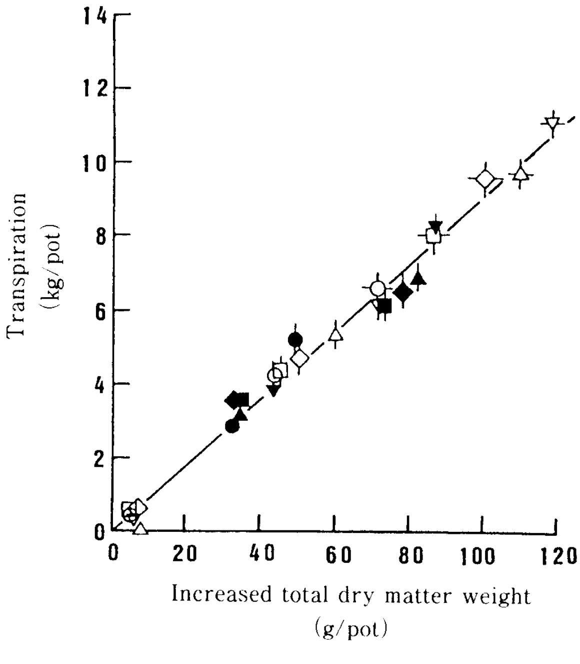

Fig. 7. Relationship between the increased total dry matter weight and transpiration*2.
Symbols are the same as those shown in Fig. 1. *2 : Transpiration was estimated by deducting unavailable evapotranspiration from evapotranspiration.

Discussion

The author observed in the previous paper[12] that there was an optimum curvilinear relationship between the soil moisture ratio and growth increment in sorghum plants. Similar relationship between soil moisture and crop growth was obtained by others[13,14]. However, such a relationship wasn't observed in the present experiment. That is, the result showed that the growth increment increased hyperbolically with an increase in soil moisture ratio (Fig.1). This was brought about probably because the upper limit of soil moisture in the present experiment was less than the optimum soil moisture condition.

In this experiment, it was quite difficult to distinguish between the effects of phosphate and calcium because not only phosphate but also calcium concentration increased with an increase in the amount of calcium phosphate application. In the present experiment, however, because a great quantity of calcium carbonate was applied as source of calcium other than calcium phosphate, there might be a little chance that calcium concentration controlled the growth increment in young sorghum plants. Gupta *et al.*[5] and Mahler *et al.*[8] gave a curve of secondary degree to the relationship between P-level and crop growth. However, the result in this experiment showed that the relationship between them was expressed not in an optimum curve but in a hyperbolic curve (Fig.3).

The responses to soil moisture and phosphorus application were more conspicuous in top than in root growth, respectively. These are in agreement with Suzuki's[13] and Davidson's[4] results. The T/R ratio decreased under dry and P-stressed conditions, respectively. This might probably have contributed to the recoveries of water status and phosphorus content of the plants. And, the T/R ratio increased with the increases in soil moisture and the amount of calcium phosphate application. Generally speaking, if the root is capable of supplying water and nutrients enough for the shoot, the smaller the dry matter partition to root becomes, the more vigorous the plant growth becomes, because the leaf area which is a assimilation tissue expands, the greater[10]. It was assumed that the result in this experiment would follow such a mechanism. As mentioned above, both soil moisture condition and the amount of calcium phosphate application affected not only dry matter production but also partition of dry matter. However, the responses of top and root growth to soil moisture and the amount of calcium phosphate application were expressed in a hyperbolic curve in either case (Figs.2 and 4).

These results suggest that the soil moisture ratio and the amount of calcium phosphate application acted as a linear factor[6] on the early growth in sorghum plants, within the limits of calcium phosphate application and soil moisture in this experiment, respectively, and that the quantitative responses of crop growth to soil moisture and P-level are susceptible to P-level and soil moisture, respectively. On the basis of these informations, the effects of the soil moisture ratio and the amount of calcium phosphate application upon early growth increment in sorghum plants were formulated by the following equation:

$$1/w = 0.1690/(f-12.8) + 0.0207/(f-12.8)(g+0.78) + 0.0062/(g+0.78) + 0.0006 \qquad \text{Eq.(1)}$$

where f, g and w are soil moisture ratio (%), the amount of calcium phosphate application (g/pot) and the increased total dry matter weight (g/pot), respectively. Fig.8 shows that the calculated values and observed values corresponded considerably well. Therefore, Eq.(1) may be considered to be an effective formula in estimating the effects of the soil moisture ratio and the amount of calcium

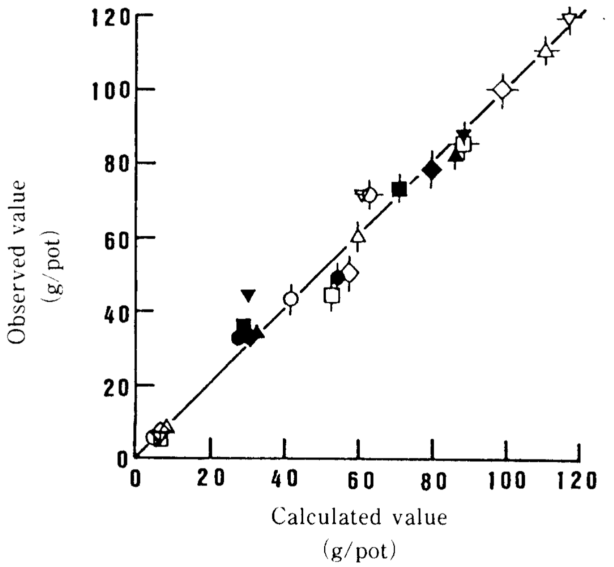

Fig. 8. Comparison of the calculated value of the increased total dry matter weight [based upon Eq. (1)] with the observed value.
Symbols are the same as those shown in Fig. 1.

phosphate application upon the growth increments in sorghum plants at early stages. It is noteworthy in Eq. (1) that not only the independent effects of soil moisture (1st term) and calcium phosphate application (3rd term) but also the interactive effect of those two factors (2nd term), suggesting that the shortages of calcium phosphate application and soil moisture ratio might be accelerated by the shortages of soil moisture ratio and calcium phosphate application, respectively, was perceived.

Fig. 9 shows the trends of the percentage inhibition (PI)[6], the one due to the shortage of soil moisture ratio ($A/f-f_0$), the one due to interaction ($B/(f-f_0)(g+g_0)$), the one due to the shortage of calcium phosphate application ($C/g+g_0$), and the one due to the shortage of time (D), as related to the change of the available soil moisture ratio ($f-f_0$, $f_0=12.8$) (a) and to the change of the amount of effective calcium phosphate application ($g+g_0$, $g_0=0.78$) (b). As a result, it was confirmed that the PI due to the shortage of soil moisture ratio increased with a decrease in the available soil moisture ratio and with an increase in the amount of effective calcium phosphate application, and that the PI due to the shortage of calcium phosphate application increased with a decrease in the amount of effective calcium phosphate application and with an increase in the available soil moisture ratio. On the other hand, the PI due to the interaction was not very important in case that either of the soil moisture or calcium phosphate was supplied sufficiently. However, once both of them were in short supply, it accounted for a great part. This result forms a pronounced contrast with the result in the previous paper[11] that ammonium sulfate application under low soil moisture ratio has made it possible to inhibit sorghum growth, considerably. It also suggests that the severe arid condition may inhibit the phosphate absorption by root and/or that the extremely low phosphate concentration may diminish the water absorption capacity.

As shown in Fig. 7, the quantitative relationship between the increased total dry matter weight and transpiration, or water use efficiency was constant, independently of soil moisture ratio and the amount of calcium phosphate application, within the limits in the present experiment. This causes us to suppose that the dry matter production and transpiration may be affected by the common factors.

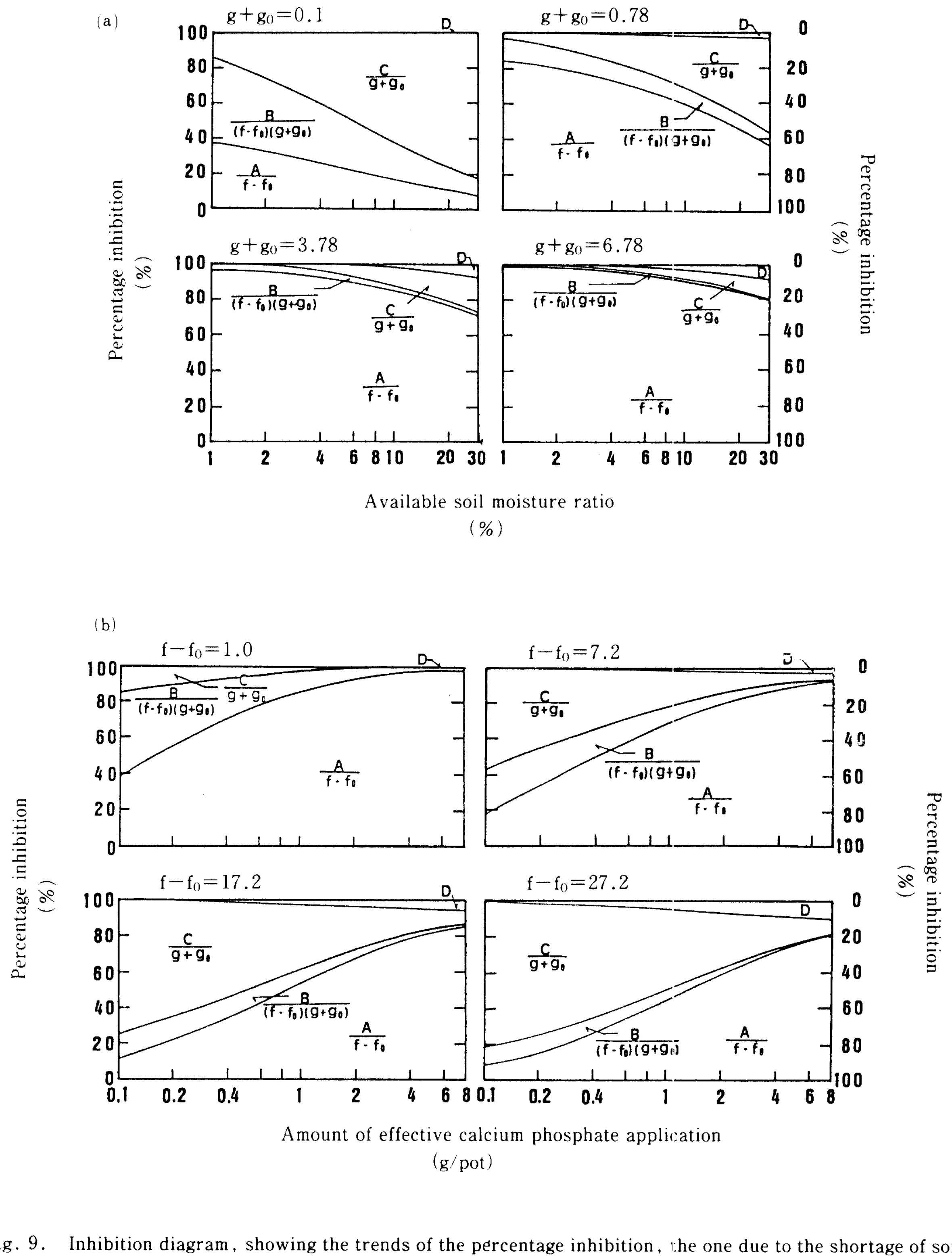

Fig. 9. Inhibition diagram, showing the trends of the percentage inhibition, the one due to the shortage of soil moisture ratio $(A/f-f_0)$, the one due to interaction $(B/(f-f_0)(g+g_0))$, the one due to the shortage of calcium phosphate $(C/g+g_0)$, and the one due to the shortage of time (D), as related to the change of the available soil moisture ratio $(f-f_0)$ (a) and as related to the change of the amount of effective calcium phosphate application $(g+g_0)$ (b).

Boyer[2,3] pointed out that a fall in leaf water potential decreased the leaf enlargement before the photosynthetic rate, and that the decrease in photosynthetic rate was attributed partly to decrease in stomatal conductance. On the other hand, Kabaki *et al.*[7] found that the deficiency of phosphorus caused rice plant to inhibit the tillering, to make the leaf width reduce, and to decrease the transpiration rate. That is, leaf expansion and stomatal conductance were made to be decreasing by water and phosphorus deficits. Judging from the fact that those decreased not only transpiration but also photosynthesis, it was to be supposed that a linear relationship between the increased total dry weight and transpiration might be based partly on those factors.

Summary

The sorghum cv. Sorghum-Sudan Hybrid was made to be grown in 13 litter seedling culture boxes, under twenty five treatments, to which soil moisture treatments of the five steps and calcium phosphate application treatments of the five steps were applied. The combined influences of soil moisture and calcium phosphate application upon growth increment and water use efficiency at the early stages were observed.

The main results obtained were summarized as follows:

1. It was observed as a general trend that the growth increment increased hyperbolically with the increases in the soil moisture ratio and the amount of calcium phosphate application, within the limits of soil moisture and the amount of calcium phosphate application in this experiment. However, the aspects of those responses changed remarkably with the amount of calcium phosphate application and soil moisture condition, respectively (Fig.1 and Fig.3).

2. The relationships between top and root weights, and, the soil moisture ratio and the amount of calcium phosphate application were expressed as a hyperbolic curve in either case, though the shortages of soil moisture and the calcium phosphate application affected not only the dry matter production but also the partition of dry matter (Fig.2 and Fig.4).

3. From the above-mentioned results, it was assumed that the influences of the combined treatments of soil moisture and calcium phosphate application upon the sorghum growth at the early stage were noted to be consisting not only of the independent effects of soil moisture and calcium phosphate application but also of the interactive effect of those two factors, which suggested that the shortages of soil moisture and calcium phosphate application might be accelerated by the shortages of calcium phosphate application and soil moisture, respectively (Eq.(1) and Fig.9).

4. The water use efficiency (increased total dry matter weight/total transpiration) was fixed constant, independent of soil moisture condition and the amount of calcium phosphate application (Fig.7). The result suggested that the influences of those two factors upon the water use efficiency were considerably small, and that there was a close connection between mechanisms affecting the dry matter production and transpiration.

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