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Some Relationships between Plant Growth and Soil Moisture Variations

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Introduction

It has become clear that there is a relationship between soil moisture condition and plant growth, while a great many experiments have been carried out from the ecological, physiological or agronomical points of view[10,11]. However, the water content in soil cannot choose but express in "mean value" in the aspects of both space and time, because we don't have on hand the measurement of soil moisture content in close proximity to the root which may affect directly the plant growth[6], and because the water content in soil has been varying continuously with space and time, depending on the ill-balanced distributions of the root and physical properties of the soil, and depending on rainfall, evapotranspiration and percolation *etc*.[4], respectively.

In spite of the fact that plants have been growing under different soil moisture variations, the relationship between soil moisture variation and plant growth has been discussed in only a few reports[2,3]. In the present paper, the author discussed how various types of soil moisture variations affect growth increments, evapotranspirations and water requirements in the two kinds of crops, namely, soybean and sorghum. In addition, the significance of "mean soil moisture" was discussed.

Materials and Methods

In order to impose various types of soil moisture variations on the plants, three experiments were carried out in the vinyl hothouse in the Experimental Farm of the Faculty of Agriculture, Kagoshima University, in 1986 and 1987.

Experiment 1. Seeds of soybean (*Glycine max* (L.) MERR. cv. Shiratori) were sown in a planter filled with vermiculite on 23 May, 1986. Seedlings were transplanted into another pot (45 litter) filled with a uniform soil of 33.78 kg of dried soil that was passed through a sieve of 5 mm across, at rate of four plants per pot, on 29 May. Compound fertilizer (8-8-8) was applied at the rate of 10 g per pot, on 31 May.

At the beginning of treatments, the soil moisture ratio in each pot was kept in about 30%. Nine soil moisture variation treatments were commenced on 26 June. The treatments used are shown in Fig. 1a. Soil moisture control was carried out by a gravimetric method. In treatment A, the pot weight was kept in about 45.03 kg/pot in order to keep the soil moisture ratio 30%, by sprinkling the water on the soil surface every day. In the treatments of B, C, D and E, soil moisture ratios varied from 23 % to 37 %, at 0-, 2-, 4- and 6-day intervals, respectively. In the treatments of F, G, H and I, it varied from 16 to 44 % at 0-, 2-, 4- and 6-day intervals, respectively. Mean soil moisture ratio during the treatments was fixed to be between 28.2 and 29.2 in all the soil moisture variation

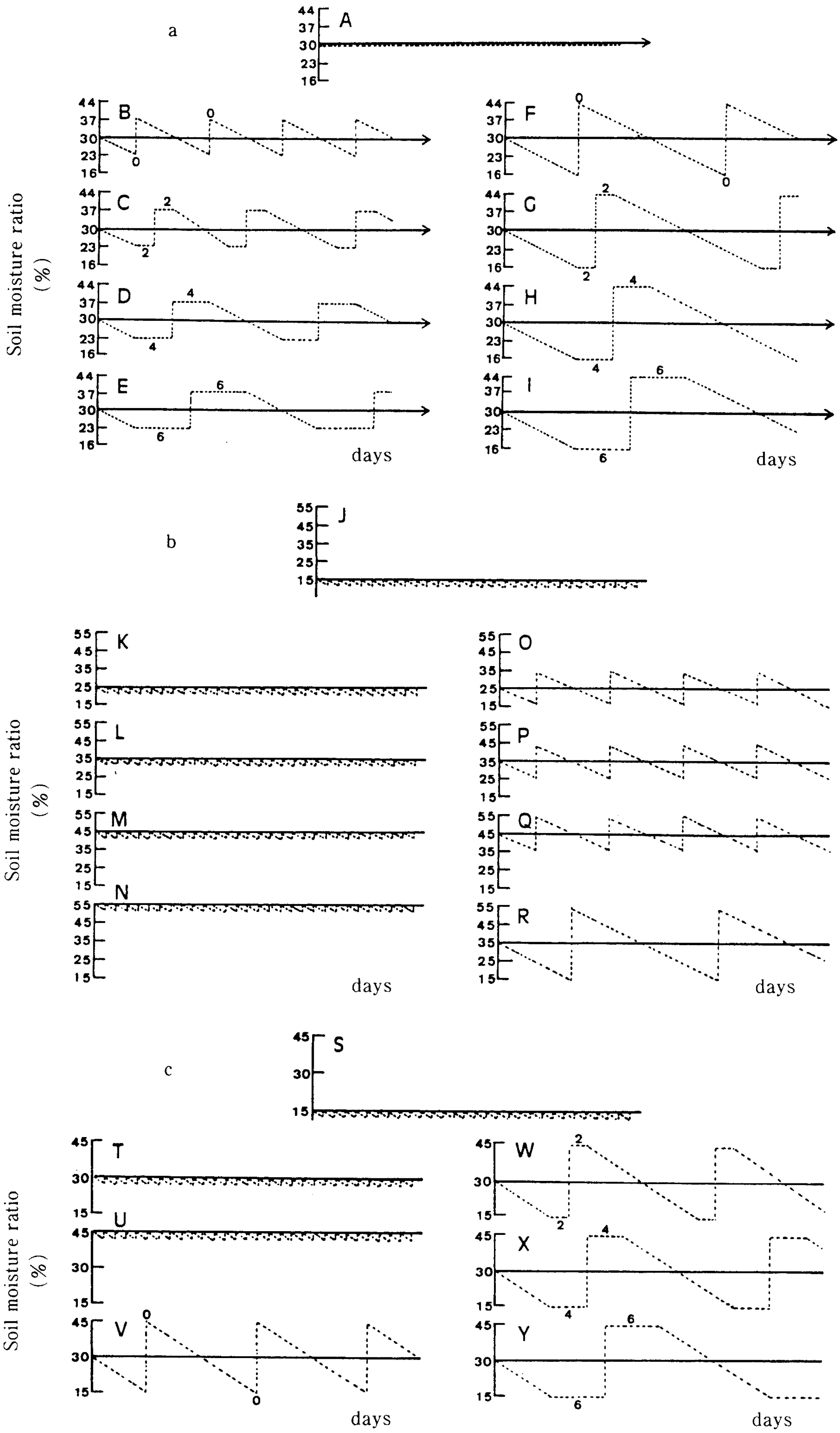

Fig. 1. Outlines of the experiments.

plots.

On 25 July, 29 days after the beginning of the treatments, 4 plants with two replications were harvested from each plot. These plants were separated into leaves, petioles, stems, pods and roots, and were dried at 80 ℃ for 72 hours to get dry weight. Total evapotranspiration during the treatments was estimated by accumulating the amount of water, supplied in order to control the soil moisture conditions.

Experiment 2. Eight grains of the sorghum (*Sorghum bicolor* (L.) MOENCH cv. Sorghum-Sudan Hybrid) were sown in a pot (18 litter) filled with a uniform soil of 12.76 kg of dried soil that was passed through a sieve of 5 mm across, on 21 May, 1987. Compound fertilizer (12-12-12) was applied at the rate of 7.1 g per pot as basal dressing on 21 May. Besides this, 1.2 g/pot of urea was applied as top dressing on 24 June.

At the beginning of treatments, the soil moisture ratio in each pot was about 20%. Nine soil moisture variation treatments were commenced on 29 May when just the 3rd leaf was expanding. The treatments used are shown in Fig. 1b. Soil moisture control was carried out by gravimetric method. In the treatments of J, K, L, M and N, the pot weights were kept in about 15.44, 16.72, 17.99, 19.27 and 20.54 kg in order to keep the soil moisture ratios 15, 25, 35, 45 and 55%, respectively, by sprinkling water on the soil surface every day. In the treatments of 0, P and Q, soil moisture ratios varied from 15, 25 and 35% to 35, 45 and 55%, respectively. And in the treatment of R, it varied from 15 to 55 %. The mean soil moisture ratios during the treatments were 14.3% in J-plot, 22.8 and 23.6% in K- and 0- plots, 32.3, 32.6 and 31.9% in L-, P- and R- plots, 42.6 and 42.8% in M- and Q- plots, and 52.1% in N- plot, respectively. On the other hand, the ranges of soil moisture variation were 1.9, 4.5, 5.5, 6.0 and 5.9% in J-, K-, L-, M- and N- plots, 21.3, 23.6 and 24.6% in 0-, P- and Q- plots, and 41.4% in R- plot, respectively.

On 17 July, 7 weeks after the beginning of the treatments, 8 plants with 5 replications were harvested from each plot. Only the top of these plants was dried at 80 ℃ for 96 hours to get top dry weight. Total evapotranspiration during the treatments was estimated by the same method as that mentioned in Experiment 1.

Experiment 3. Eight grains of the Sorghum cv. Sorghum-Sudan Hybrid were sown in the respective pots (18 litter) filled with a uniform soil of 12.36 kg of dried soil that was passed through a sieve of 5 mm across, on 6 May, 1987. Compound fertilizer (12-12-12) was applied at the rate of 7.1 g per pot as basal dressing on 19 May. Besides this, 1.2 g/pot of urea was applied as top dressing on 24 June.

At the beginning of treatments, the soil moisture ratio in each pot was about 20%. Seven soil moisture variation treatments were commenced on 29 May when just the 7th leaf was expanding. The treatments used are shown in Fig. 1c. Soil moisture control was carried out by gravimetric method. In the treatments of S, T and U, the pot weights were kept in about 14.98, 16.84 and 18.69 kg in order to keep the soil moisture ratios 15, 30 and 45%, respectively, by sprinkling water on the soil surface every day. In the treatments of V, W, X and Y, the soil moisture ratio varied from 15 to 45% at 0-, 2-, 4- and 6-day intervals, respectively. The mean soil moisture ratios during the treatments were 13.7% in S- plot, 41.2% in U- plot, and between 25.7 and 27.3% in T-, V-, W-, X- and Y- plots. The ranges of soil moisture variation were 3.6% in S- plot, 5.4% in T- plot, 4.2% in U- plot and between 31.4 and 32.5% in V-, W-, X- and Y- plots, respectively.

On 17 July, 7 weeks after the beginning of treatments, 8 plants with 5 replications were harvested from each plot. Only the top of these plants was dried at 80 ℃ for 96 hours to get top dry weight. Total evapotranspiration was estimated by the same method as that mentioned in Experiment 1.

Results

1. A basic relationship between soil moisture ratio and plant growth

Figs. 2, 3 and 4 show basic relationships between the soil moisture ratio and the top dry weight,

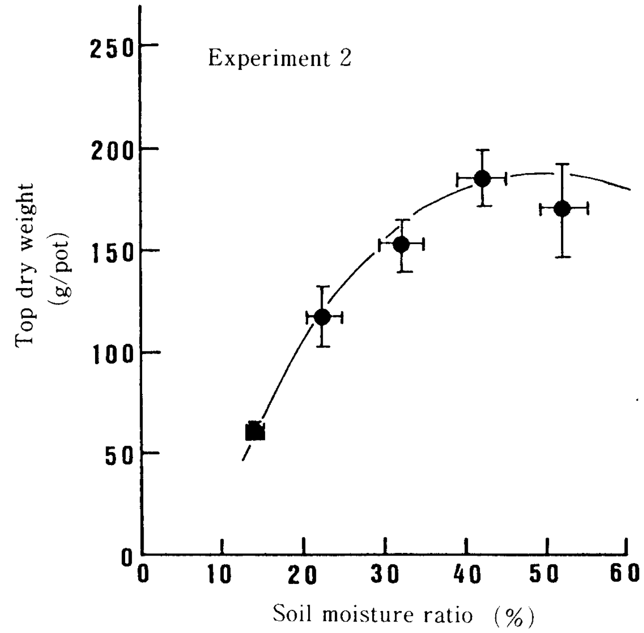

Fig. 2. Relationship between the mean soil moisture ratio and top dry weight when the range of soil moisture variation was less than, or equal to, 6% (Experiment 2).
Horizontal and vertical bars indicate the range of soil moisture variation and the confidence interval for population mean at 5% level, respectively.

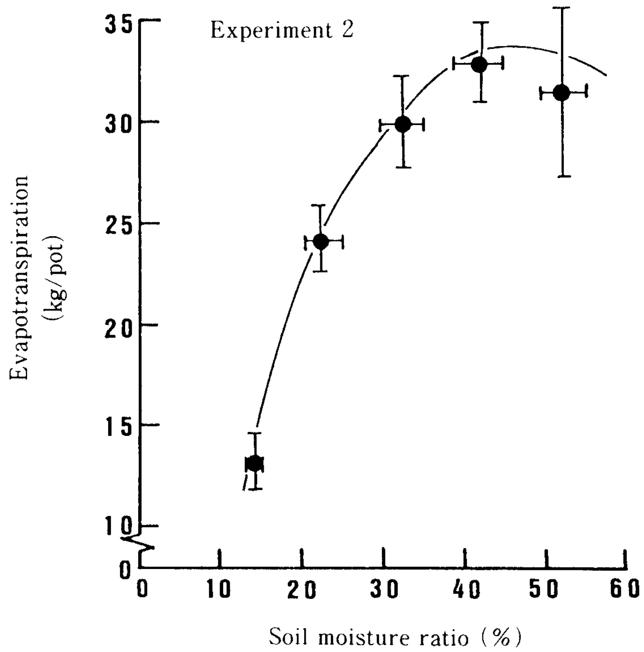

Fig. 3. Relationship between the mean soil moisture ratio and evapotranspiration when the range of soil moisture variation was less than, or equal to, 6% (Experiment 2).
Symbols are the same as those shown in Fig. 2.

evapotranspiration and water requirement (evapotranspiration/top dry weight) in sorghum plants, when the range of soil moisture variation was less than, or equal to, 6 % (Experiment 2). It was observed that there was an optimum curvilinear relationship between the soil moisture ratio and the top dry weight, and that the optimum soil moisture ratio was about 45 %, which was equivalent to 70 % of maximum water-holding capacity (Fig.2). Evapotranspiration as well as top dry weight increased with an increasing in the soil moisture ratio, and showed the maximum value at 45 %, and then it decreased with an increase in soil moisture ratio (Fig. 3). On the other hand, water requirement was fixed to be between 175 and 210, and it tended to be decreasing gradually with an increase in soil moisture ratio (Fig. 4).

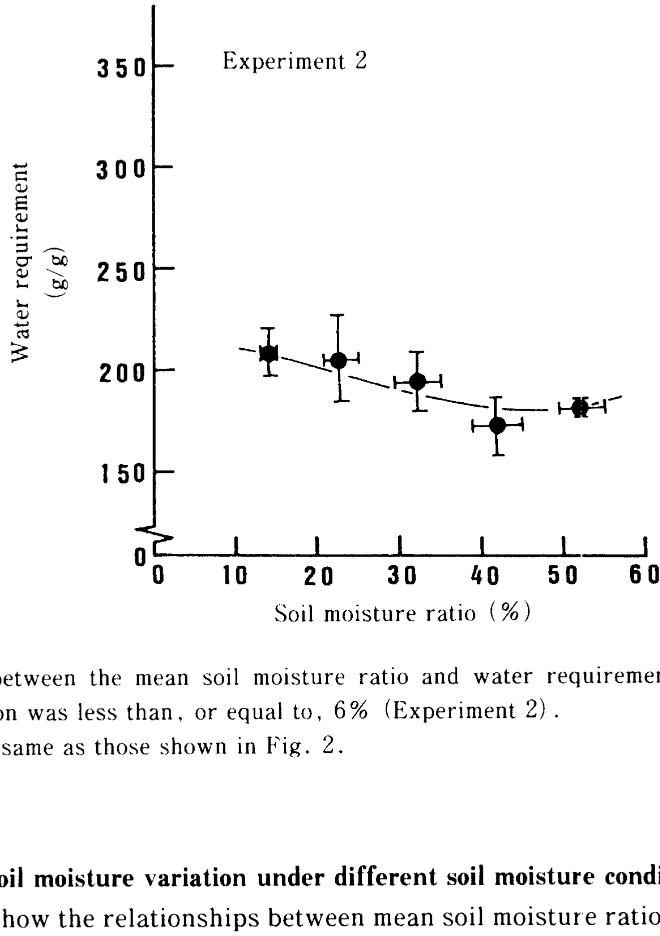

Fig. 4. Relationship between the mean soil moisture ratio and water requirement when the range of soil moisture variation was less than, or equal to, 6% (Experiment 2).
Symbols are the same as those shown in Fig. 2.

2. The effect of soil moisture variation under different soil moisture conditions upon plant growth

Figs. 5, 6 and 7 show the relationships between mean soil moisture ratio and growth increment, evapotranspiration and water requirement when the range of soil moisture variation was between 21.3 and 24.6 % (Experiment 2). Growth increment tended to be smaller in soil moisture variation plots than in the less variation plots under all the soil moisture conditions, and such a tendency became more conspicuous under the lower soil moisture conditions. However, the difference between them was insignificant (Fig.5). The evapotranspiration in soil moisture variation plots as well as in less variation plots increased with an increasing in the mean soil moisture ratio. However, the absolute quantity varied in dependence on the range and the central value of soil moisture variation. That is, although the evapotranspiration in O- plot, where mean soil moisture ratio was 23.6 % and the range of soil moisture variation was 21.3 %, was smaller in significance than that in K- plot, where the mean soil moisture ratio was 22.8 % and the range of soil moisture variation was 4.5 %, the evapotranspiration in soil moisture variation plot (Q- plot) was nearly equal to that in less variation plot (M- plot) when the mean soil moisture ratio was about 43% (Fig. 6). On the other

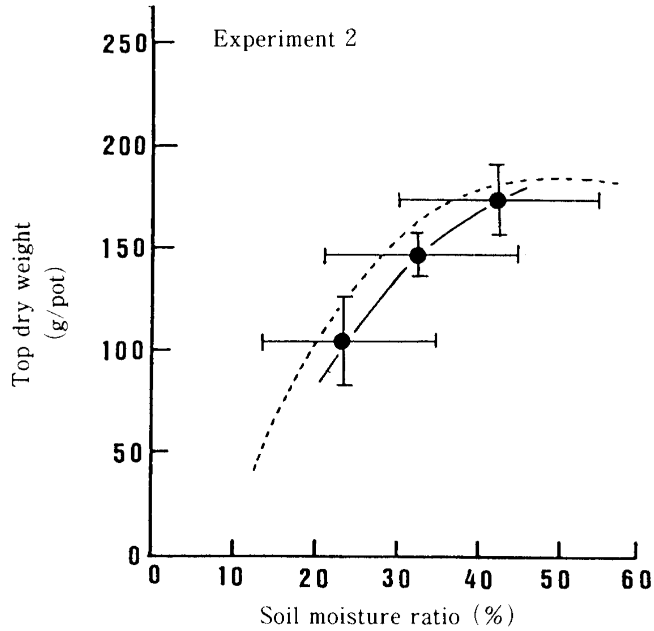

Fig. 5. Relationship between the mean soil moisture ratio and top dry weight when the range of soil moisture variation was 21.3-24.6% (Experiment 2).
Symbols are the same as those shown in Fig. 2. Broken line indicates the relationship between them when the range of soil moisture variation was less than, or equal to, 6%.

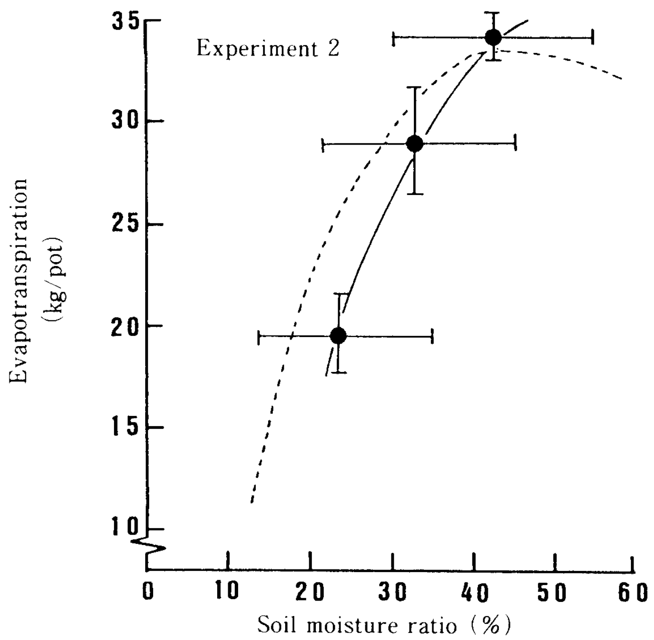

Fig. 6. Relationship between the mean soil moisture ratio and evapotranspiration when the range of soil moisture variation was 21.3-24.6% (Experiment 2).
Symbols are the same as those shown in Fig. 5.

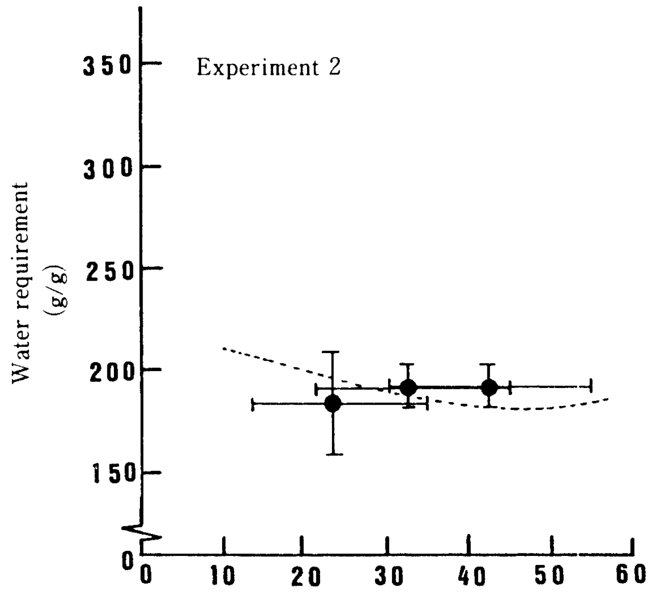

Fig. 7. Relationship between the mean soil moisture ratio and water requirement when the range of soil moisture variation was 21.3-24.6% (Experiment 2).
Symbols are the same as those shown in Fig. 5.

hand, the water requirement was about constant, independently of the central value of soil moisture variation (Fig. 7).

3. The relationship between the range of soil moisture variation and plant growth

Figs. 8, 9 and 10 show the relationships between the range of soil moisture variation and the growth increment, evapotranspiration and water requirement when the mean soil moisture ratio was 28-33% (Experiment 1 and Experiment 2). Growth increments and evapotranspirations in soybean and sorghum plants tended to be decreasing in proportion to square of the range of soil moisture variation. However, a difference between them under soil moisture variation and under less variation was small comparatively and insignificant, until the range of soil moisture variation arrived at a figure greater than 30% (Figs. 8 and 9). On the other hand, it couldn't be recognized that there was a significant difference between water requirements under soil moisture variation and under less variation, within the limits of soil moisture variation used in the present experiments (Fig.10).

4. The relationship between the interval of soil moisture variation and plant growth

Figs. 11, 12 and 13 show the relationships between the interval of soil moisture variation and growth increment, evapotranspiration and water requirement in soybean and sorghum plants (Experiment 1 and Experiment 3). Growth increment and evapotranspiration were kept nearly constant, independently of the interval of soil moisture variation, within the limits of soil moisture variation in the present experiments (Figs.11 and 12). On the other hand, water requirement tended to show the minimum value at the 4-5 days of intervals of soil moisture variation, and to be increasing when the interval of soil moisture variation became either greater or less than that mentioned above. And, the smaller the range of soil moisture variation was, the more conspicuous such a tendency became. However, it wasn't always the changes full of significance.

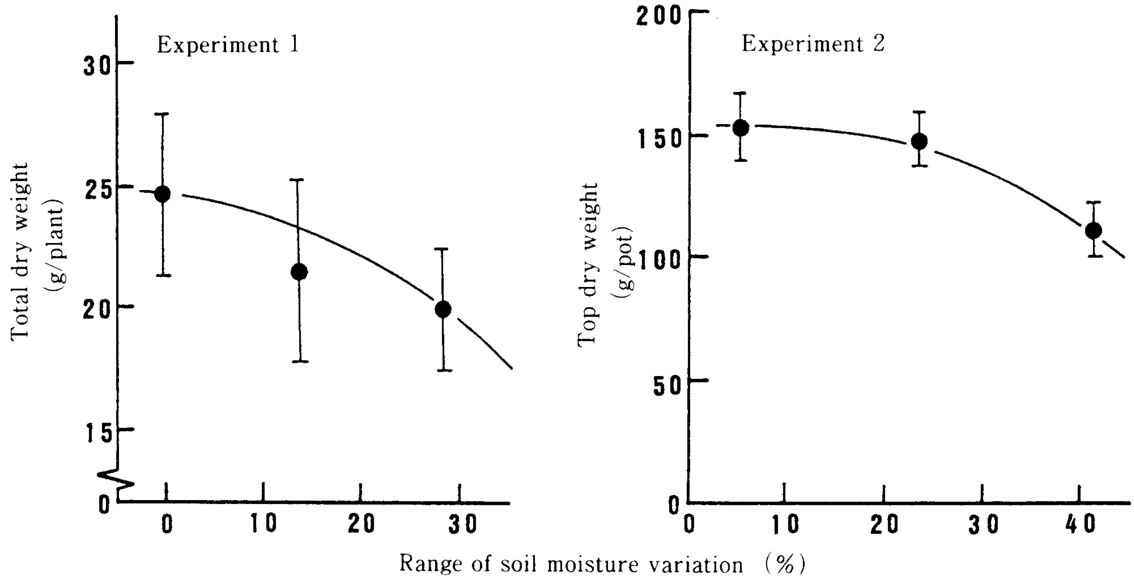

Fig. 8. Relationship between the range of soil moisture variation and growth increment when the mean soil moisture was 28-33% (Experiment 1 and Experiment 2).
Vertical bar indicates the confidence interval for population mean at 5% level.

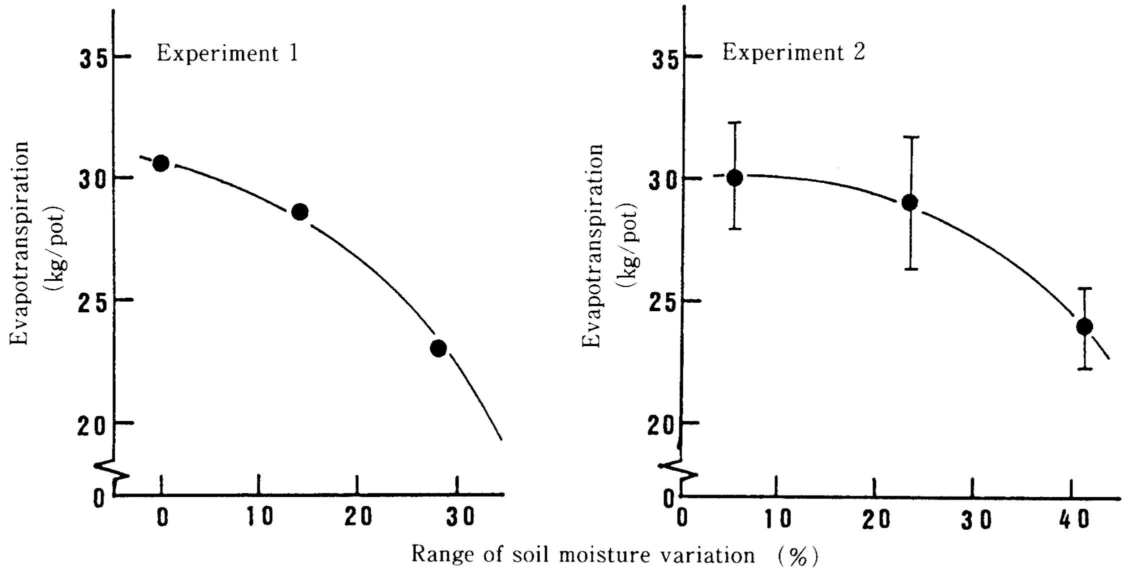

Fig. 9. Relationship between the range of soil moisture variation and evapotranspiration when the mean soil moisture was 28.2-32.6% (Experiment 1 and Experiment 2).
Symbols are the same as those shown in Fig. 8.

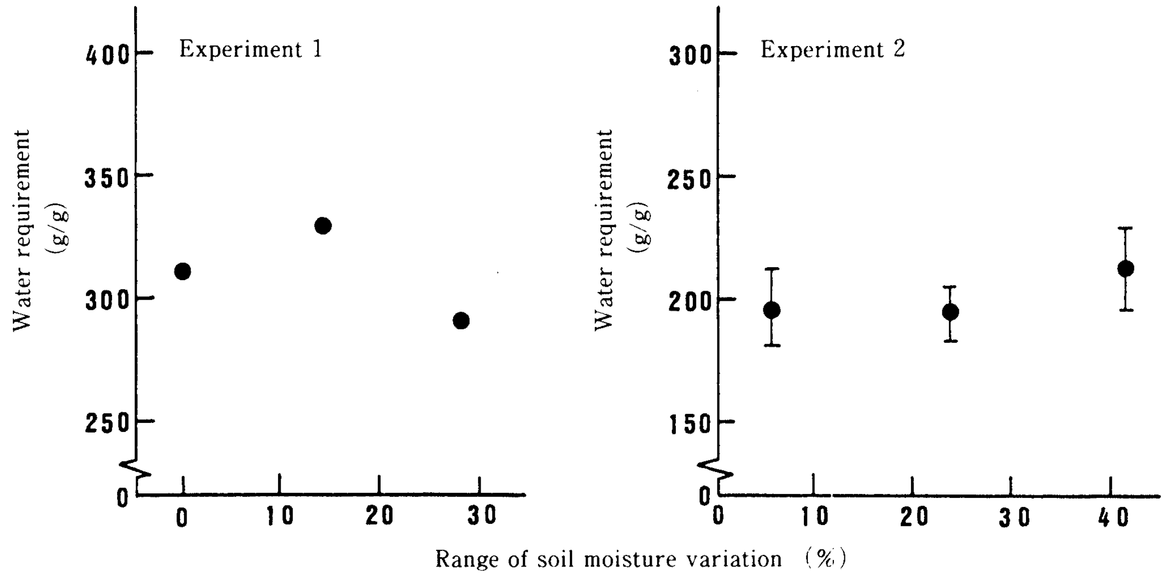

Fig. 10. Relationship between the range of soil moisture variation and water requirement when the mean soil moisture ratio was 28.2-32.6% (Experiment 1 and Experiment 2).
Symbols are the same as those shown in Fig. 8.

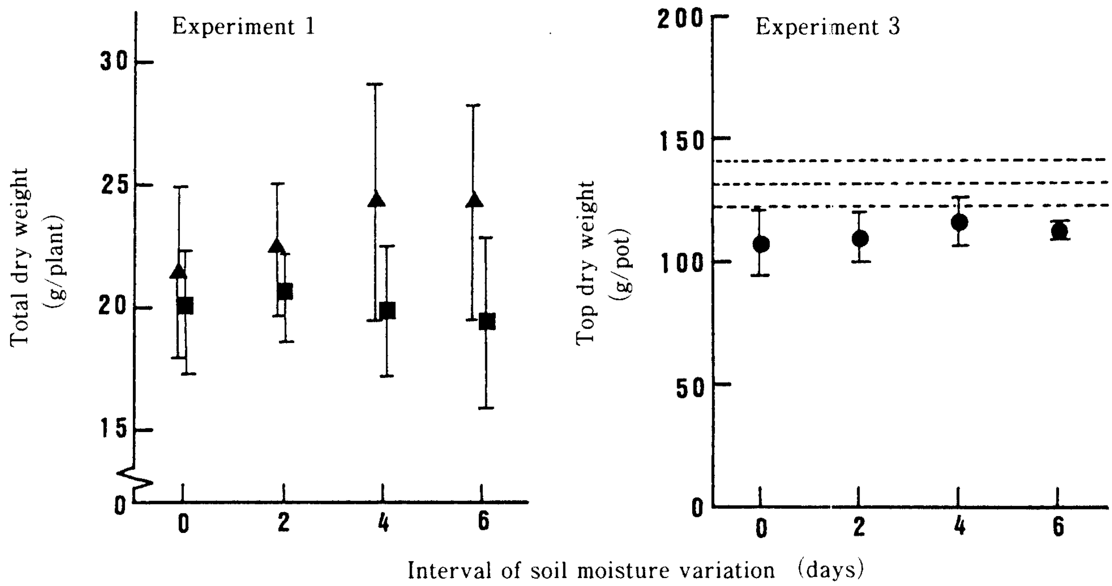

Fig. 11. Relationship between the interval of soil moisture variation and growth increment when the mean soil moisture ratio was 26-29% (Experiment 1 and Experiment 3).
▲, ■ and ● indicate that the range of soil moisture variation was 14, 28 (Experiment 1) and 31-33% (Experiment 3), respectively.
Broken line indicates the level in less soil moisture variation plot. Vertical bar indicates the confidence intervals at 5% level.

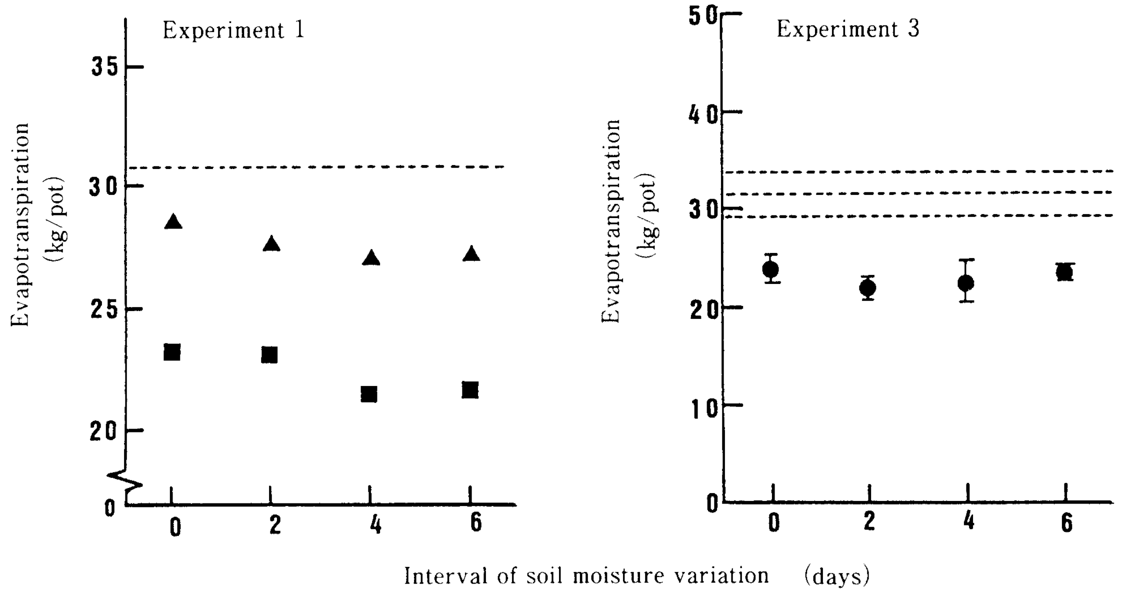

Fig. 12. Relationship between the interval of soil moisture variation and evapotranspiration when the mean soil moisture ratio was 26-29% (Experiment 1 and Experiment 3).
Symbols are the same as those shown in Fig. 11.

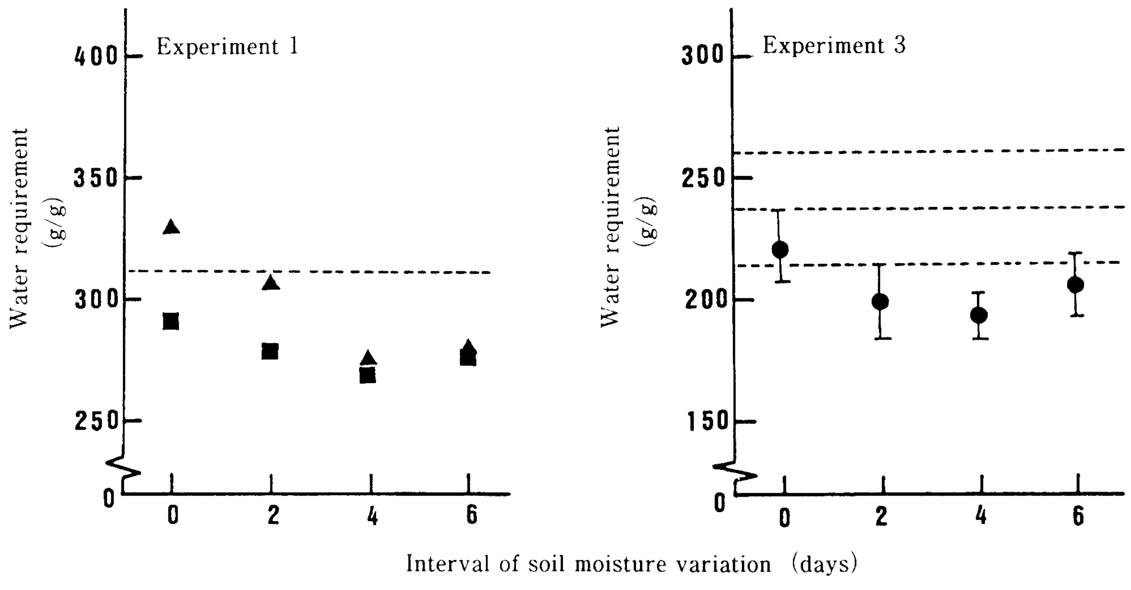

Fig. 13. Relationship between the range of soil moisture variation and water requirement when the mean soil moisture ratio was 26-29% (Experiment 1 and Experiment 3).
Symbols are the same as those shown in Fig. 11.

Discussion

Growth increment and evapotranspiration in sorghum plants under less soil moisture variation condition, as mentioned above, increased with an increasing in soil moisture ratio until 45% in soil moisture ratio (70% of maximum water-holding capacity), and then it tended to be decreasing with an increase in soil moisture ratio. Such a relationship between soil moisture and plant growth is in agreement with Suzuki's[10] and Tamai's[11] results obtained with upland rice, groundnut and pimiento, and jute and soybean, respectively.

On the other hand, sorghum plants in soil moisture variation plots reiterated a chain of cycle which was made up of the rolling and the withering of leaves under drier condition and of the recovery and the expanding of new leaves under wetter condition, during the treatments. Itoh and Kumura[3], and Furuhata and Monji[2] found that leaf area and leaf area/root weight ratio was low under water deficit and high under well water condition, and that when soil moisture content changed, it was readjusted quickly to that to be fit for the new condition. It is assumed that a chain of response of plant growth to soil moisture variation obtained in the present experiments may be corresponding to those results. The top dry weight and the evapotranspiration of plants which followed such a growing process were, on the whole, smaller than, or equal to, those of plants grown under less soil moisture variation.

Boyer[1] observed in sunflower plants that after desiccation to leaf water potential as low as -16 bar, net photosynthesis under high light, transpiration, and the relative diffusive resistance of the leaf did not return to predesiccation levels, even though leaf water potential did. Itoh and Kumura[3] found that relative growth rate (RGR) and net assimiration rate (NAR) decreased considerably below those of the plants grown under a dry condition when soybean plants were transferred from a wet to a dry condition. Furuhata and Monji[2] observed that when soybean plants were transferred from a wet to a dry condition, the transpiration rate decreased sharply below that of plants grown under a dry condition. These results emphasized that a temporary desiccation inhibited considerably plant growth, photosynthesis and transpiration. Sugimoto *et al.*[7] observed that soybean plants were damaged not only by excess-moisture but also by drought when they were grown under excessive soil moisture condition followed by insufficient precipitation at the early growth stage. This suggests that the sensibility to drought was increased by excess-moisture injury. Judging synthetically from these results, it is assumed that soil moisture variation may influence considerably and negatively plant growth and transpiration.

In the present experiments, the top dry weight and the evapotranspiration under soil moisture variation, as shown in Fig.14, fell to "mean value" between those of plants grown under both limits of soil moisture variation. And, the influence of the interval of soil moisture variation wasn't so conspicuous. The results in the present experiments suggest that the sharp fall of growth increment and transpiration observable when the plants were transferred from a wet to a dry condition, which was found by them, might be compensated, to some extent, with the recovery observable when those were transferred from a dry to a wet condition, and that the influence of soil moisture variation upon plant growth and evapotanspiration, in fact, may be decided not by "mean soil moisture ratio", but by the soil moisture status in both limits of soil moisture variation.

Nevertheless, when the mean soil moisture ratio and the range of soil moisture variation were higher and smaller, respectively, growth increment and evapotranspiration under soil moisture variation lay in close proximity to those of the plants grown under soil moisture condition which was kept at about "mean value" between the lower limit and the upper limit of soil moisture variation. In

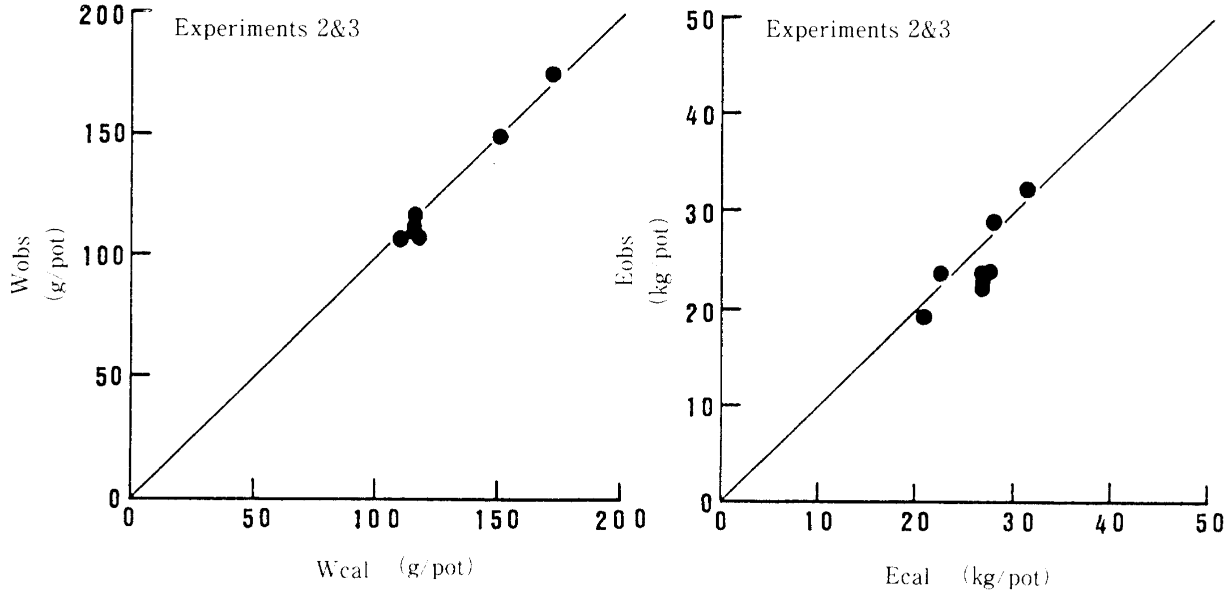

Fig. 14. Relationship between the top dry weight (Wobs) and evapotranspiration (Eobs) under soil moisture variation and "mean value" (Wcal and Ecal) between those of plants grown under both limits of soil moisture variation (Experiment 2 and Experiment 3).

addition, there was no significant difference between growth increments under soil moisture variation and under less variation, until the range of soil moisture variation arrived at a figure greater than 30%. This suggests that "mean soil moisture ratio" may be valid to a certain extent, excepting under extreme soil moisture variation. On the other hand, there was a significant difference between evapotranspirations under soil moisture variation and under less variation when the mean soil moisture ratio and the range of soil moisture variation were 23.6% and 21.3%, respectively. This was brought about probably because evaporation as well as transpiration decreased considerably with a decreasing in soil moisture.

Under less soil moisture variation, water requirement tended to be increasing as soil moisture decreased. Judging from the results that transpiration efficiency (transpiration/dry plant weight) was nearly constant, independently of planting density[5], and soil moisture and the amount of fertilizer application[8,9], this was probably due to the fact that the smaller the soil moisture became, the larger the percentage of evaporation for evapotranspiration became. On the other hand, considering the fact that there was not always a significant difference between water requirements under soil moisture variation and under less variation, it was assumed that the effect of soil moisture variation upon water requirement, broadly speaking, was not so important.

Summary

The soybean and sorghum plants were made to be grown under various types of soil moisture variations. The effects of soil moisture variation upon growth increment, evapotranspiration and water requirement were examined.

The main results obtained were summarized as follows:

1. Although the growth increment under soil moisture variation tended to be smaller than that under less soil moisture variation in all the mean soil moisture plots, it couldn't be recognized that there was a significant difference between them, until the range of soil moisture variation arrived at a

figure greater than 30% (Figs. 5, 8 and 11).

2. Evapotranspiration was significantly smaller under soil moisture variation than under less soil moisture variation in the following cases in which the range of soil moisture variation became greater than 30%, and the mean soil moisture ratio and the range of soil moisture variation were 23.6 and 21.3%, respectively. However, the former was nearly equal to the latter when the range of soil moisture ratio was less than 25% and the mean soil moisture ratio became greater than 30% (Figs. 6, 9 and 12).

3. From the result that there was not always a significant difference between water requirements under soil moisture variation and under less variation, it was judged that the effect of soil moisture variation upon water requirement was not so important (Figs. 7, 10 and 13).

4. From the above mentioned results, it was concluded that "mean soil moisture ratio" was valid, to a certain extent, in the relationships of plant growth, evapotranspiration and water requirement with the soil moisture conditions, excepting under extreme soil moisture variations.

Acknowledgment

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