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AUTECOLOGICAL STUDIES ON THE HYDRATURE ACCOMMODATION IN HIGHER PLANTS*

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The plants grow accommodating themselves to the environmental factors in their habitats both in the morphological structures and in the physiological functions. The osmo-regulation of cells and related phenomena of the adaptation may be observed in the water relation of the plants. The expression "hydrature" was first introduced by Walter (1931) for "water condition". There is an equilibrium between the hydrature of the plasm and the osmotic value of the cell sap. Therefore the osmotic value may serve as an index of the hydrature of the plasm. Walter (1931, 1955) classified the plants into two different types, i.e. poikilohydrous plants and homoiohydrous plants, in accordance with the mode of correspondence to the environmental hydrature changes. In the former, the hydrature is completely dependent upon that of the environment and the plant has no individual hydrature. The lower plants such as bacteria, algae, fungi, lichens, and mosses belong to this group. In the latter, the hydrature is largely independent of that of their environment and the plant has its individual hydrature which changes within a definite range. The ascension of the osmotic value beyond the range leads to the reduction of the activities of plants. Spermatophytes or Angiosperms may be included in this type. The osmotic value of the plant varies not only according to the environmental conditions but also to its age. In general, the hydrature of a plant is high in the early stage of growth and it descends as growth advances. However, there are few detailed studies done as yet, and especially none on the hydrature accommodation in relation to the combined effect of environment and age. Thus the present author used three plants, soybeans, broad beans and orpines, which are different in the types of hydrature accommodation, and investigated their capability of accommodation in accordance with the changes of soil moisture condition and also at different growth stages artificially prepared by the changes of photoperiodic condition. The soybean was a suitable material for the

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studies from the above-mentioned viewpoint, because the plant accommodates itself widely to the changes of environmental conditions and also because it is a short day plant the aging of which can be changed through several photoperiodic treatments. The orpine is very suitable in comparison with the soybean plant as it is narrow in accommodation and is a long day plant. The broad bean is also a long day plant. As these studies required continuous experiments for a number of years, some of the results were previously partially reported but now all of them are presented as a whole.

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Material and Method

These studies were carried out from summer, 1951 to autumn, 1958. The main materials were soybeans (*Glycine max* (L.) MERRILL), "Tamanishiki", "Asomasari" and "Iyo" for the late variety, "Shakkinnashi" and "Shirosaya No. 1" for the medium one. Broad beans (*Vicia Faba* L.) and orpines (*Sedum alboroseum* Baker) were also used. The seedlings were planted in pots. The soil used was sandy loam which was not manured. The soil moisture in the pots was kept at 80% of saturated water capacity except in special cases. The osmotic value of upper epidermal cells of leaves which were stained by neutral red (0.005%) was measured at incipient plasmolysis in sucrose or KNO_3 solution. Each value was the average of measurements done on five lowest leaves vertically situated in succession on a stem. The evaporation from the pots was shut out except from plant bodies. The pots were weighed daily and the loss of water was made up for by watering. The transpiration rate per unit leaf area was obtained by dividing the transpired water amount by the total leaf area. Permeability of cells to water was measured by the time of deplasmolysis: samples plasmolyzed in two-fold isotonic solution for 20 minutes were deplasmolyzed in 2/3 isotonic solution, and the time needed for deplasmolysis was taken as the indication of water permeability.

Experimental Results

I. The Variation of Osmotic Value of a Soybean Plant in Relation to Leaf Order

Exp. 1) The osmotic value in a plant measured from the lower position to the higher.

As is shown in Fig. 1, in general the higher the position of the leaf was, the greater the osmotic value was. The maximum, however, was not always observed in the apical part of the plant, but also on a little lower position than the top. This phenomenon appeared as a general tendency in soybeans both in different soil moisture conditions and at different growth stages. According to the reports of previous investigators the upper leaves always showed higher osmotic values than the lower ones (Pringsheim, 1906), and the higher ones were more xero-morphied than the lower ones (Zalenski, 1904; Maximov, 1925). The osmotic value of leaves on the other hand was related to the aging of leaves. Young leaves generally showed a lower value than old ones (Walter, 1955; Takaoki, 1962). In this experiment the lower ones were old, and the upper ones young. Then the osmotic value of leaves on the same plants may be decided by the two opposing factors, i.e., the distance order of the leaves from the ground and their aging order. The osmotic value of immature leaves in the apical portion may be the highest owing to their highest position but at the same time the lowest owing to their young age. The maximum was observed at a little lower position than the top as this part was sufficiently mature and situated high enough. The average value of five leaves of different positions may serve as the mean value of

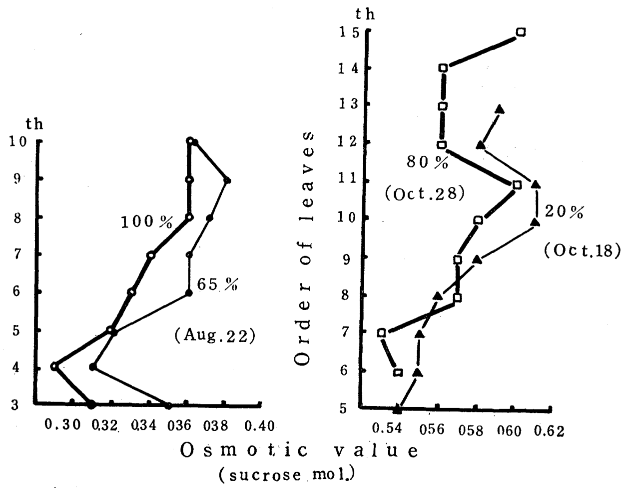


Fig. 1. Changes of the osmotic value according to the leaf order in the same plant of soybeans. (Variety—Tamanishiki)

the plants. The osmotic values reported in the following are the means of the measurements on five leaves obtained by the method described in the former chapter.

II. Acquirement of Hyper Osmotic Value through Wiliting in Soybean Plants

Plants grown in 80% soil moisture were subjected to wilting by stopping water supply. In several days the soil moisture reached near the point of permanent wilting. Then the soil was once more watered to regain 80% soil moisture, and how the osmotic value ascended and was fixed by the wilting treatment was examined.

Exp. 2) Osmotic variation in plants wilted 4 times.

After the plant in 80% soil moisture had been wilted four times before and after the flowering season, the soil moisture was regained to 80% constant. The symptom of wilting appeared at 20% of water capacity in the first treatment and at 15% in the 4th. Thus the soil moisture in which the plant reaches wilting gradually lowered as the time of the treatment advanced. The variation curve of the osmotic value caused by the wilting is shown in Fig. 2. The plant grown in the 80% and 50%

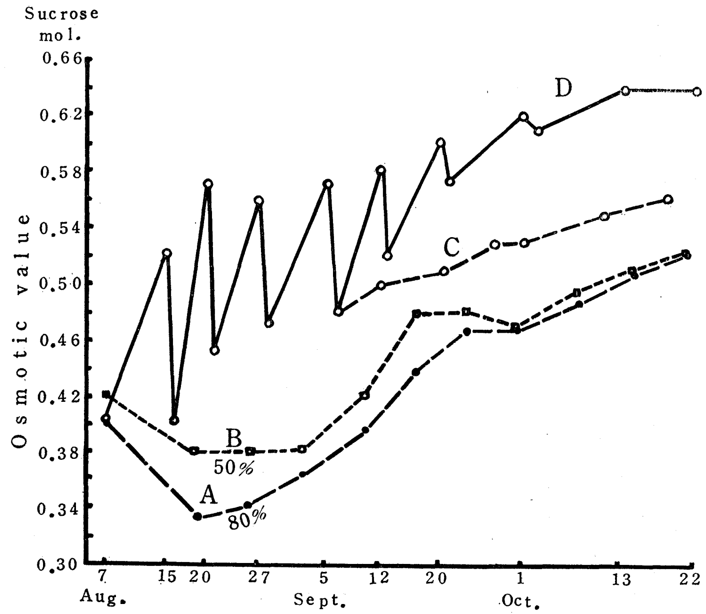


Fig. 2. Variation curves of the osmotic value of soybeans caused by the wilting treatment. (Variety Tamanishiki)

A Control (80% constant) B Control (50% constant)

C Maintained in the moist soil condition after wilting 4 times

D Wilting 8 times

soil moisture was denoted as the control A and B respectively. Even in the plant grown in constant soil moisture as in the case of the controls A and B, the osmotic value gradually increased as the plant grew. In the plant subjected to wilting the osmotic value rose at wilting and dropped at recovery.

The ascended maximum value and the descended minimum value increased step by step as the treatment was repeated. The curve of the mean value ascended as wilting was repeated. When soil moisture was regained, the osmotic value decreased but it remained a little higher than that of the control. This acquired value was maintained to the last stage of growth. Therefore it was considered that by the hardening of four times wilting the physiological accommodation was established in the form of the fixed ascension of the osmotic value.

Exp. 3) Osmotic variation in plants wilted 8 times.

This time plants were subjected to wilting 8 times. The repetition of osmotic ascension and descension at every treatment was observed as in the former experiment not only till the 4th wilting but also until the 8th wilting. But at the last treatment the minimum value became equal

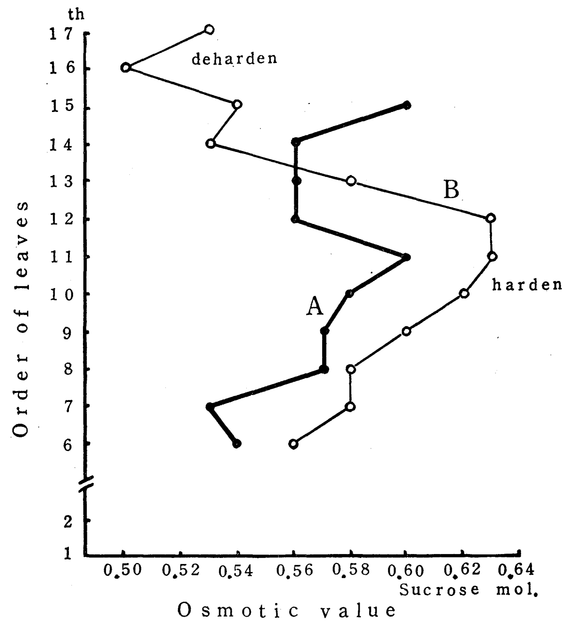


Fig. 3. Comparison of the osmotic value of the leaves hardened with the wilting treatment with that of the dehardened leaves which regenerated after the treatment.

A Control (80% constant) B Maintained in the moist soil condition after wilting 4 times to the maximum, and the acquired value maintained itself when soil moisture was regained to 80% constant (Fig. 2).

Exp. 4) Osmotic value of the hardened and dehardened leaves.

When the plants grew in moist soil condition after the 4 times wilting treatment, new leaves developed in the upper parts of the shoots. The comparison of the osmotic value of the lower leaves (subjected to wilting) with that of the upper leaves (rejuvenated) is indicated in Fig. 3. The lowest 5 leaves had been dropped when the observation began. The osmotic value of the 6th to the 13th which grew during the wilting was 0.04 mol higher than that of the control A (80%). The leaves above the 14th developed after wilting and their osmotic values were 0.06 mol lower than that of the control A. This fact indicated that the new shoot which sprouted from the rejuvenated growing part adapted itself to the regained moisture condition. It was affirmed that even in the hardened individual some parts can be dehardened.

III. Influences of Soil Moisture Conditions on the Osmotic Value and Transpiration of Soybean Plants During the Period of Sexual Organ Formation

The growth stage in which the plant is particularly susceptible to undesirable environmental conditions is called "critical period" (Brounov, 1912). It is considered that the critical period in soybean plants lies in and around the flowering period on the basis of the temporary decrease of the osmotic value (Fukuda and Kaku, 1952) and of active transpiration (Matsubayashi, 1956). This experiment was carried out under the assumption that the period of flower bud differentiation began 20 days before flowering, since the duration of this period in soybean plants does not differ very much according to their varieties and its sowing time (Nagata, 1950).

Exp. 5) Effect of the temporal drying treatment during the period of flower bud differentiation or in the flowering period.
(Exp. plots F and G)

In plants grown in properly moist soil condition 80%, irrigation was temporarily stopped either during the period of flower bud differentiation (Exp. plot F) or during the flowering period (Exp. plot G), and the plants were forced to grow in dry soil condition (40%). The treatment was similarly done in the following Exp. 7 (Exp. plots B and C). As is shown in Fig. 4, the osmotic value of the plants (B and C or F and G) ascended during the treatment. Both in this case (F and G) and in Exp. 7 (B and C), the osmotic value was always higher in the plant in which the treatment had begun in the early stage of growth than in the one in which the treatment had begun in the later stage. Even when the soil moisture was regained to the previous properly moist condition (Full line in Fig. 4), the descension of osmotic value was not recognized. Namely the acquirement of the hyper-osmotic value was caused not only by wilting but also through a slight drought. Such fixation of osmotic ascension may be regarded as xeromorphic accommodation.

As shown in Fig. 5, during the drying treatment the transpiration of the plants dropped lower than that of the control (A) and even lower than the level of constant 40% control (J). When the soil moisture of the (G) plot regained its previous properly moist condition, the plants of these plots transpired more than those of the control (A) (Fig. 5).

Though the morphological characters of the plants in these plots (F·G) became xeromorphic as the growth of branches and leaves had been

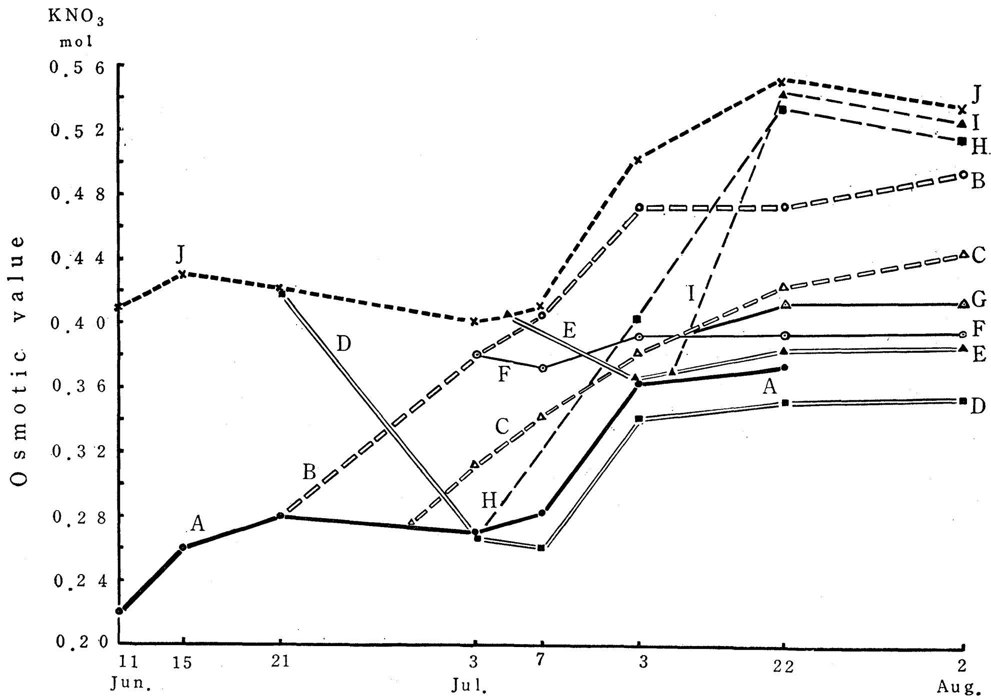


Fig. 4 Variation of the osmotic value with the changes of soil moisture condition in the period of flower bud differentiation or the flowering period.

A—Properly moist condition constant B—Drying treatment which began in the period of flower bud differentiation and kept until the last stage of growth C—Drying treatment which began in the flowering period and kept until the last stage of growth D—Moistening treatment which began in the the period of flower bud differentiation and kept until the last stage of growth E—Moistening treatment which began in the flowering period and kept until the last stage of growth F—Temporal drying treatment during the period of flower bud differentiation G—Temporal drying treatment during the flowering period H—Temporal moistening treatment during the period of flower bud differentiaton I—Temporal moistening treatment during the flowering period J—Dry condition constant restrained, the yield of seeds did not decrease so much as was expected in the dwarfed plants (Table 1). The restrictive effect of this treatment was stronger when the treatment was given during the period of flower bud differentiation than during the flowering period. This result agrees with the previous report of Fukui and Ito (1952), who stated that in soybean plants the deficiency of water is most restrictive in the period of flower bud differentiation. The restrictive effect of drying was distinct on vegatative growth, flower falling and the sterility of seeds. But a few seeds ripened which became larger in size than the normally ripened seeds. The larger weight per one seed prevented the decrease of seed yield.

Exp. 6) Effect of the temporal moistening treatment during the period of flower bud differentiation or in the flowering.
(Exp. plots H and I)

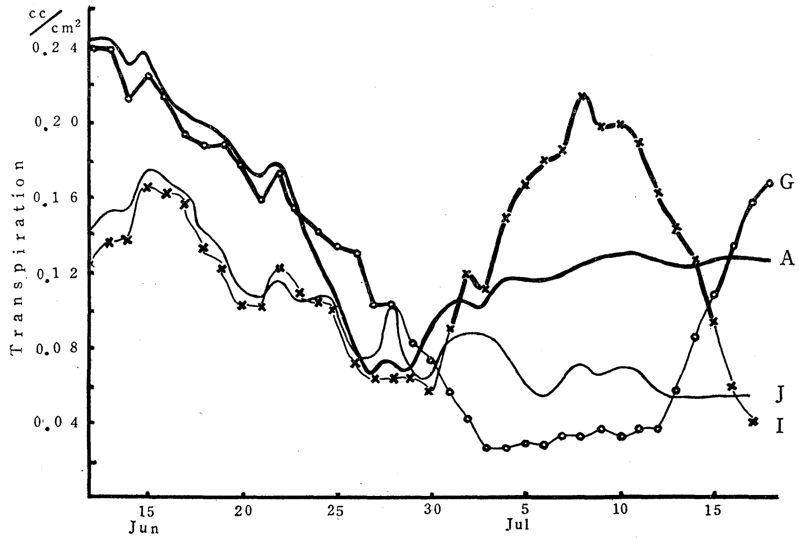
The plants grown constantly in dry condition 40% (J) was transferred to properly moist condition 80% (J→H and I). Both when the treatment was carried out during the period of flower bud differentiation (H), and in the flowering period (I), the osmotic value suddenly descended to the same value with that of the control (A) which was constantly grown in the properly moist condition 80%. But when the soil moisture had been made to decrease and returned to the dry moisture condition (40%), the osmotic value ascended to the same value with that of the control (J) grown in constantly dry condition 40%. From these results it may be concluded that the physiological accommodation caused by drought hardening may be fixed, but that the effect of physiological regulation to the wet condition is not fixed (Fig. 4, H•I).

As is shown in Fig. 5, the transpiration level of (I) plants kept in 40% soil moisture condition became twice higher when transferred to 80% soil moisture, and this level was one and a half times higher than that of the control (A) in constant 80% moisture. When the (H) and (I) plants, whose osmotic value and transpiration were regulated to adapt the plants to the wet condition, were transferred back to the initial constant 40% dry condition, the transpiration level became lower than the initial level (J).

The treated plants received larger benefit than the control (J) in increasing vegetative growth by reason of water supply, rather than in increasing the yield of seeds. As is shown in Table 1, the effect of this water supply was larger when the treatment was done in the period of flower bud differentiation than in the flowering period.

Exp. 7) Effect of the drying treatment which began in the period of flower bud differentiation or in the flowering period and kept until the last stage of growth.
(Exp. plots B and C)

When the plants in the constant moist condition 80% (A) was trans-



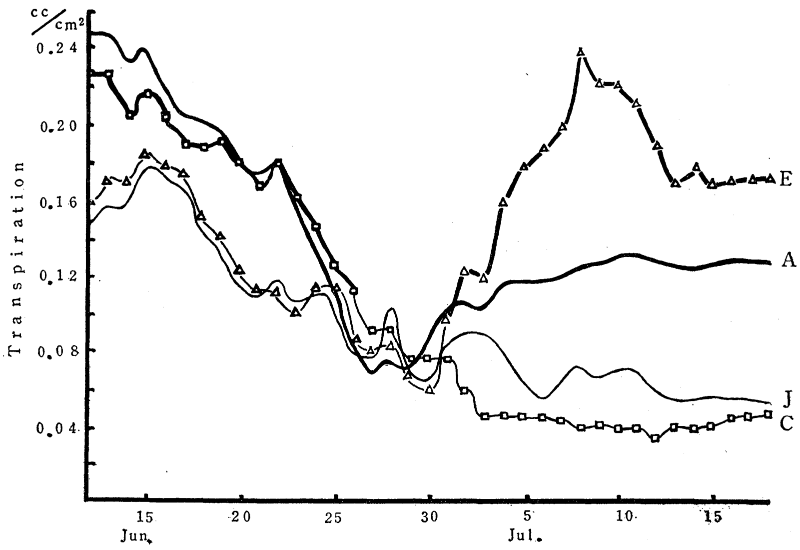


Fig. 5. and Fig. 6 Variation of transpiration with the changes of soil moisture condition in the flowering period.

ferred to the dry condition 40% in the period of flower bud differentiation (B) or in the flowering period (C), the result was similar to that obtained in Exp. 5 (Exp. plots F and G). The osmotic value suddenly ascended and transpiration suddenly dropped lower than those of the control of 40% contant (J) as is shown in Figs. 4, 6. The osmotic value of (B) plants which are treated in and after the period of flower bud differentiation ascended to the value of the control (J) plant grown in constant 40% dry condition but that of the (C) plant treated in the flowering period did not reach that of the control (J). As is already observed in Exp. 5, the capability of osmo-regulation in this Exp. 7 was larger in the earlier stage of growth than in the later stage. In this Exp. 7, the dry condition had been kept until the last stage of growth. The osmotic ascension corresponding to aging was weaker in the treated plants than in the control plants which had been kept in the constant dry condition. The difference of the osmotic value between (B) and (C) plants did not lessen. So that the value was highest in the constant dry plot (J), medium in (B), and the lowest in (C). The yield was very much restricted. This growth inhibiting effect was larger in the early stage of growth than in the later stage.

Exp. 8) Effect of the moistening treatment which began in the period of flower bud differentiation or in the flowering period and kept until the last stage of growth.

(Exp. plots D and E)

As is shown in Fig. 4, when the plant grown in constant dry condition 40% (J) was transferred to the moist condition 80% in the period of flower bud differentiation (D), the osmotic value suddenly descended so much that its level became lower than that of the control (A) of the constant 80% moist plot. When the treatment was done in the flowering period (E), the value descended to that of the control (A).

In the plants, grown in dry condition in their early stage, and keeping a high osmotic value, the high value entirely disappeared by the moistening treatment done in the period of flower bud differentiation or in the flowering period. Thus these descensions of the osmotic value occurred at the stage when the osmotic ascent accompanied by vegetative aging did not progress remarkably yet even in the plant (J) in Fig. 4. The enlarged osmotic value in the hardened plant in Exp. 4 (Fig. 3) was fixed in the leaves which were aged enough. So that the fixation of the osmotic value which occurred through the repetitive wilting treatment or by the temoral drying treatment may have happened with the aging of leaves. According to Hatakeyama (1947), the osmotic value of lawland rice grown in a dry field for one month, was higher than the value of control plants grown in a paddy field and this difference was observed for one month even after the transplantation of them to a paddy field. Thus he affirmed the continuance of hardening effect on rice plants. The leaves of a rice plant begin to have their own aging pace in a short time after tillering and the aging of this plant progresses stage by stage. The present author considers that the fixation in the rice plant might have happened in the aging state of the seedling leaves.

As is shown in Fig. 6, the transpiration of the (E) plot suddenly increased by the moistening treatment and was more vigorous than that of the control (A) of constant 80%. According to Wada (1949), the rice plant grown in a dry nursery transpires very weakly in a paddy field. He considers that the control of transpiration in rice seedlings grown in dry condition may happen during the first half of the growth stage. Clark and Levitt (1956) state that even the relatively mesophytic soybean plant may be able to reduce cuticular transpiration as a result of exposure to drought but this is not a true drought hardening i.e., the plant can undergo pseudohardening. Then, the author supposes that the transpiration of the soybean plant may be regulated by the stomatal transpiration which varies

Table 1. Yields in soybeans influenced by the changes of soil moisture condition during the period of sexual organ formation. (Variety—Shirosaya No. 1)

Exp. plot	Length of stem	Number of pods	Number of beans	Weight of total beans
A	61.0 cm	25	47	3.7 gr.
B	26.0	9	14	1.5
C	42.0	13	20	1.9
D	35.7	15	25	2.6
E	26.3	10	18	1.8
F	33.6	19	30	3.6
G	38.0	17	25	3.0
H	29.6	6	7	0.7
I	25.6	6	7	0.7
J	15.0	4	4	0.2

A Properly moist condition constant
B Drying treatment which began in the period of flower bud differentiation and kept until the last stage of growth
C Drying treatment which began in the flowering period and kept until the last stage of growth
D Moistening treatment which began in the period of flower bud differentiation and kept until the last stage of growth
E Moistening treatment which began in the flowering period and kept until the last stage of growth
F Temporal drying treatment during the period of flower bud differentiation
G Temporal drying treatment during the flowering period
H Temporal moistening treatment during the period of flower bud differentiation
I Temporal moistening treatment during the flowering period
J Dry condition constant

easily according to the changes of soil moisture condition. In this point the rice plant is very different.

The yield of seeds and the growth of branches and leaves distinctly became larger through the moistening treatment than those of the control (J) in Table 1. In this case the increase of yield caused by moistening treatment was more remarkable in plants treated after the period of flower bud differentiation than those treated in the flowering period. Many investigators report various irrigation stages most effective for soybean plants. Tamai (1961) states it is in the period of branching and Urano (1958) in and after flowering. The result of this experiment suggests that the most important stage falls in the period of flower bud differentiation. Therefore irrigation may be needed earlier than those investigators mention. When comparison was made between two examples of moistening treatment (Exp. plot B—D), one treated before flower bud differentiation and the other after, the yield was more in the latter. So irrigation was more effective in the later stage than in the earlier. Urano (1958) explains this fact by pointing out that the moistness in the early stage of growth in the soybean plant brings about the injury of excessive moistness. Also it is considered that water requirement is larger in the latter half of growth than in the first. When the time of irrigation before and after the flowering period were compared in this experiment (Exp. plot C—E), the growth of branches and leaves was more prosperous in moistening before the flowering period, but there was little difference in the yield of seeds. It can be concluded that though the growth of branches and leaves became prosperous by the moistening done before the flowering period, the yield of seeds was remarkably restricted by dryness happening after that.

IV. Growth Periodical Variation of the Osmotic Value in Soybean Plants

There are many studies on the seasonal and daily changes of the osmotic value in plants (Craft et al., 1950), but the growth periodical variation is not yet elucidated. In general, the osmotic value increases as growth advances (Sato, 1925) and the value is low when the growth is prosperous and increses as growth slows down, and it is asserted that there is an inverse correlation between the osmotic value and the growing speed (Ursprung and Blum, 1916; Reed, 1921). Now to analyse the growth periodical variation of the osmotic value, comparative investigations were carried out on two varieties of soybeans with a different growth periodicity each, cultivating them in the same culture condition and also in the same season.

Exp. 9) Comparison of growth periodicity between the medium and late varieties.

The medium variety and the late variety which are different in growth periodicity, were cultivated in two soil moisture conditions, e.g., in a moist plot (80%) and in a dry plot (20%) at the same time and their growth periodicities were compared (Tables 2, 3). Table 2 shows the growth periodicity of the plant sown in early summer. The late variety flowered 12 days later and podded 23 days later than the medium variety in a moist plot. This is because the late variety required a long time from flowering to podding. In a dry plot the medium variety matured earlier and the late one later than the one grown in a moist plot. Table 3 shows the growth periodicity of the plant sown in midsummer. The plant sown in midsummer matured earlier than one sown in early summer but the relation between the medium and the late varieties was similar to that of those sown in early summer.

Table 2. Comparison of growth periodicity in the medium and the late variety of soybeans in early summer.

Variety of soybean	Moist plot (80%)			Dry plot (20%)		
	Days before flowering	Days before podding	Difference	Days before flowering	Days before podding	Difference
Late-season (Tamanishiki)	72	89	17	75	89	14
Medium-season (Shakkinnashi)	60	66	6	54	60	6
Difference of two varieties	12	23		21	29	

Table 3. Comparison of growth periodicity in the medium and the late variety of soybeans in midsummer.

Variety of soybean	Moist plot (80%)			Dry plot (20%)		
	Days before flowering	Days before podding	Difference	Days before flowering	Days before podding	Difference
Late-season (Iyo)	45	59	14	53	63	10
Medium-season (Shakkinnashi)	31	37	6	36		
Difference of two varieties	14	22		17		

Exp. 10) Growth periodical variation of the osmotic value.

As is denoted in Figs. 7 and 8, the tendency of osmotic variation did not differ according to the difference of variety or to the time of sowing. The osmotic value gradually increased as the plant grew, and attained the maximum value at ripening. But once before flowering there appeared a sudden decrease of the osmotic value, which, however, again ascended at podding. This periodical variation similarly occurred in two varieties, medium and late, although both matured under different meteorological conditions. Therefore the temporary descent of the osmotic value in the flowering period is regarded as a characteristic of the growth periodical variation in soybean plants.

Exp. 11) Regulation of the growth periodical osmotic variation caused by the changes of climatic conditions.

The osmotic value in the dry plot is indicated by thin lines in Figs.

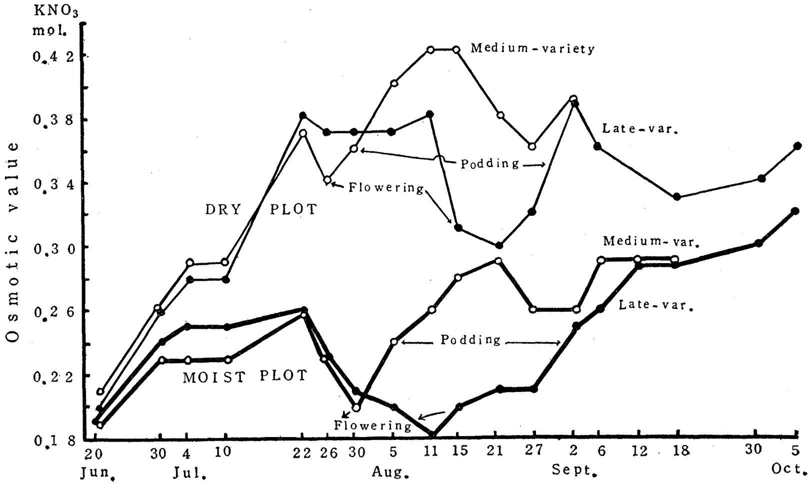


Fig. 7. Osmotic variation during the growing duration in the medium and the late variety of soybeans cultured in early summer.

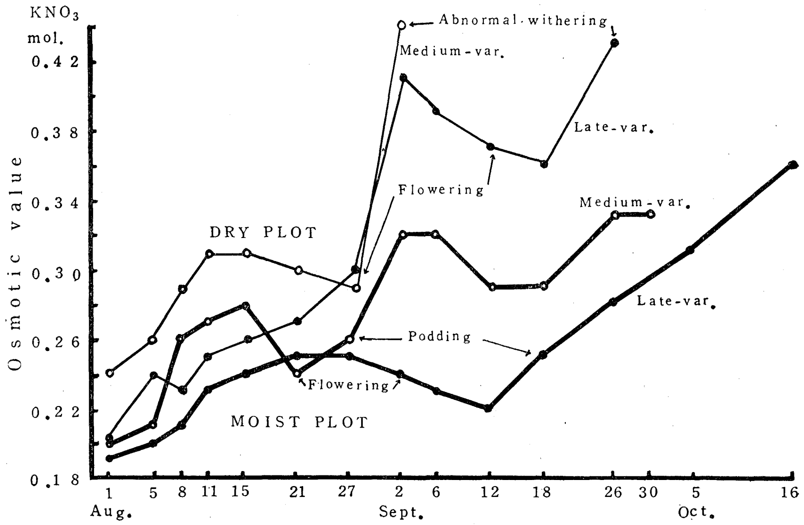


Fig. 8. Osmotic variation during the growing duration in the medium and the late variety of soybeans cultured in midsummer.

7 and 8. Growth periodical variation was observable both in the plant in a moist plot and in a dry plot before podding, but in the last stage of growth, with the exception of the withered one sown in midsummer, it gradually decreased and approached the value of the moist plot. Namely the differences of the osmotic value in the moist and the dry plot are remarkable in the middle stage of growth (the flowering and the podding). It is asserted that the ascended osmotic value in the dry plot in midsummer is caused by the forced catatonosis owing to the meteorological condition, and the plant gradually grows keeping the descended osmotic value with the cool autumn weather. That is to say, the changes of air temperature affect only secondarily the growth periodical osmotic variation.

V. Effect of the Photoperiodic Treatment on the Growth Periodical Variation of Osmotic Value in Soybean Plants

The medium and the late varieties of soybeans which are different in growth periodicity were cultivated and their variation of the osmotic value in the growing duration was investigated. Then both of the varieties showed a similar tendency of growth periodical osmotic variation according to each growth periodicity regardless of meteorological conditions. Therefore individuals which have different velocities in growth periodicity by different photoperiodic treatments were made in the same variety and the growth periodical osmotic variation in each was investigated.

Exp. 12) Shortening of growth periodicity caused by the short day treatment and its effect on the growth periodical osmotic variation.

As is seen in Table 4, the flowering period was shorter in the early treated short day plot (C) by 39 days and in the late treated short day plot (B) by 15 days than the natural day length plot (A). In short day treated plots (B, C), podding began only 4~5 days after the commence-

Table 4. Effect of the shortening of growth by short day treatment. (Variety—Asomasari)

Experimental plot	Beginning of short day treatment		Beginning of flowering					Days from flowering to podding	Diff. (A-B, C)
	Date	Days after germination	Date	Days after germination	Diff. (A-B, C)	Days after short day treatment	Diff. (C-B)		
Natural day length (A)			Aug. 8	77				21	
Late treated short day (B)	Jul. 5	43	Jul. 24	62	15	19		5	16
Early treated short day (C)	Jun. 1	8	Jul. 1	38	39	30	11	4	17

ment of flowering, while in the control (A) it took place three weeks after it. The short day treatment accelerated not only flowering but also podding. Borthwick and Parker (1938, 1940) stated that matured leaves are more sensible to photoperiodic stimulus than younger ones. In this experiment the late treated short day plot (B) flowered 11 days earlier than the early treated one (C). So it may also be said that a matured plant is more susceptible to photoperiodic stimulus than an immature one. It is already reported by many authors that dwarfishness occurs as a result of the precocious differentiation of reproductive growth caused by the short day treatment. The same was also observed as is indicated in Fig. 9.

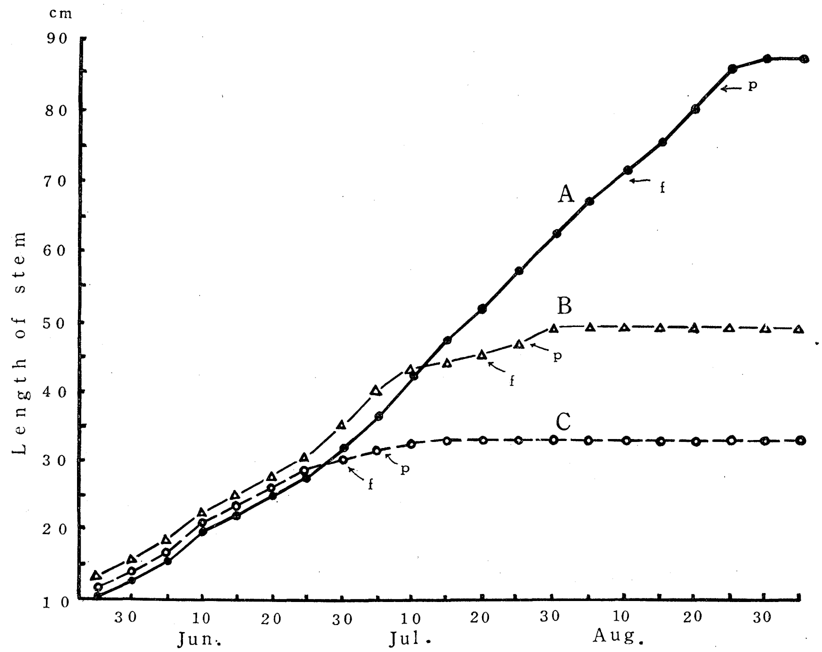


Fig. 9. Growth curves of stems of soybeans whose short day treatment began at various times.

A—Natural day length plot B—Late treated short day plot
C—Early treated short day plot
f—flowering time p—podding time

As is denoted in Fig. 10, the osmotic values of all plants increased gradually as the plants grew, whether or not by the short day treatment, and they descended somewhat at flowering and ascended again at podding. The maximum value appeared at the ripening period. This common tendency was similar to that in the above-mentioned case and this tendency appeared under different climatic conditions because growth periodicity lags in each experimental plot. Therefore this is considered as a characteristic of growth periodical variation, and this peculiar tendency shows no change by the short day treatment.

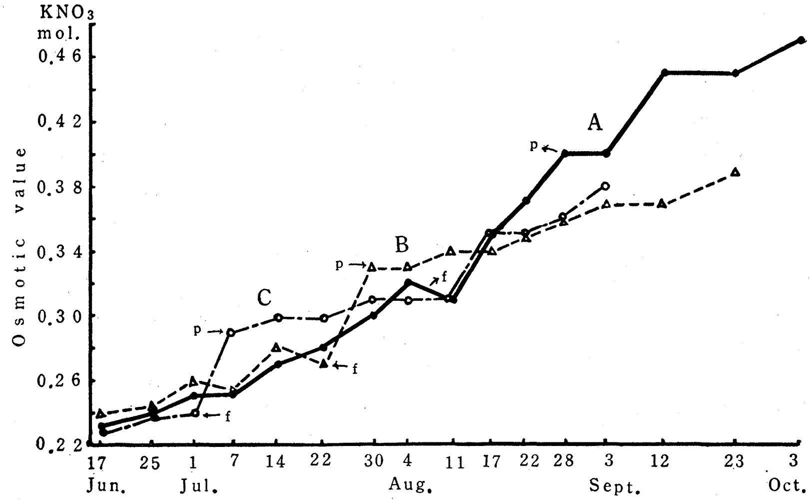


Fig. 10. Osmotic variation during the growing duration in soybeans which showed different growth periodicities by the short day treatment.

A—Natural day length plot B—Late treated short day plot
C—Early treated short day plot
f—flowering time p—podding time

In Table 5, in comparison with the osmotic value of each plot at the same physiological stage, the values of the early treated short day plot (C) are the lowest, and those of the natural day length plot (A) are the highest, at each stage. These differences of the osmotic value in each plot gradually increases as growth advances. Therefore the above-men-

Table 5. Osmotic value in the same physiological stage of soybeans which have different growth periodicities by the short day treatment.

Experimental plot	Flowering period			Podding period			Riening period			Number of ripe pod
	Date	Osmotic value (KNO_3 mol)	Diff. (A-B, C)	Date	Osmotic value (KNO_3 mol)	Diff. (A-B, C)	Date	Osmotic value (KNO_3 mol)	Diff. (A-B, C)	
Natural day length (A)	Aug. 7	0.31		Aug. 28	0.40		Sept. 22	0.45		55
Late treated short day (B)	Jul. 22	0.27	−0.04	Jul. 28	0.33	−0.07	Aug. 22	0.35	−0.10	40
Early treated short day (C)	Jul. 1	0.24	−0.07	Jul. 7	0.28	−0.12	Jul. 28	0.31	−0.14	18

tioned fact may be considered to indicate that the plant which has its growth period shortened by the short day treatment attains flowering in the state of a lower osmotic value and the plant in the natural day length attains the state of a higher osmotic value because the growth period lags. That is, there is no interrelation between the degree of aging in vegetative body and the differentiation of flower bud.

Exp. 13. Influences of the after effect of the short day treatment on growth periodicity and on osmotic variation.

If the short day treatment is done at the beginning of growth of a plant only for nine days from the 5th day after its germination, and then the plant grows under natural day length, the inflnence of the short day treatment is effective on flowering. As is shown in Table 6 the beginning of flowering was earlier by 42 days in the short duration (9 days) short day plot (C) and by 46 days in the long duration (31 days) short day plot (B) than in the natural day length plot (A). Therefore the after effect of the earlier stopped short day treatment may be sufficiently observed on the acceleration of flowering even though the treatment continued only for 9 days and not so long as 31 days. Podding took place 16 days after the commencement of flowering in the short duration short day plot (C) as in the natural day length plot (A), while it took place only 2 days after in the long duration short day plot (B). This indicates that the effect of the short day treatment in the early growth stage is remarkable on the acceleration of flowering but none on podding. From this result and from the experiment of Kiyosawa et al (1962), it is clarified that the ac-

Table 6. Influences of the after effect of short day treatment and the light break treatment on the growth periodicity in soybeans. (Variety—Asomasari)

Experimental plot	Photoperiodic treatment		Beginning of flowering			Beginning of podding		
	Duration	Days	Date	Days after germination	Diff.	Date	Days after flowering	Diff.
Natural day length plot (A)			Aug. 6	83		Aug. 22	16	
Long duration short day plot (B)	May 22 ~Jun. 21	31	Jun. 21	37	46	Jun. 23	2	14
Shortduration short day plot (C)	May 20 ~May 28	9	Jun. 25	41	42	Jul. 11	16	0
Light break plot (D)	May 22 ~Jul. 29	69	Jul. 20	66	17	Jul. 28	8	8

celeration of podding results only from the short day treatment continued after flowering. Osmotic variation is shown in Fig. 11. The osmotic value in the early stage of growth is lower for some time than in the natural day length plot. However, after flowering and podding it exceeds the latter and at the last stage of growth it is exceeded by the natural day length plot. The treated plant became precocious with a high osmotic value in comparison with that of the natural day length plot which had a long duration of vegetative growth. The latter, however, came to have a higher osmotic value than the former when it reached the same physiological stage. Consequently, the more slowly the plant matures, the higher the osmotic value is in proportion to their length of duration of vegetative growth (Table 7).

Table 7. Osmotic value in the same physiological stage of soybeans which have different growth periodicities by several photoperiodic treatments.

Experimnetal plot	Flowering period			Podding period			Ripening period		
	Date	Osmotic value (Sucrose mol)	Diff.	Date	Osmotic value (Sucrose mol)	Diff.	Date	Osmotic value (Sucrose mol)	Diff.
Natural day length plot (A)	Aug. 8	0.45		Aug. 23	0.55		Sept. 14	0.61	
Long duration short day plot (B)	Jun. 22	0.34	−0.11	Jun. 24	0.35	−0.20	Jul. 22	0.41	−0.20
Short duration short day plot (C)	Jun. 24	0.35	−0.10	Jul. 7	0.37	−0.18	Aug. 2	0.48	−0.13
Light break plot (D)	Jul. 22	0.41	−0.04	Jul. 28	0.45	−0.10	Aug. 31	0.54	−0.07

Exp. 14) Influences of light break treatment on growth periodicity and on osmotic variation.

The light break is a treatment to insert a short light period in the midst of a dark period. It prevents the accelerating effect of the short day treatment on flowering (Hamner et al, 1938). In this experiment, as is shown in Table 6, when the light break for 30 minutes was inserted in the midst of the dark period of 14 hrs., the coming of flowering of the treated plot (D) became earlier by 17 days than that of the natural day length plot (A), but later by 29 days than that of the long duration short day plot (B). The effect of the short day treatment was so much diminished by the light break. The accelerated podding in the long duration short day plot (B) began 2 days after the commencement of flowering, but in the light break plot (D) it took place 8 days after. The acceleration effect on podding of the short day treatment was also diminished by 6 days by the light break.

Therefore the light break treatment does not diminish the whole effect of the short day treatment. The tendency of osmotic variation is shown in Fig. 11. The plant in the light break plot shows a higher osmotic value than that in the natural day length plot in or after flowering, because the latter is in a younger stage of growth than the former. The osmotic value of the latter, however, exceeds that in the other plots when the latter matured.

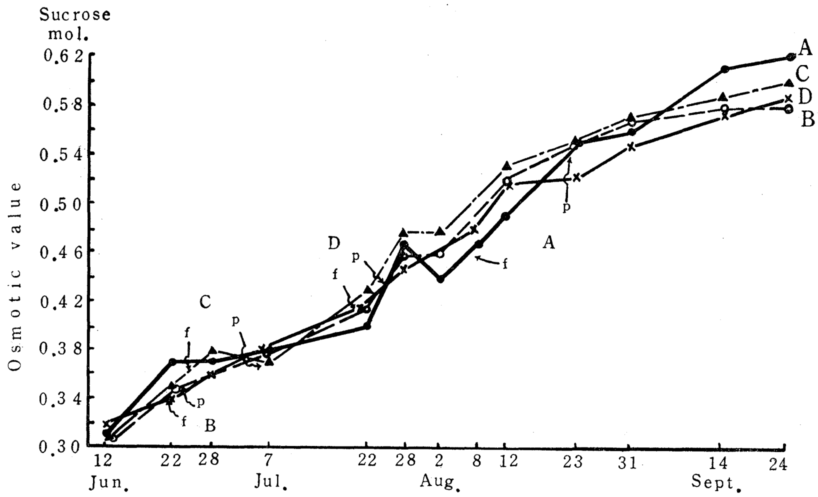


Fig. 11. Osmotic variation during the growing duration in soybeans which showed different growth periodicities by several photoperiodic treatments.
A—Natural day length plot B—Long duration treated short day plot
C—Short duration treated short day plot D—Light break plot
f—flowering time p—podding time

VI. Hydrature of Soybeans on the Gradient Condition of the Soil Moisture

Soil moisture was kept in eight plots at 100, 80, 65, 50, 35, 27, 20 and 13% respectively of saturated water capacity, and some factors of water economy on soybean plants grown in these soil moisture gradients were examined.

Exp. 15) Variation of the osmotic value during the growing duration.

The variation of the osmotic value in the eight gradients of soil moisture is shown in Fig. 12. Throughout the eight gradients the osmotic value was lower under a moist condition and higher under a dry condition as is generally observed. But the osmotic value was not invariably deter-

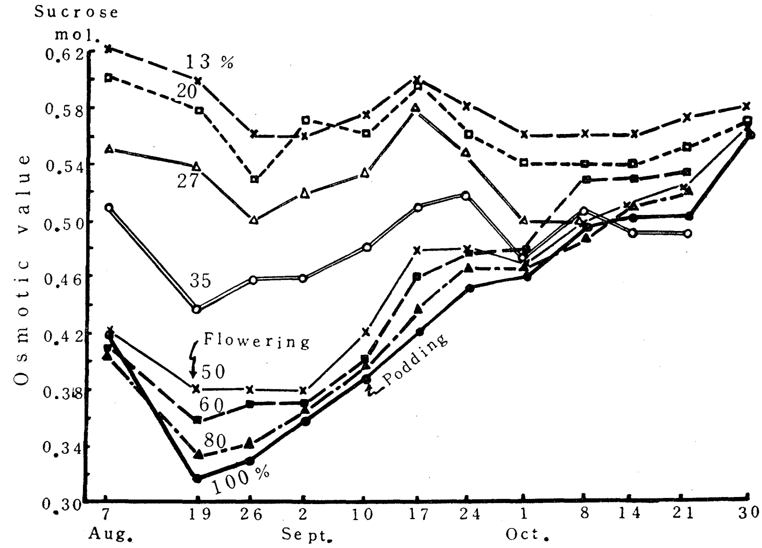


Fig. 12. Osmotic variation during the growing duration in soybeans grown in the gradient condition of soil moisture.

mined only by soil moisture. The periodical variation of osmotic values under the gradients may be broadly divided into three categories.

(A) Moist plots (100, 80, 65, 50% soil moisture)

In spite of the difference in soil moisture, the osmotic values of these plants grown in these four soil moisture plots were not very different. They increased as the growth stage advanced though they temporarily descended in the flowering period.

(B) Shift plots from moist to dry (35, 27% soil moisture)

The osmotic values of these plots were almost intermediate among the eight plots, and the tendency of osmotic variation during the growing duration also was between (A) and (C).

(C) Dry plots (20, 13% soil moisture)

Plants grown in these plots always showed a higher osmotic value than those in the other plots. Though in the other plots the osmotic value increased as growth advanced, with the exception of the temporal descent in the flowering period, a gradual descension of the osmotic value was observed through the later stage of growth. Therefore in the last stage of growth, the osmotic value of dry plots approached that of the moist plots, and also that of the shift plots. These osmotic descensions observed in the dry soil moisture condition were similar to the result of Exp. 11, and are regarded as the secondary modification of general growth periodical variation which took place with the change of air temperature.

In the early stage of growth, the range of osmotic differences caused by the differences of soil moisture was very extensive, but it became narrow in the last stage of growth because the osmotic value gradually increased in moist plots and descended in dry plots.

Exp. 16) Variation of the water content of leaves in the soil moisture gradient.

As is seen in Table 8, the water content became less as the growth period advanced, and the less the soil moisture, the less the water content. In comparing the ratio of the water content and osmotic value on Oct. 1 with that on Sept. 17, an inverse relation was observed between the moist

Table 8. Water content of leaves in soybeans grown in the gradient condition of soil moisture (g/dry wt.).

Soil moisture plot	Sept. 10	17	Oct. 1	8	14	21	29
100%	2.33	2.55	1.89	1.98	2.00	2.00	2.10
80	2.31	2.00	2.14	2.26	2.00	2.40	2.10
65	2.69	2.28	2.00	2.17	2.70	2.20	—
50	2.49	2.20	1.76	1.55	2.46	1.96	1.89
35	2.38	1.55	1.75	1.57	2.19	1.93	1.56
27	2.31	1.16	1.74	1.65	2.01	1.96	2.10
20	2.13	1.62	1.83	1.76	1.92	1.64	1.84
13	1.94	1.50	1.90	1.57	1.84	1.74	1.73

Table 9. Ratio of the osmotic value and water content before and after podding.

Soil moisture plot	Osmotic value (atm.)			Water content (g/dry wt.)		
	Sept. 17 (a)	Oct. 1 (b)	Ratio (b/a)	Sept. 17 (a)	Oct. 1 (b)	Ratio(b/a)
100%	11.7	13.8	118%	2.55	1.89	74%
80	12.4	13.3	107	2.00	2.14	107
65	13.0	13.7	105	2.28	2.00	87
50	13.7	13.3	97	2.20	1.76	80
35	15.0	13.3	89	1.55	1.75	110
27	17.1	14.3	84	1.16	1.74	150
20	17.4	15.0	86	1.62	1.83	113
13	17.4	16.0	92	1.50	1.90	120

and dry plots. As is denoted in Table 9 in October as compared with September, the osmotic value increased and the water content decreased in the moist plots while an opposite tendency was seen in the dry plots.

Exp. 17) Variation of transpiration in the soil moisture gradient.

The mean transpiration of ten days from a unit leaf area ($1\,cm^2$) in each soil moisture is indicated in Fig. 13. Transpiration was much in moist plots and less in dry plots. The transpiration in each plot decreased as the season advanced though the relative air humidity was 60~70% through the whole season. In each soil moisture, no seasonal variation of relative transpiration was distinct. In the moist plots, shift plots from

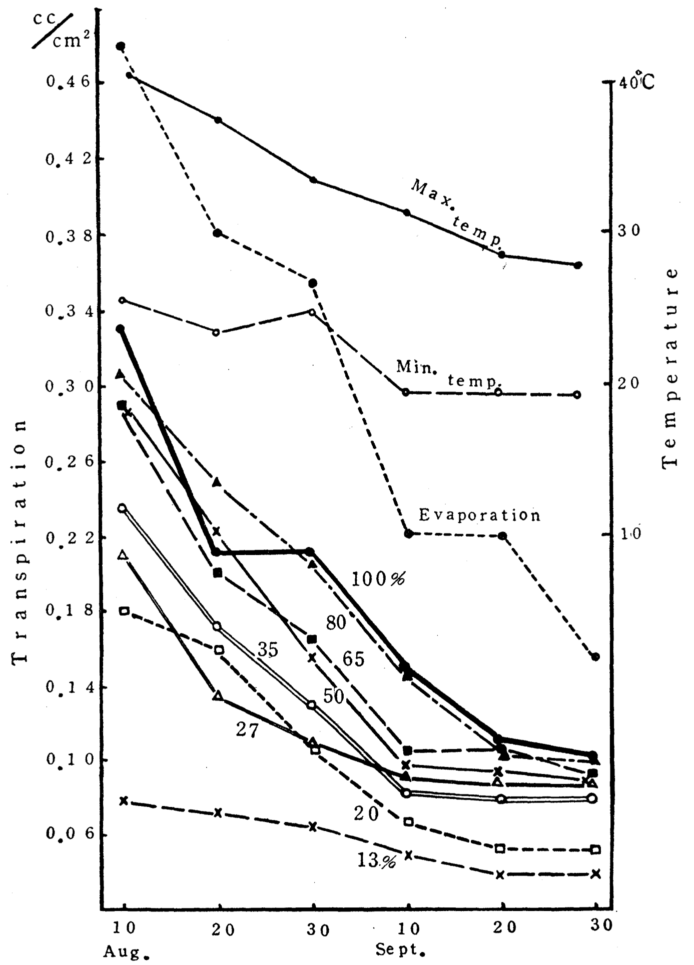


Fig. 13. Changes of transpiration during the growing duration in soybeans grown in the gradient condition of soil moisture.

moist to dry, and dry plots the relative transpiration was respectively 70～45, 50～35 and 40～15%. The evaporation decreased till it dropped to 1/3 at the end according as the maximum and minimum temperatures gradually decreased.

Table 10. Relative transpiration in soybeans grown in the gradient condition of soil moisture.

Soil moisture plot	Aug. 5—14	15—24	Sept. 25—3	4—13	14—23	Oct. 24—4
100%	69.9	54.0	60.0	70.0	50.2	65.5
80	63.0	62.8	60.0	68.0	43.8	61.6
65	58.0	50.2	46.0	48.5	49.1	57.8
50	58.3	58.0	44.5	46.0	48.1	63.0
35	50.5	44.2	37.0	41.0	35.0	51.0
27	44.4	38.0	33.5	43.0	39.5	59.0
20	39.1	40.0	32.0	31.0	24.2	33.0
13	16.8	24.8	18.2	22.0	14.8	31.2

Exp. 18) Relation between the osmotic value and yield.

In comparing the yield in different soil moisture plots, there may be distinguished three groups (Table 11).

(A) Moist plots (100, 80, 65, 50% soil moisture)

Though 100% water capacity is generally an excessive moisture, plants grown in 100% were not observed to be in excessive moisture, because the original habitat of soybeans is a moist land, and the plant was kept in 100% only just after the watering which was done only one time a day. In 80 and 100% plots, the growth of branches and leaves and the ripening of seeds were very prosperous compared with the other plots, and the plots were considered as properly moist. In 65 and 50% plots the growth was a little worse than the 100 and 80% plots but far better than the shift plots from moist to dry.

(B) Shift plots from moist to dry (35, 27% soil moisture)

These plots also shifted between (A) and (C) in yield as well as in osmotic difference.

(C) Dry plots (20, 13% soil moisture)

In these plots the yield was much worse than in the other plots, and especially the yield of seeds was more checked than the growth of stems and branches.

Table 11. Yields in soybeans grown in the gradient condition of soil moisture. (Variety—Tamanishiki)

Soil moisture plot		Length of stem	Number of pods	Number of beans	Weight of total beans	Weight of a bean
Moist plots	100%	73cm	25	36	7.9gr.	0.22gr.
	80	73	21	36	7.5	0.21
	65	70	19	27	5.1	0.19
	50	62	17	20	4.5	0.23
Shift plots from moist to dry	35	52	12	11	2.2	0.20
	27	52	9	10	2.2	0.22
Dry plots	20	48	2	3	0.7	0.25
	13	30	1	2	0.5	0.23

VII. Influences of the Photoperiodic Treatment on Hydrature in Long Day Plants

Influences of the photoperiodic treatment on the osmotic value and transpiration in the broad bean

The broad bean has been regarded as a long day plant in photoperiodicity (Yoshii, 1949). In these experiments carried out both in cultivation of autumn and winter sowing, the outer morphological changes, i.e. the accerelation of stem elongation and the decrease in branching markedly appeared in the long day treated plant, as is shown in the Fig. 17B, but no change of growth period in flowering and podding was found. According to these results the broad bean must be regarded as a poor long day plant in flowering habit. Now it is observed that changes of the osmotic value and transpiration take place with several photoperiodic treatments.

Exp. 19) Cultivation in autumn sowing. Plants germed on Nov. 13, 1957, were placed in three experimental plots. One plot was the control of natural day length (day length 10.5~13.0 hrs.), and the other two experimental plots were a long day plot (illuminated through the night) and a short day plot (day length 8 hrs.). The osmotic value was the highest in the long day plot and the lowest in the short day plot as is shown in Fig. 14, and this tendency did not change through the whole growing duration.

Transpiration was not measured through the whole growing duration but the rates of water loss from detached leaves were measured by torsion balance. As is seen in Table 12, the rates of water loss were higher in the short day plot than in the long day plot.

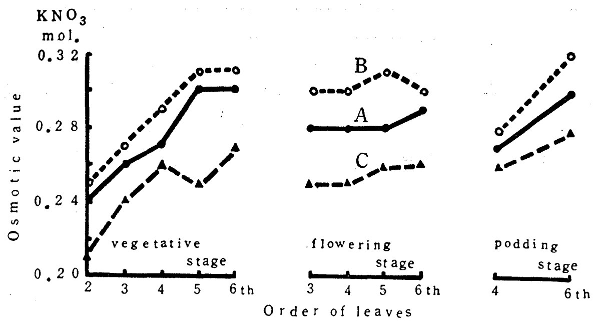


Fig. 14. Osmotic value in broad bean which suffered several photoperiodic treatments. (Autumn sowing)
A—Natural day length plot B—Long day plot C—Short day plot

Table 12. Water loss from the detached leaves of broad beans which suffered several photoperiodic treatments. (mg/cm^2)

Experimental plot	2nd leaves (Mar. 23)			5th leaves (Apr. 17)		
	10 min.	30 min.	60 min.	15 min.	30 min.	90 min.
Natural day length plot (A)	0.330	0.970	1.500	0.833	1.097	2.650
Long day plot (B)	0.233	0.660	0.837	0.785	1.355	2.715
Short day plot (C)	0.651	2.690	4.550	1.315	1.805	3.255

Exp. 20) Cultivation in winter sowing.

Plants germed on Jan. 26, 1956, were placed in two experimental plots. One plot was a natural day length plot (day length 10.0 hrs.~13.5 hrs.), the other a long day plot (day length 14.0 hrs.~16.5 hrs.). As is shown in Fig. 15, before the flowering period the osmotic value was higher

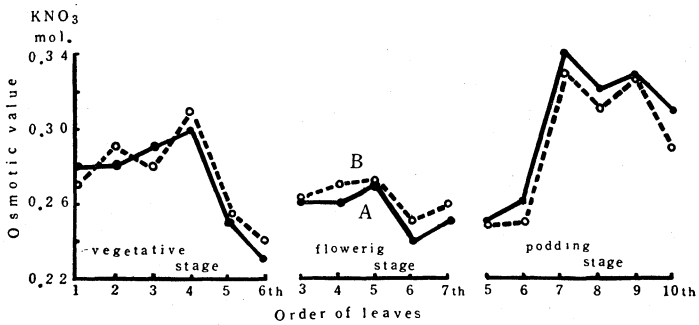


Fig. 15. Osmotic value in broad bean which suffered a long day treatment. (Winter sowing)
A—Natural day length plot B—Long day plot

in the long day plot than in the natural day length one, and this tendency was similar to the case of cultivation in autumn sowing but reversely after the podding period the osmotic value became higher in the natural day length plot than in the long day plot.

Transpiration from all the leaves of the plant was measured through the whole growing duration and the result is shown in Fig. 16. In general, transpiration was less in the long day plot than in the natural day length one and this was similar to the tendency of water loss from detached leaves in the case of sowing in autumn, in which case the rate was lower in the long day plot than in the short day plot. The number of stomata per unit leaf area was less in the long day plot than in the natural day length one, as is shown in Fig. 16.

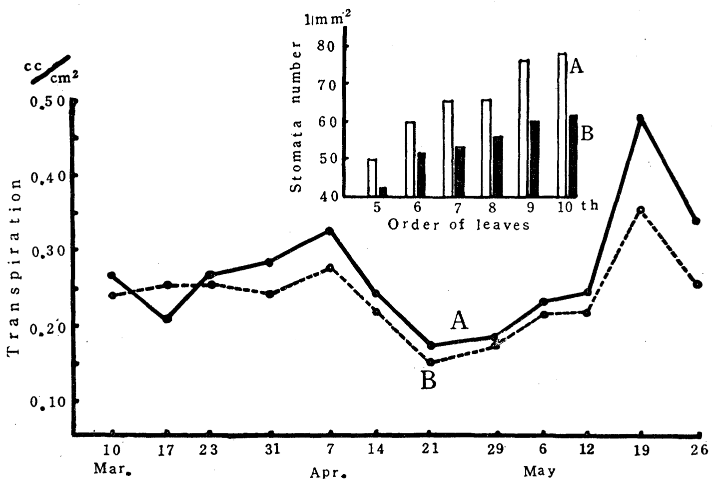


Fig. 16. Changes of transpiration during the growing duration and the number of stomata per unit leaf area of broad beans which suffered a long day treatment. (Winter sowing)

A—Natural day length plot B—Long day plot

As is seen above, both in sowing in autumn and in winter, the broad bean did not show long day reaction in growth periodicity though morphological changes by the long day treatment were observed. Then the changes of the osmotic value and transpiration with the long day treatment must be caused by the physical effect of light in the long day treatment. Now, the long day plot was in an extremely sunny condition by adding artificial illumination at night to natural day length. According to previous reports, the number of stomata in a unit area and transpiration were more in sun leaves than in shade leaves. This was observed experimentally by using an illuminated lamp (Maximov, 1925). Leaves grown in the sun have a higher osmotic value than those grown in the shade. From these experiments it is considered that the plant grown in the long day plot seems to be placed in the sunny condition, that photosynthesis increases, and that the osmotic value was higher in the long day plot than in the short day one.

Transpiration and the number of stomata in a unit area decreased in the long day plot and this is contrary to the case of sun leaves. This can be explained by the fact that the sun leaf in natural condition can not grow excessively owing to the repressive effect of the sunlight, but the growth in the long dry treatment was more or less immoderate because the osmotically active substance and growth hormone increase and this brings about the high growth of leaf size and the decrease of number of stomata per unit leaf area.

Exp. 21) Influences of the photoperiodic treatment on the osmotic value, transpiration and water permeability in the orpine.

The short day treatment (day length 8 hrs.) was carried out on this plant when the natural day length was in the long day condition (13 hrs.$\sim$14 hrs.). The growth of stems took place normally in the natural day length condition and the plant flowered at the beginning of September but in the short day plot the growth of the stem restricted and the plant did not bloom, as is shown in Fig. 18B. The orpine seems to be morphologically and photoperiodically a long day plant (Yoshii, 1949).

It is well known that this plant has a much lower osmotic value and less transpiration than common plants. In this experiment the osmotic value was within the range of 0.10$\sim$0.15 mol in KNO_3, and the growth periodical variation was not distinct. The effect of the short day treatment on the osmotic value was not very clear but it showed a lower value rather than in the natural condition (Fig. 19). This tendency was similar to the fact that the broad bean grown in the short day plot showed a lower osmotic value than the one grown in the long day plot. The transpiration of this plant was very little compared with the broad bean and no effect of the short day treatment was observed (Fig. 21). The number of stomata per unit leaf area was more in the short day plot than in the natural day length plot. This is similar to the case of the broad bean and is regarded as morphological changes caused by the short day treatment (Fig. 20).

As is shown in Table 13, the water permeability of protoplasma membrane of the short day treated plant was lower than that of the plant in the natural day length plot. That the osmotic value and water permeability were higher in the natural day length plot than in the short day plot is similar to the result of the following reports. Onoda (1943) observed in a rhododendron that the osmotic value and water permeability were higher in sun leaves than in shade leaves. And in winter the osmotic value and water permeability increased and also the frost hardiness of

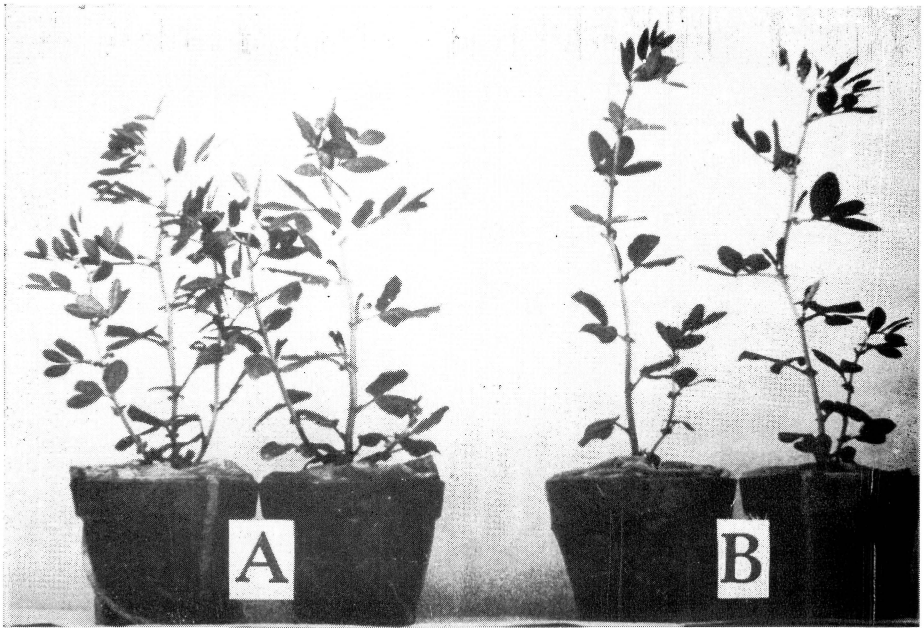


Fig. 17. Comparison of growth in broad beans which suffered a long day treatment. (Winter sowing) A—Natural day length plot B—Long day plot

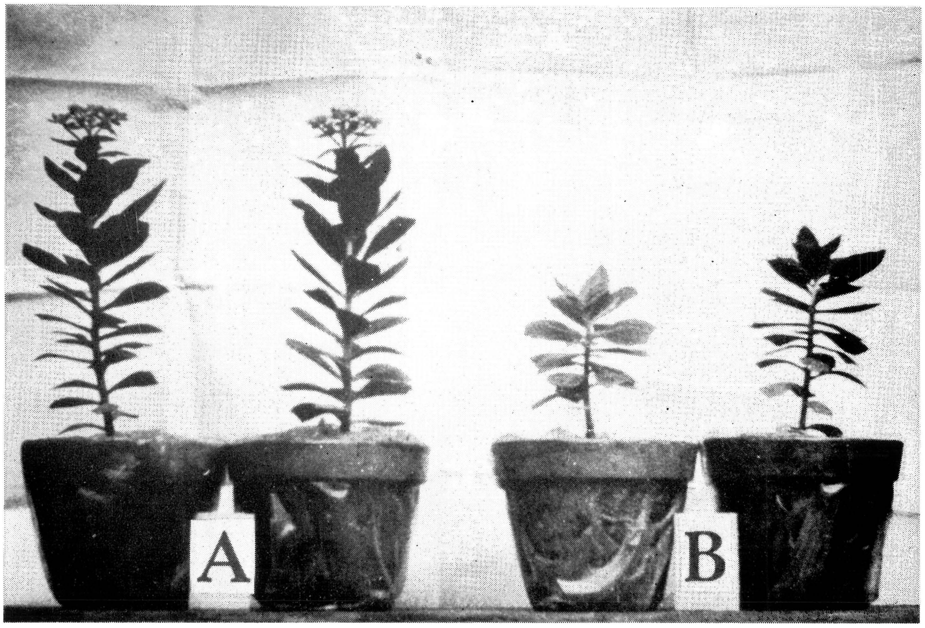


Fig. 18. Comparison of growth in orpines which suffered a short day treatment. A—Natural day length plot B—Short day plot

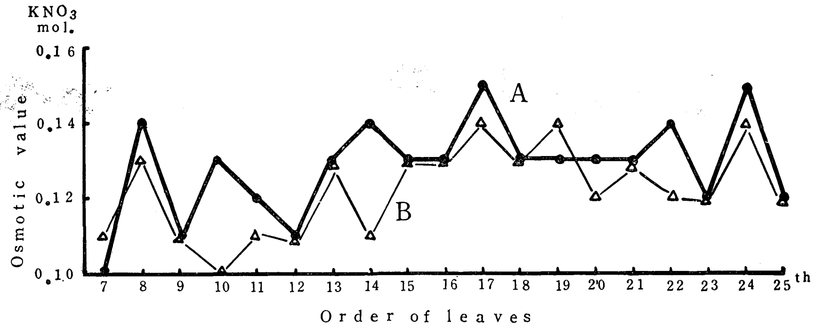


Fig. 19. Osmotic value in orpines which suffered a short day treatment.
A—Natural day length plot B—Short day plot

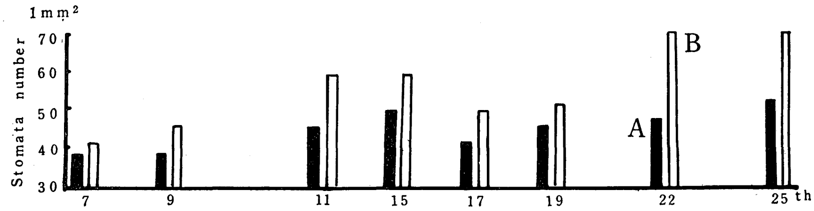


Fig. 20. Number of stomata per unit leaf area in orpines which suffered a short day treatment. A—Natural day length plot B—Short day plot

the plant did (Scarth and Levitt, 1937; Onoda, 1942). From these results it can be concluded that there is an interrelation between the osmotic

Table 13. Comparison of the osmotic value and water permeability in orpines which suffered a short day treatment.

Date	Order of leaves	Osmotic value (KNO_3 mol)		Water permeability (sec.)	
		Natural day length plot	Short day plot	Natural day length plot	Short day plot
Jul. 29	14 th	0.14	0.11	56	240
	20	0.13	0.12	117	190
Jul. 30	12	0.11	0.11	149	237
	23	0.12	0.12	148	60
Jul. 31	11	0.12	0.11	109	132
	21	0.13	0.13	180	227
Aug. 17	8	0.14	0.13	—	161
	24	0.15	0.14	71	175
Aug. 29	29	0.14	0.14	79	234

value and water permeability. On the other hand, Boon-Long (1941) stated that several treatments to increase the osmotic pressure of lesf cell sap caused a decrease in the water permeability of tissues. But his opinion does not seem to agree in general with the above-mentioned results.

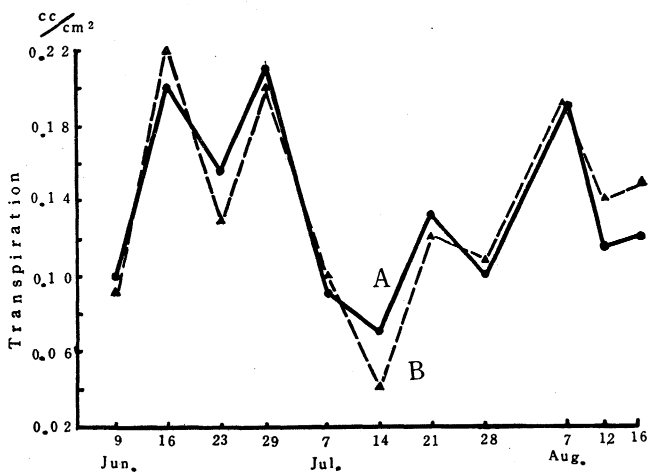


Fig. 21. Changes of transpiration during the growing duration in orpines which suffered a short day treatment.
A—Natural day length plot B—Short day plot

Discussion

Three plants, soybeans, broad beans and orpines used as materials have their respective characteristics in adaptability to the environmental factors. Nevertheless the soybean has an inclination for moistness, may endure in a heavy drought and in a high temperature. So that this plant may be taken as a type which has a wide capability of adaptation. Moreover this plant is sensitive to the photoperiodic treatment, by which its growth period can be changed. Morphologically, the broad bean showed the long day reaction but not in the flowering habit. This is also weak to a high temperature and not strong to drought. The orpine has a narrow adaptability to the external factors though it can tolerate severe drought by the characteristics as a succulent. Then the orpine and the broad bean may be taken as types which make a contrast to the soybean type.

(*1*) *The osmotic value in relation to the variation of soil moisture condition*

That the osmotic value of the plant increases when the external hydrature decreases may be considered as a phenomenon of functional adaptation (Fukuda, 1937; Takaoki, 1954). The range of hydrature accommodation when the plant meets with the dry soil condition varies in different plants, and at different growth stages in the same plants. In this study the variation of the osmotic value during the growing duration in soybean plants in the gradient condition of soil moisture was observed. The osmotic value did not always regularly follow the grade of soil moisture. For example, the osmotic values of plants in the moist soil conditions, i.e., 100, 80, 65, and 50% plots were approximately the same but they considerably varied in the dry soil moisture condition, i.e., 35, 27, 20 and 13% plots, and also the tendency of osmotic variation during the growing duration was different from that in the moist soil condition. These differences in plants in the moist and the dry soil moisture condition are concerned with the relation of soil-moisture content and moisture tension in the soil. The moisture tension suddenly increases when the soil-moisture contents become less than 40% in a sandy soil (Kramer 1949). Then, it is ascertained from these results that the osmotic value of the plants is not a distinct index to soil moisture in their habitat.

The wilting treatment has been known as one of the methods which give drought resistance to the plant (Tumanov, 1927). Soybean plants showed the symptom of permanent wilting, several days after irrigation stopped. When these treatments were repeated 8 times the minimum of the descended osmotic value in moistening became equal to the maximum of the ascended value in wilting and the value was fixed. When the soil moisture was regained to the properly moist condition after the 4th wilting, the osmotic value kept a little higher level than that of the control. This fixation of the osmotic value was seen only in the leaves grown while the treatment was continued, and the sprouted new leaves which rejuvenated in the regained moist condition were dehardened. Then, the ascension of the osmotic value by the wilting treatment is due to the hydrature accommodation accompanying aging. And this ascension is similar to the osmotic ascension accompanying the advances of growth.

(2) *Growth periodical osmotic variation and osmo-regulation caused by the changes of climatic conditions*

In the case of the same plant grown in the same soil moisture conditions, the osmotic value changes with the progress of growth. In general, the osmotic value increases as growth advances. This is termed the growth periodical osmotic variation in vegetative part. However the degree of osmotic ascension with the progress of growth differs in different kind of plants. For example, the osmotic value of the soybean plant in the last stage of growth is several times higher than that of the early stage but this distinct increase is not observed in the broad bean. And the osmotic value in the orpine is lower than that in general plants, and the range of its variation is very limited. It may safely be said that the soybean is euryhydrous and that the orpine is stenohydrous in hydrature regulation. The growth periodical osmotic variation is distinct in the soybean but is not observed in the orpine. Then, it can be considered that this growth periodical osmotic variation is peculiar to each plant. In the soybean, a secondary change may be observed that the osmotic value once descends in the flowering period but is regained with podding. And this secondary change seems to be one of the characteristic of growth periodical variation, because it may be observed in the cultivation of both the medium and late-varieties of the soybean which have different growth periodicities (Figs. 7, 8). So is it with one and the same variety which shows different growth periods by different photoperiodic treatments (Figs. 10, 11). According to Fukuda (1958), this osmotic descension is caused by much expenditure of solutes in cell sap to accelerate respiration which elevates physiological activity in reproductive organ formation and also in suction force of protoplasm. Then, the secondary change observed in the soybean plant is termed as the growth periodical variation where reproductive organ formation intervenes.

As is mentioned above, though the marked growth periodical osmotic variation in the soybean plant is distinct in the plant grown in the moist soil condition, in the plant grown in the dry soil condition the osmotic value ascends in the early stage and descends in the later stage of growth, and the value at the last stage comes nearer to the value of the moist soil condition (Figs. 7, 12). These phenomena of osmotic descension observed in the dry soil moisture condition seem to indicate that the osmotic ascension in a high temperature in summer is an unnatural osmo-regulation which is abnormal for the plant, and that it is a limited adaptation corresponding to the meteorological condition in summer. Therefore the osmotic value descends with the changes of meteorological conditions in autumn. It is termed the osmo-regulation caused by the changes of climatic conditions.

(3) *The osmotic value in relation to the aging of the plant*

The growth periodical osmotic variation in vegetative part is remarkable in soybean plants. Therefore, if their growth period is different, each osmotic value differs in the same variety grown in the same soil moisture condition. In the same growth season, the precocious plant advanced in growth shows a higher osmotic value than the serotinous plant delayed in growth, and in the same physiological growth stage, the osmotic value is lower in the more precocious plant and higher in the more serotinous plant (Figs. 10, 11; Tables 5, 7). Namely, the osmotic value at the same physiological stage is determined by the length of growing duration to reach this stage. Then the osmotic value depends on the vegetative growth stage and the length of aging duration. From this fact the ascension of the osmotic value may be an index which decides the grade of aging in vegetative part. There is no interrelation between the degree of aging in vegetative parts and the degree of maturation in the reproductive growth.

The capability of osmo-regulation is larger in the early stage of growth but osmo-accommodation does not happen unless growth advances to some degree. For instance, when the plant with the ascended osmotic value in the dry soil moisture condition in and before the period of flower bud differentiation or in the flowering period is transferred to the properly moist soil condition, the osmotic value descends to the value of the control and is not fixed (Fig. 4). When the plant with a low osmotic value in the moist soil condition from the early stage of growth is treated by temporary drying in the period of flower bud differentiation or in the flowering period, the osmotic value ascends and the value is fixed to same extent afterward though generally in these stages the osmotic value is kept low. Thus osmo-accommodation is observed. When the plant grown in the moist soil condition at the early stage of growth is transferred to the dry soil condition from in and after the period of flower bud differentiation or in the flowering period to the last stage of growth, the osmotic value ascends. In this case the grade of osmotic ascension is larger in the one treated after the period of flower bud differentiation than in the one treated after the flowering period (Fig. 4). Namely, the earlier the growth stage is, the larger the capability of osmo-regulation is, and osmo-accommodation is larger at a more advanced growth stage. These changes in the capability of osmo-accommodation in accordance with the growth stage has been overlooked by former students.

(*4*) *The osmotic value in relation to growth and yield*

Hitherto, the osmotic value has been studied physiologically in relation to drought resistance and frost resistance as one of the factors of water relation, and ecologically in relation to the habitat of the plant but has been relatively neglected in relation to the growth and yield. However, Ursprung and Blum (1912) and Reed (1921) pointed out that there is an inverse tendency between the growth speed and the osmotic value, and recently it has been stated that there is an interrelation between hydrature and yield in cultivated plants (Bauman, 1957; Kreeb, 1961). The osmotic value has an inverse relation to water content in general. When the osmotic value is low, and the water content is much, it is considered that hydrature is high and the physiological activity also high. Walter (1955) stated that the increase of the osmotic value beyond the optimal leads to the reduction of the activities of life, e.g., growth, photosynthesis, and respiration. These facts are observed in many experimental results in the present report. For example, the soybean plant grown in the gradient condition of soil moisture is divided by the difference of the osmotic variation, into three categories, i.e., the properly moist plots (100, 80, 60, 50%), the shift plots from moist to dry (35, 27%), and the dry plots (20, 13%). This may be done about the yield, too. The osmotic value gradually increases with the progress of growth in the properly moist plot, but in the dry plot osmotic descension is observed all through the last stage of growth, and it approaches the value of the moist plot. This indicates that the ascended osmotic value shown in summer is due to osmo-regulation unnatural for growth and so it descends in autumn. In fact, the yield and growth in the dry plot is markedly reduced in comparison with the moist plot. And when the plant grown in the moist soil condition from the early stage of growth is transferred to the dry soil condition in and after the period of flower bud differentiation or the flowering period, the grade of osmotic ascension is remarkable in the former period. In yield, the one treated after the flowering period shows a slight osmotic ascension and is much in yield. It can be concluded that adaptation to heighten the osmotic value is carried on by sacrificing growth.

Conclusion

The hydrature regulation and the hydrature accommodation were investigated in gradation both of the soil moisture and growth periods in soybeans, broad beans and orpines. In general, the osmotic value increases as growth advances. The degree of the increase, however, differs in different kinds of plants.

The osmotic ascension accompanying growth is very remarkable in soybeans and is not in broad beans. The lower osmotic value of orpines as compared with other plants is their characteristic, and the range of its variation is very narrow. Therefore, the soybean plant is a euryhydrous type and it grows actively in the soil moisture condition which varies from moist to dry. The orpine is a stenohydrous one and it is considered that it endures passively in the dry soil moisture condition.

There are three periodicities in osmotic variation accompanying growth periods. They are distinctly observed in the soybean plant. The first is the variation accompanying the periodicity of vegetative growth. That is to say, the osmotic value gradually increases as growth advances. The second is the temporary osmotic descension accompanying the rejuvenation caused by the intervention of reproductive organ formation which takes place in flowering. The normal osmotic value is afterward regained at podding. This growth periodical osmotic variation, however, may be distinctly observed in the plant grown under the properly moist soil condition. In the plant grown under the dry soil condition, a forced osmotic ascension takes place in summer when the plant is at its height of prosperity of growth. The normal osmotic value is regained with the cool autumn weather. This is the third periodicity of osmotic variation caused by the changes of climatic conditions.

The osmotic value ascends by the drying treatment of the soil. This ascended value is fixed when a leaf matures, but the normal osmotic value is regained when the treatment is discontinued while the leaf is growing. The daily fluctuation of osmotic value according to meteorological conditions is observed. But the osmotic variation of the soybean plant grown in moderate soil moisture condition is induced mainly by the first periodicity though it ranges over a long period of time through summer and autumn.

The fundamental tendency of the growth periodical osmotic variation does not deviate from the combination of the first two periodicities, and was observed alike both when two different varieties which have different growth periods were cultivated at the same time and when one and the same variety showed different growth periods by different photoperiodic treatments.

It is considered that the osmotic variation accompanying the progress of growth keeps pace with the progress of aging. So the ascension of the osmotic value may be regarded as a measure of the aging of a plant. When the growth period is made to change by the photoperiodic treatment in two plants which have the same age of growth, the osmotic value is higher in the precocious plant than in the serotinous one, and as to the time when the plants reach the same physiological growth stage, the precocious plant can reach it with a lower value and the serotinous plant with a higher one. Special attention may be paid to the phenomenon that the intervention of reproductive organ formation takes place in the plant which is photoperiodically made precocious at the lower level of the osmotic value than that in the plant which is made serotinous. Therefore, the level of the osmotic value of a plant may be regarded as a measure of the vegetative age, but it can not be taken as an index of the maturation degree of reproductive age.

The capability of hydrature regulation is high in the early stage of growth but this regulation in the early stage is temporary and is not fixed. The hydrature accommodation does not yet appear in the early stage of growth, but its capability appears when growth advances to some degree and the fixation of the ascended osmotic value is recognized afterward. Therefore the capability of osmotic ascension is similar whether caused by drought hardening or by aging, because the value caused by the former can not be fixed without accompanying the latter.

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