Chapter IV

Drought Resistance

(RESPONSES OF SPV-504 AND RSV-10R VARIETIES OF SORGHUM TO WATER STRESS)

1. Introduction :

According to Samuels (1972), Singh *et al.* (1979) as the soil water content is one of the important factors with respect to nutrient availability, drought also exerts a great influence on ion uptake and translocation. It is now clearly established that water stress injury has a metabolic base that is concerned with damage to the protein synthesizing mechanism (Stewar~~d~~t *et al.*, 1966; Huffaker *et al.*, 1970). According to Singh *et al.* (1973) water stress is accompanied by definite changes in the level of free amino acids and amides. Water stress leads to release or activation of degradative enzymes (Genkel *et al.*, 1967).

Crafts (1968) reported that the translocation of photosynthetic assimilates is suppressed by water stress. All the above metabolic disturbances finally lead to a retardation of plant growth and a considerable reduction in the overall yield. The stage at which water stress occurs can exert an important influence on the final yield of some crop plants, particularly in annual cereals. Denmead and Shaw (1960) showed that a reduction in yield about 50% was caused by water stress at the sinking stage in corn.

There is a sufficient research on the drought resistance in various crops. But there is a great variation in drought resistance capacity among the various crop species. The crops like sorghum, wheat, chickpea, safflower and millets are well known for their resistance nature; while rice, tomato and other vegetable crops are prone to water stress. Sorghum is generally cultivated on the lands where rainfall is scanty and only marginal irrigation fascilities are available for poor farmers. Now a days there are many successful efforts in supplying the irrigation fascilities for increasing the acreage of sorghum in different countries of world.

Drought resistance in sorghum is studied by different research workers and they came to know the importance of the research, as the sorghum is one of the important food crop. Mejority of the world's sorghum crop is grown under unirrigated areas. The problem is to enable the drought resistant sorghum to produce more yield under water deficit conditions. In the last few years a good amount of knowledge has accumulated on the mechanism of drought resistance in plants, like sorghum and other cereals.

According to Freeman (1970), sorghum roots are more fibrous than corn and form too many laterals at any stage of development, which contributes to the drought resistance in sorghum. Bhan et al. (1973), have correlated the root development and drought resistance in sorghum and found that resistant strains have deeper penetrating roots, greater total root weight and more extensive primary, secondary root system than non-resistant strains.

Glover (1959) has suggested that the stomatal behaviour during the period of drought is responsible for the superiority of grain sorghum to overcome dry conditions. Even under severe drought, sorghum stomata appear to open slightly during early morning and then remains closed.

McCree (1974) has noted the stomatal responses of grain sorghum under water stress during growth, by measuring leaf diffusion resistance. The response of leaves grown in hot, dry and warm, humid atmospheric conditions was very similar to one another.

Simpson (1978) has studied drought resistance in sorghum. The studies have indicated that the leaf water potential decreased due to osmoregulation resulting in the formation of the more osmotically active cellular solutes. According to the observations in sorghum, the stomata remain open between 11.00 a.m. and 1.00 p.m. which indicate that at this time of the day the leaf water potential did not decrease much in nonirrigated sorghum plants. Hence, they proposed that sorghum responds to drought by avoidance mechanism mainly by osmoregulation rather than stomatal closure. Blum (1974 a, 1974 b) studied the genotypic responses in sorghum to drought stress and reported that "Shallu" and "Feterita" as the most drought susceptible whereas "Durra", "Hegari", "Milo" and "M 35-1" as drought resistant genotypes.

Anjaneyula and Shivaraj (1969) recorded the drought resistance of four improved varieties of sorghum viz. M 35-1, CSH-1

(hybrid) IS-84 and MsCK-60 under stimulated drought and avoidance mechanism. Drought tolerance is the equilbrium relative humidity which causes 50% killing of the cells, that is at slightly higher water potential the cell will survive or function matabolically although the tissues are desiccated. It appears that the total drought and heat resistance is the result of many complex and interacting tolerance and avoidance mechanisms.

It has been reported by several workers that presowing seed treatment of sorghum with distilled water, salt solutions or some growth regulators can provide better resistance to drought.

2. Meterial and Methods :

The seeds of the two varieties of sorghum i.e. SPV-504 and RSV-10R are collected from the Agriculture Research Centre Mundhe (Karad) conducted by the Mahatma Phule Krishi Vidhyapeeth. The seeds were sown in big (18" diameter) earthenware pots in the month of November. The type of the soil used was loam mixed with farmyard manure. The plants were equally watered and given equal doses of fertilizers. After four weeks, water was withheld from various pots so that at the time of harvest there were pots receiving no water for 4, 8, 12 and 16 days. The plants which received regular water supply (control) and which were exposed to water stress were harvested separately. The relative readings of the plants were recorded after every fifteen days (Fig 4.1 and Fig. 4.2).

FIG. 4.2 EFFECT OF WATER STRESS ON GROWTH OF VAR. RSV-10R OF SORGHUM.

1. CONTROL
2. 4-DAYS STRESS
3. 8-DAYS STRESS
4. 12-DAYS STRESS
5. 16-DAYS STRESS

FIG. 4.1 EFFECT OF WATER STRESS ON GROWTH OF VAR. SPV-504 OF SORGHUM.

1. CONTROL
2. 4-DAYS STRESS
3. 8-DAYS STRESS
4. 12-DAYS STRESS
5. 16-DAYS STRESS

The method for stomatal studies was that of Stoddard, (1965). The widths of stomatal apertures were established under the microscope, on films of clear nail polish. In this method nail polish was applied to the middle of lower as well as upper epidermis of the leaf. To avoid errors, maximum care was taken to select third leaf of the plant from each group of plants like control, 4, 8, 12 and 16 days water stress. The films were made from 7.00 A.M. in the morning to 6.00 P.M. in the evening. Measurements of stomatal apertures, were made under precalibrated microscope. Five stomata were observed by random sampling for their width from a single peeling of the leaf.

For estimation of chlorophylls the method adapted by Arnon (1949) is used. Chlorophyll is estimated by the following method: Take weighted amount of one gram of clear and dried plant material. The weighed leaves are crushed in the 80% acetone in mortle with pestle. Then filter the extract through buchner funnel. Make the final volume of filtrate 100 ml. with adding 80% acetone. Then take the readings on Spectronic 20 (Bauch and Lamb) at 663 nm and 645 nm wave lengths. First switch on the colorimeter and wait for half an hour. Then select a proper wavelength. Take a blank solution (here 80% acetone) in a cuvette upto the mark. Introduce the cuvette in the cuvette holder. Set the absorbance zero with the help of set absorbance zero knob. Then replace blank by sample and note down the absorbance at 663 nm and 645 nm wavelengths respectively. Calculate the amount of chlorophyll using the equations (MacKinney - Arnon, 1949).

a) Chl. a = $12.7 \times A\ 663 - 2.69 \times A\ 645 = X.$

b) Chl. b = $22.9 \times A\ 645 - 4.68 \times A\ 663 = Y.$

c) Chl.(a+b) = $8.2 \times A\ 663 + 20.20 \times A\ 645 = Z.$

a) Chl. a mgs/100 gms of fresh wt. $= \dfrac{X \times \text{Volume of extract} \times 100}{1000 \times \text{Volume of material in gms.}}$

b) Chl.b mgs/100 gms of fresh wt. $= \dfrac{Y \times \text{Volume of extract} \times 100}{1000 \times \text{Volume of material in gms.}}$

c) Total Chl. (a+b) mgs/100 gms of fresh wt. $= \dfrac{Z \times \text{Volume of extract} \times 100}{1000 \times \text{Volume of material in gms.}}$

For estimation of inorganic constituents an acid digest from the oven dried plant material was used. The plant material was digested following the method of Toth *et al.* (1948). First 0.5 gms of the oven dried powdered plant material was taken in 150 ml. beaker and 20 ml. concentrated HNO_3 were added to it and allowed to stand for sometime till the initial reactions were subsided. It was then subjected to heating till the particles of the plant material were completely dissolved. Then 10 ml. of concentrated perchloric acid (60%) were added to it. It was then heated strongly until the volume of plant extract was reduced to approximately 3-5 ml. It was cooled to room temperature, transferred to 100 ml. capacity volumetric flask and diluted to 100 ml. with distilled water. It was kept over night and next day filtered through a dry Whatman filter paper No. 44. The filtrate was used for estimation of various inorganic constituents. Na and K are determined on flame photometer while other constituents are estimated by the Atomic absorption spectrophotometer.

3. Results and Discussion :

A. Effect of water stress on soil temperature :

The Table No.IV.1 shows the comparative values of soil temperature and soil moisture percentage in SPV-504 and RSV-10R varieties of sorghum. The Fig. No. 4.3 and 4.4 indicates the same values of graphical manner.

The results depicted in Table No.IV.5 shows the clear data of the observed soil temperature. In control plants due to normal supply of water the soil temperature noted is 22°C. In the 4 days stressed plants the soil temperature is gradually increased i.e. 24.5°C. Finally 16 days water stressed plants show the 31.5°C. soil temperature in both the cultivars like SPV-504 and RSV-10R. The values of soil temperature are increased as the period of water stress is increased. Thus soil temperature has a direct relation with the amount of water stress.

Soil temperature has a profound influence on rates of water absorption. Low soil temperature reduce water absorption has been known for 200 years, but only within relatively recent

Table No. IV.1

Effect of water stress on soil temperature in SPV-504 and RSV-10R var. of sorghum.

	Water Stress	Soil temperature (0$_c$)	
		SPV-504	RSV-10R
1)	Control	22.0	21.0
2)	4 - days	24.5	24.5
3)	8 - days	28.5	28.0
4)	12 - days	30.0	30.0
5)	16 - days	31.5	31.5

* Values expressed are the mean of three readings.

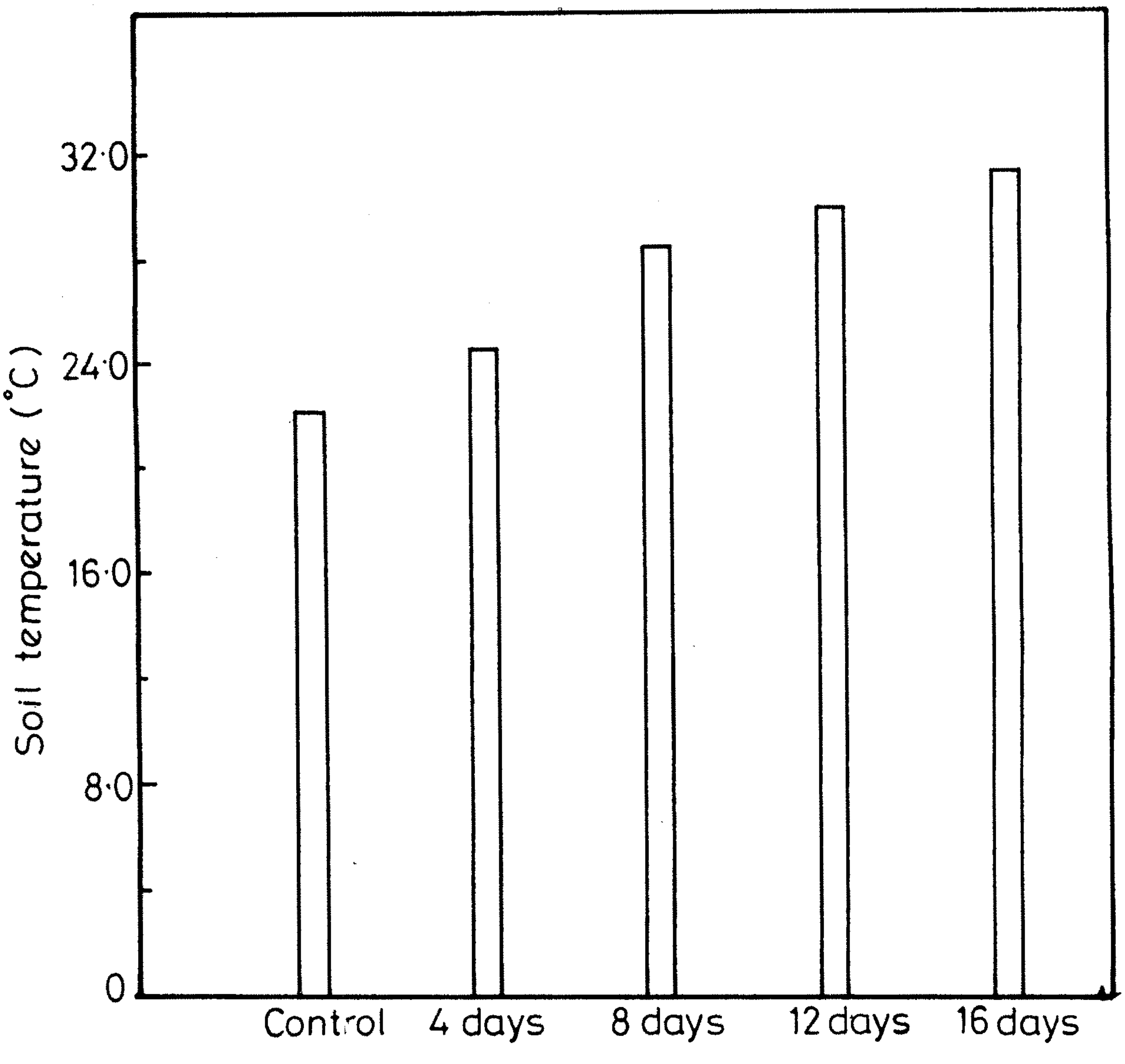

FIG. 4·3 EFFECT OF WATER STRESS ON SOIL TEMPERATURE IN SPV-504 VAR. OF SORGHUM.

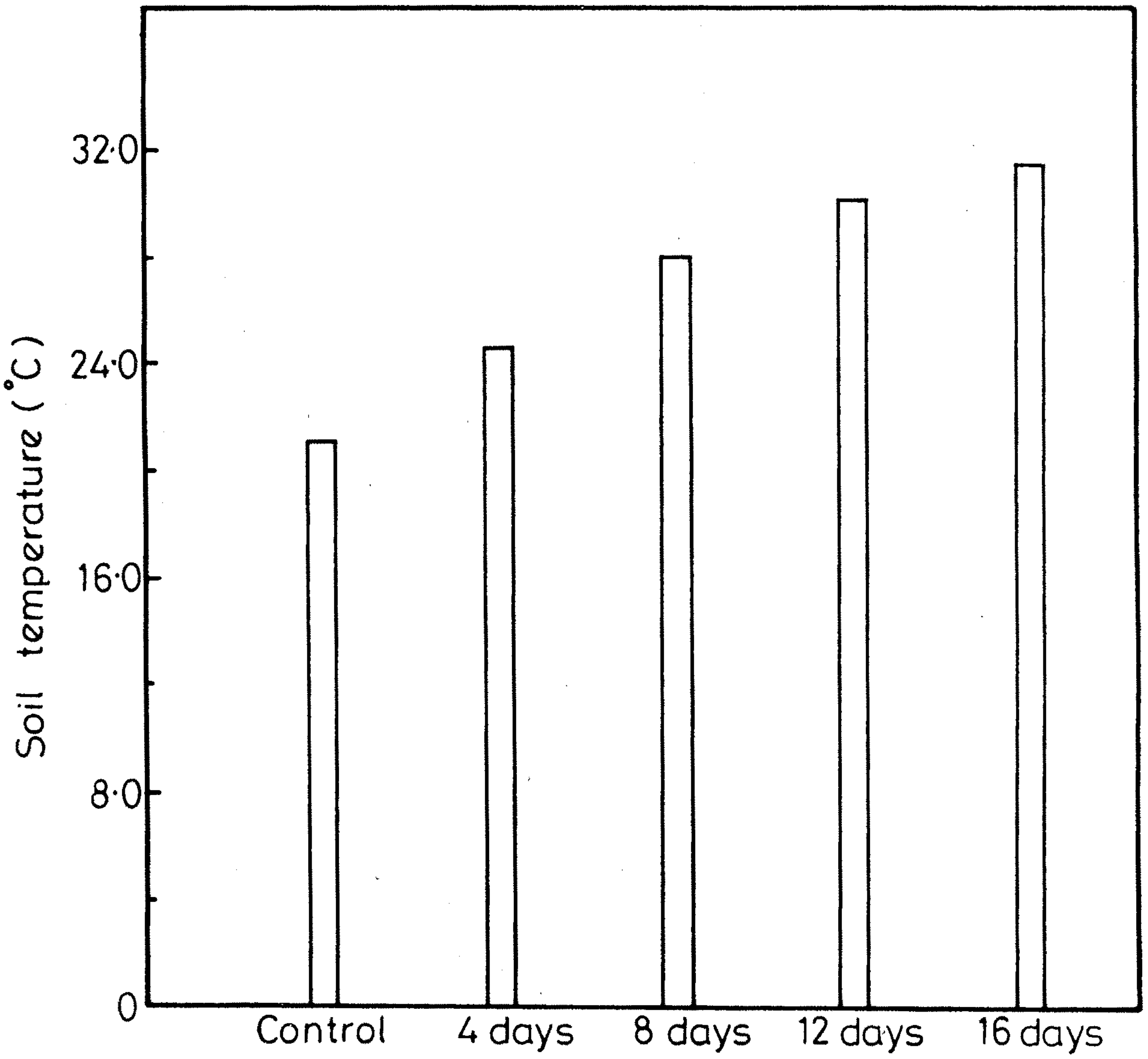

FIG. 4·4 EFFECT OF WATER STRESS ON SOIL TEMPERATURE IN <u>RSV-10R</u> VAR. OF SORGHUM.

years this effect has been explained. Appearantly the inhibitory influence of low temperature on water absorption is manifested in a variety of ways. First of all water is more viscous at lower temperature, a factor which reduces its mobility. Protoplasm is less permeable at low temperature and root growth is inhibited. The combined effect of these factors causes a reduction in water absorption at low temperature.

The soil surface receives heat as short- wave radiation of light of which 10% from the wet soil and 20% from the dry soil is immediately reflected. The remainder is absorbed, part of it is re-radiated into the atmosphere, part conducted to the atmosphere above, part used to evaporate water and part conducted into the soil. The surface temperature is dominated by the fluxes of incoming radiation and re-radiation, hence shows the greatest variation and is much influenced by the degree of cloud. If the surface layers are wet, much of the energy is used in evaporation. Dark surfaces absorb and emit radiation more efficiently than do light coloured surfaces and so dark soils show wider fluctuations than light coloured soils. The surface temperature and that of the lower levels depends also on the rate of heat conduction through the soil and heat capacity. These properties vary mainly with the water content.

The temperature of the soil is a significant factor in plant growth, chiefly through its effects on absorption of water and minerals. At low temperature the rate at which the root respire is decreased, and elongation is checked; resulting in a slower rate of penetration into new areas where water and minerals are available.

Chu T.M. et al. (1974) studied stress metabolism in some plants. They especially studied temperature stress and found the accumulation of proline in barley and radish. Turner and Kramer (1980) studied the water stress and high temperature stress. They came to know that due to water stress and high temperature stress the plants are adapted for such conditions of stress. Southwick et al. (1986) the water stress and low temperature effects in citrus plant. They observed that due to water stress for 4 to 5 weeks and low temperature treatment the flowering was induced in *Citrus latifolia*.

From our Table No.IV.1 it clearly shows that the soil temperature is increased as the period of water stress is increased in both cultivars. Thus soil temperature is directly proportional to the amount of water stress.

B. Effect of water stress on soil moisture percentage :

The Table No.IV.2 depicts the comparative values of soil moisture percentage in SPV-504 and RSV-10R varieties of sorghum. The Fig.No. 4.5 and 4.6 indicates the same values in graphical manner.

Table No. IV.2

Effect of water stress on soil moisture percentage in SPV-504 and RSV-10R var. of sorghum.

Water Stress	Soil moisture percentage	
	SPV-504	RSV-10R
1) Control	11.0	12.0
2) 4 - days	9.5	10.0
3) 8 - days	6.5	7.0
4) 12 - days	6.0	6.5
5) 16 - days	4.5	5.0

* Values expressed are the mean of three readings.

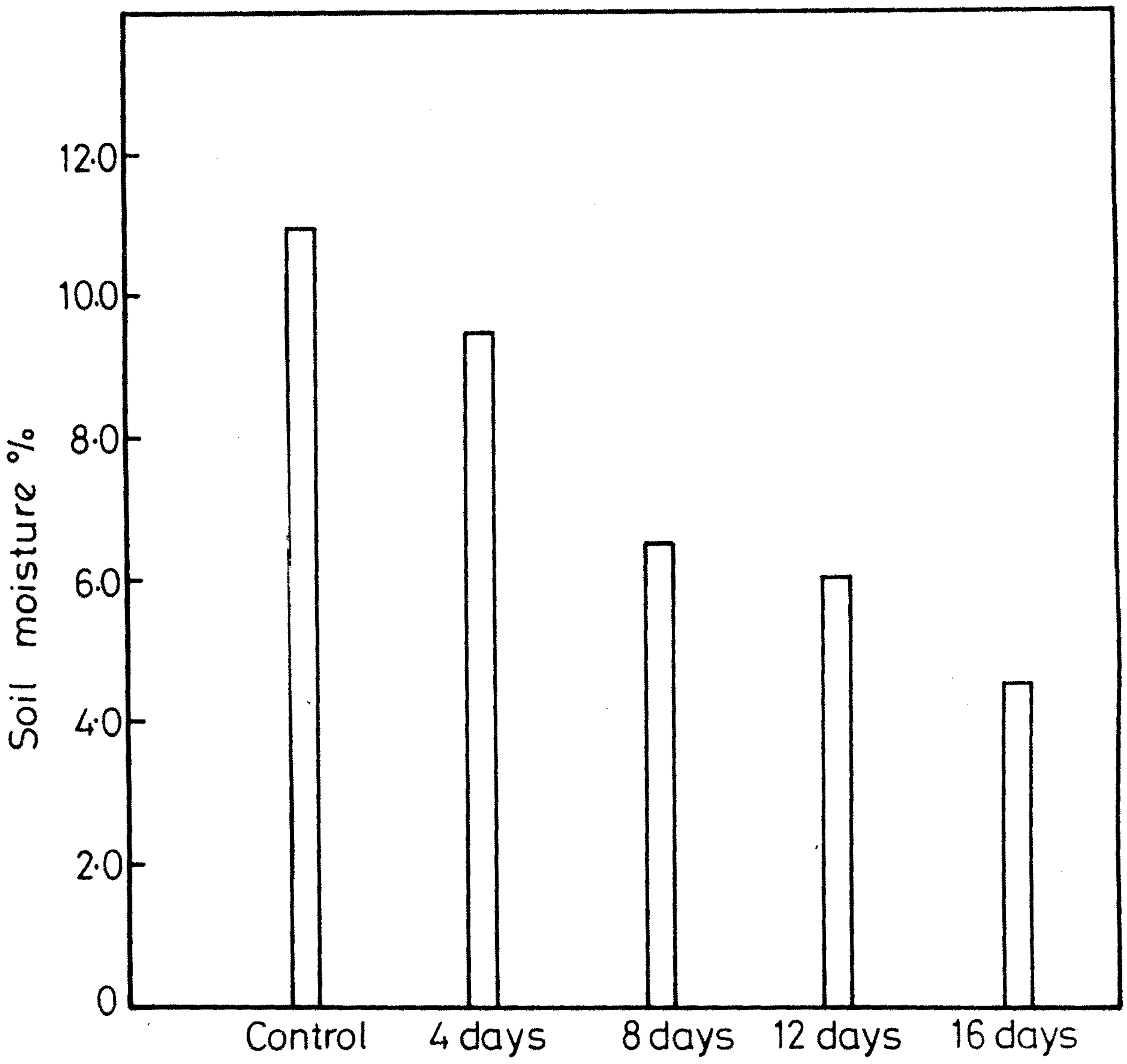

FIG. 4·5 EFFECT OF WATER STRESS ON SOIL MOISTURE % IN SPV–504 VAR. OF SORGHUM.

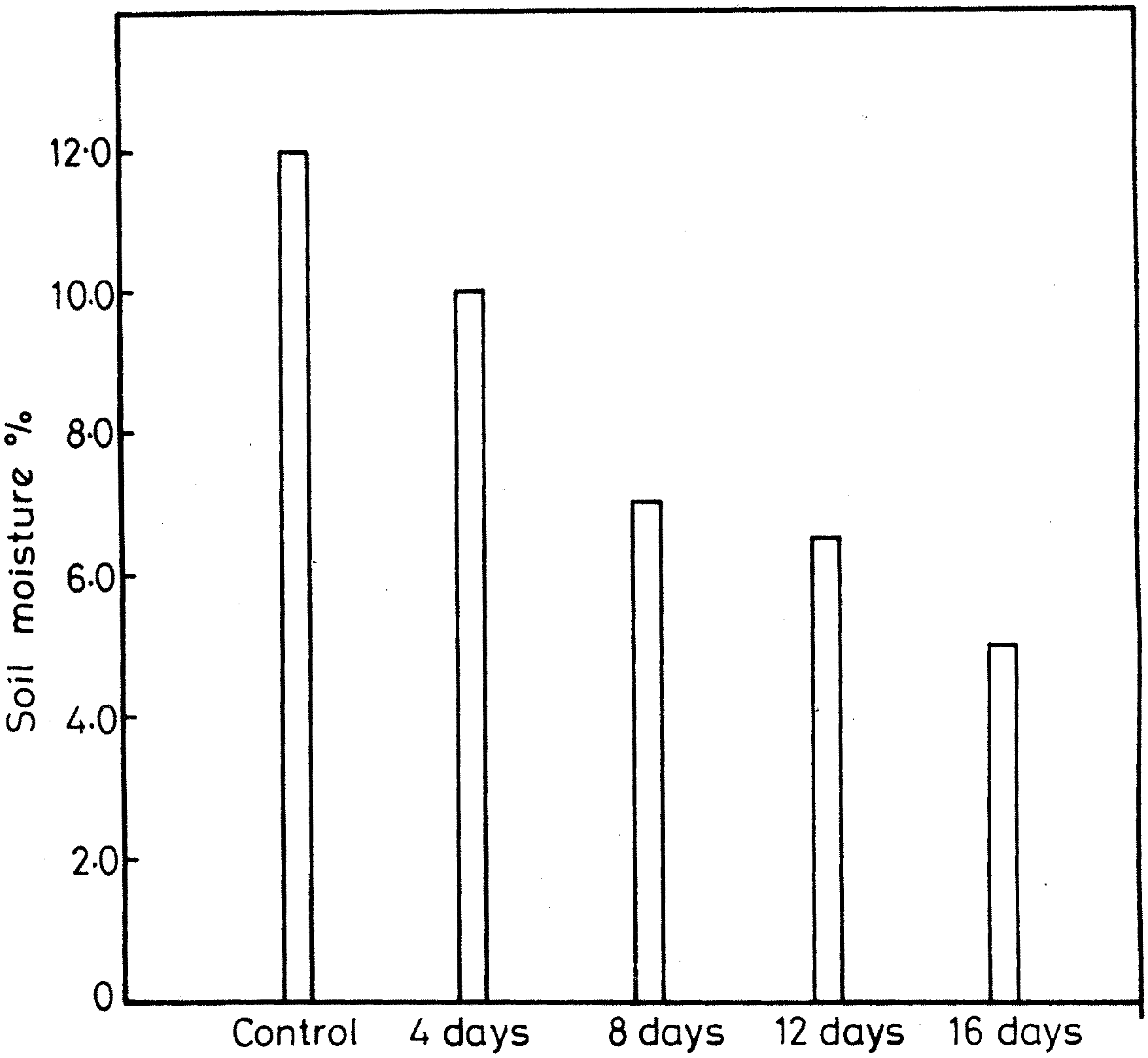

FIG. 4·6 EFFECT OF WATER STRESS ON SOIL MOISTURE % IN RSV-10R VAR. OF SORGHUM.

The results depicted in Table No. IV.2 show the clear data of observed soil moisture percentage. In control due to normal supply of water the soil moisture noted is 11.0% and 12.0% in sorghum varieties SPV-504 and RSV-10R respectively. In the 4 days stressed plants soil moisture is gradually decreased to 9.5% and 10.0% values. Finally, 16 days water stressed plants shows minimum values (4.5% and 5.0%) of soil moisture. The values of soil moisture percentage are decreased as the period of water stress is more.

Not all the water in the soil is available to the plants. As the soil in the immediate area of the root system is depleted of its water supply, the absorption of water by the plant becomes more and more difficult. Evantually those physical factors that hold water to the soil become stronger than the physical factors involve in the uptake of water by the plant.

There are four terms about the soil water-plant relationships.

i) Field Capacity :

According to Kramer (1969) it is the water content of the soil after it has been thoroughly wetted and then allowed to drain until capillary movement of water has essentially ceased.

ii) Permanent Wilting Percentage (PWP) :

It is the percentage of soil water left when the level of the plant growing in the soil first exhibit the symptoms of permanent wilting. That is the leaves will not regain turgor when placed in a saturated atmosphere.

iii) Total Soil Moisture Stress (TSMS) :

Wadleigh and Ayers (1945) introduced the term TSMS as the sum total of the osmotic potential of the soil solution and soil moisture tension.

iv) Water Potential :

It is the difference between the chemical potential of water in the system and chemical potential of pure water.

According to Wadleigh *et al.* (1946) there is a definite correlation between the soil moisture content and PWP. Work done in the early part of the twentienth century established that field capacity and PWP differ with the type of the soil tested. However field capacity and PWP were also thought to be soil moisture constants for any particular type of soil. The PWP of the soil appears to differ depending upon the test plant used.

Statyer (1957) has indicated that the PWP of a soil is determined by plant osmotic factors rather than soil factors. In other words the PWP of a soil is dependent upon the ability of the plant to draw water from the soil and is not a soil moisture constant.

During the day, as the soil in the near visinity of the root surface is depleted of water, its TSMS increases. This decreases during night as water moves from the remaining soil mass to the surface of the root. The water potential of the plant follows the same pattern; it is more negative during the day and less negative at night. However the plant water potential always remaining more negative than the TSMS. This is essential if water is to be drawn into rather than out of a plant. As the soil dries a little more each day, the TSMS and the plant water potential become progressively more negative. As this drying proceeds, the gradient from soil to plant becomes increasingly less steep, and night recovery for both TSMS and plant water potential becomes slower.

Nature of the soil :

The soil which is used in earthen pots is the loam. The soil is mixed with the farmyard manure. The soil has 11.5% moisture which is evident from the Table No. IV.2. The loam type of the soil is a medium soil which is having porosity about 46%.

The pore space is important to allow the penetration of roots as well as the entry of water and air. If the soil consisted of uniform spherical particles, the highest packing would give a porosity (Volume of air and water per unit volume of soil in situ) of about 26%. Actually the pore space varies from about 40 to 60% in most agricultural soils.

The porosity of different typical soils can be given in following table.

Nature of the soil	Porosity %
1) Sandy soil	35
2) Loam	46
3) Heavy clay	53
4) Clay	60

The quantity of water held in a particular soil at the field percentage is determined primarily by the size of the soil particles i.e. by the soil texture. The small particles of clay have more surface and produce more fine capillary spaces. A clay soil, therefore will hold much more water than a sandy one. Typical soil moisture percentage in several soil types can be given in the following table.

Soil type	Field % (moisture)
1) Sandy soil	6
2) Loam	10
3) Heavy clay	20
4) Clay	40

The clay shown here holds four times as much water as the loam in a form that plants can not use. Heavier soils, are from heavy clay to silty clay loams, are preferred for dry land farming because of their greater ability to store moisture for crop use. The lighter textured loams and sandy soils are preferred where water is more available, because they are earlier to work, absorb rainfall more rapidly, and permit better aeration for root growth.

Gilmore,A. R. (1971) studied the effect of soil moisture stress on foliar nutrients of loblolly pine. He submitted a data on nutrient availability in relation to soil moisture availability.

Blum (1974 a, 1974 b) studied the genotypic responce in sorghum to drought stress and also responce to soil moisture stress. He observed that soil moisture stress gives response with the drought resistance. Our results of soil moisture percentage reveal that more than 50% of soil moisture is get decreased as the period of water stress is increased. Thus soil moisture percentage is universally proportional to the amount of water stress.

C. Effect of water stress on chlorophyll contents :

The result of effect of water stress on the chlorophyll content of the leaves of sorghum var. SPV-504 is recorded in the

Table No. IV.3 and it is graphically shown in Fig. No. 4.7.

It is observed that in control plants chl. a is less as compared to chl.b. In water stressed plants also as the period of water stress is increased the chl. a is less and chl. b is more. But if you observed the results of chl. a, chl. b total chlorophylls and chl.a/b ratio in water stressed plants and compared with those of normal plants, it shows that the values of chl. a and chl. b are increased as the period of water stress is increased. The plants under 16 days stress are showing more chlorophyll content than control.

The results of the effect of water stress on the chlorophyll content of the leaves of RSV-10R variety of sorghum is depected in Table No. IV.4 and graphically shown in the Fig. No. 4.8. The same type of pattern like SPV-504, is recorded in water stressed plants of jowar var. RSV-10R. The values of the chlorophyll contents go on increasing as the period of water stress is increased. The total chlorophyll content is more in the stressed plants is due to the amount of water which is available to plant is less.

Chlorophyll content varies from plant to plant and species to species. It is also influenced by the environmental conditions where the plant grows. Chlorophylls play a major role in light reactions of photosynthesis and hence, the content as

Table No. IV.3

Effect of water stress on chlorophyll content in SPV-504 var. of sorghum.

	Water Stress	Chlorophyll content		
		Chl. a	Chl. b	Total Chl.(a+b)
1)	Control	61.5	74.5	136.0
2)	4 - days	62.5	75.5	138.0
3)	8 - days	65.5	76.0	141.5
4)	12 - days	69.5	79.5	149.0
5)	16 - days	70.2	80.4	150.6

* Values in mg 100^{-1}g fresh tissue.

* Values expressed are the mean of three reddings.

Table No. IV.4

Effect of water stress on chlorophyll content in RSV-10R var. of sorghum.

Water Stress	Chlorophyll content		
	Chl. a	Chl. b	Total Chl. (a+b)
1) Control	63.5	67.5	131.0
2) 4 - days	64.0	69.5	133.5
3) 8 - days	64.5	71.5	136.0
4) 12 - days	65.0	73.5	138.5
5) 16 - days	68.0	79.0	147.0

* Values in mg 100^{-1}g fresh tissue.

* Values expressed are the mean of three readings.

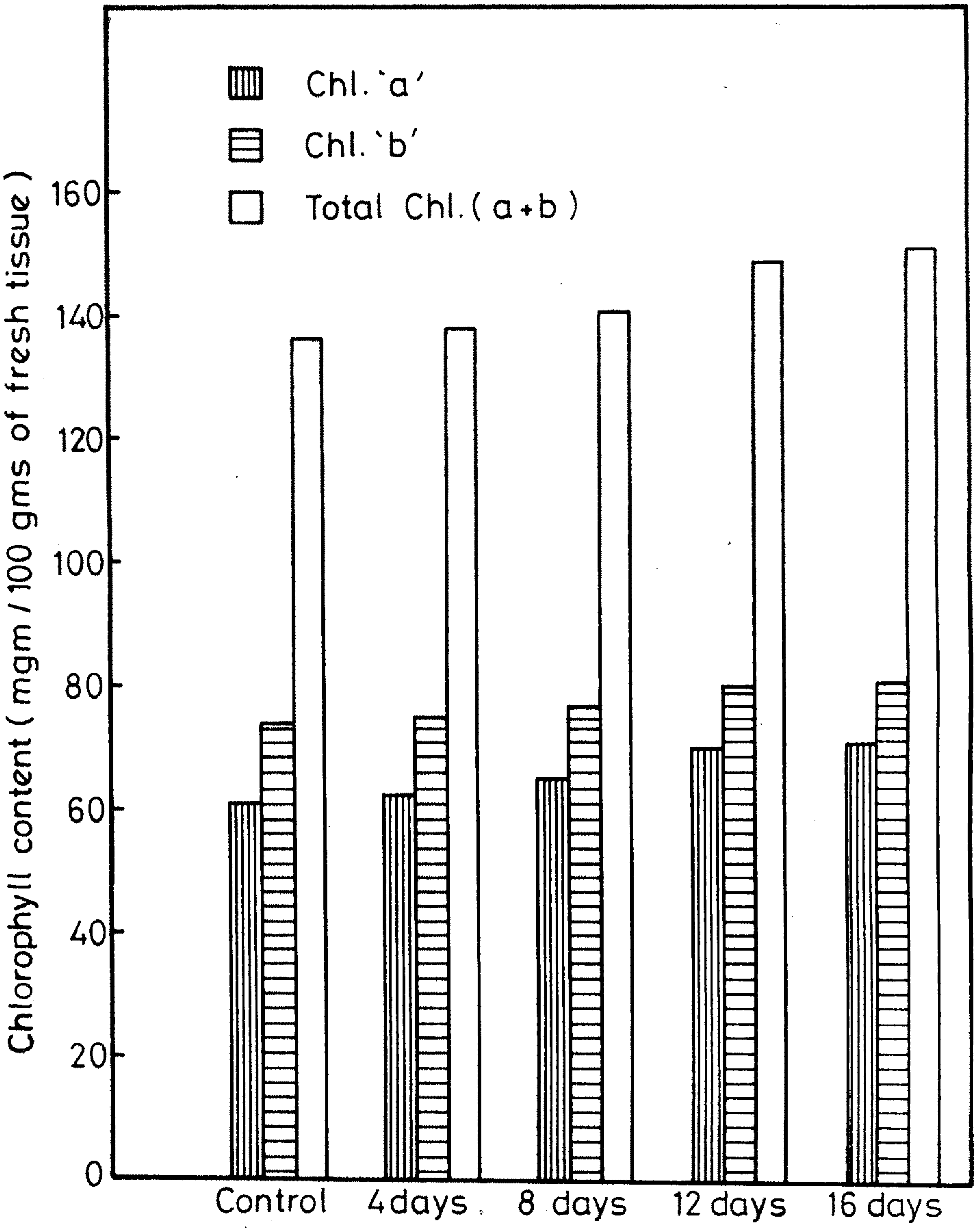

FIG. 4·7 EFFECT OF WATER STRESS ON CHLOROPHYLL CONTENT IN SPV-504 VAR. OF SORGHUM.

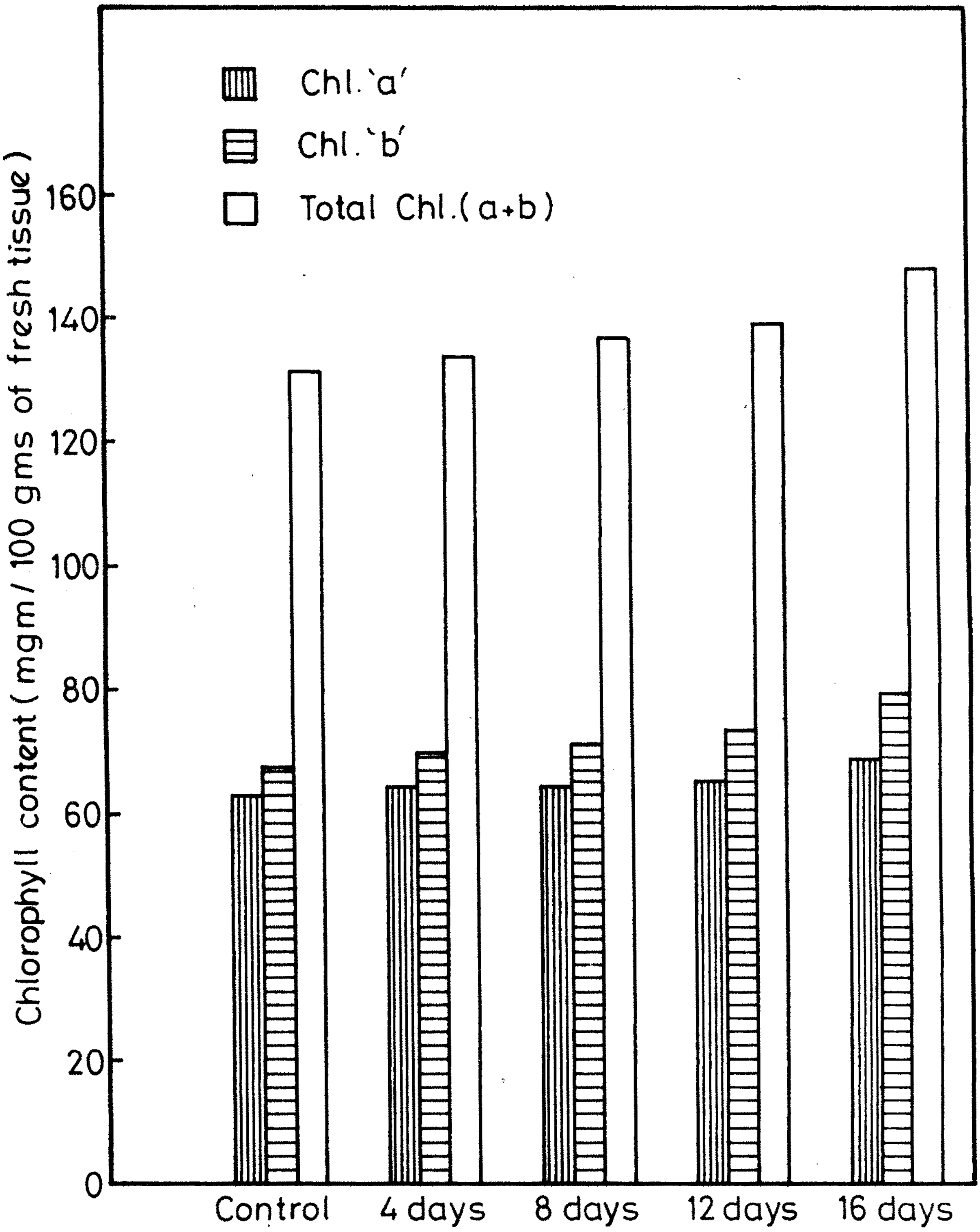

FIG. 4·8 EFFECT OF WATER STRESS ON CHLOROPHYLL CONTENT IN RSV-10R VAR. OF SORGHUM.

well as the status of these pigments in the leaves have a direct bearing on the photosynthetic effeciency of the plant. The amount of chlorophyll decreases at the ripening stage. The stability of chlorophyll molecules has long been considered as an essential parameter of drought resistance. One thing is certain that loss of chlorophyll during drought is harmful to the plant. Less than 1% of the water absorbed by a plant is used in photosynthesis. It therefore seems probable that the indirect effects of the water factor upon photosynthesis are more pronounced than its direct effects. In other words deficiency of water as a raw material is not commonly a limiting factor in photosynthesis.

Heichel and Mugrave (1970) have recorded varietal differences in 12 maize varieties in the field for photosynthetic efficiency under stress; varieties which suffer a major decrease in the rate of photosynthesis at critical water potential are the poor yielders while those with very little decrease in photosynthesis at even leaf water potential as low as - 27 bars in maize are found to be good yielders. In which it is demonstrated that the differences in the yield of cultivars as subjected to moisture stress is due to the differences in integrated net photosynthetic potential.

There are conflicting reports are recorded regarding the effect of water stress on cholorophyll content. According to

Virgin (1963), even rather small water deficit caused strong inhibition of chl. a formation. He further stated that this effect was due to decreased rate of formation of protochlorophyll a which is responsible for chlorophyll synthesis. Maranville and Paulsen (1970) found that drought reduced chorophyll content as well as light absorption in maize. Sestak _et al_. (1971) have reported that water stress in prosomillet leaves reduces the total chlorophyll contents. Sing _et al_. (1973) and Dnysen and Freeman (1974) noticed an impaired synthesis of chlorophylls due to water stress in barley and wheat respectively. Sanchez _et al_. (1983) reported that water stress in maize leaves reduces chlorophyll content, stomatal conductance and photosynthesis but the nitrogen content of the leaves is not affected. Eventually the stress induced loss of chlorophyll is not mediated by a lack of nitrogen. Losses upto 40% of leaf chlorophyll content were insufficient to affect the rate of photosynthesis.

According to Kushnirenko _et al_. (1971) drought conditions affected to lesser degree of quantity of segments strongly bound with the lipoprotein complex particularly chlorophyll b. Bourque (1971) studied the effect of small water deficit on chlorophyll accumulation in elongated leaves of _canavalia ensiformis_ L. and found that at low relative humidity (25%) very low chlorophyll accumulation occured. Jadhav (1984) has recorded the chl.a, chl. b and total chlorophylls in the flag and mature leaves of _Panicum_ miliaceum under water stress. He found that the values of chlorophylls are increasing as the period of water stress is increased. Gaikwad (1987) also reported that there is increase in chlorophyll content in the leaves of Phaseolus aconitifolius due to water stress, He further added that increase in chlorophyll content due to stress is an adaptive features for drought resistance.

In SPV-504 and RSV-10R varieties of sorghum also we can see that the plants exposed to water stress (16 days) still retain more amount of chlorophylls on the fresh weight basis. Thus such retaintion of chlorophylls even after stress can be considered as a drought resistant feature of the plant and insufficient to affect the rate of photosynthesis. It may be useful in the process of drought recovery when water becomes available.

D. Stomatal behaviour during water stress :

i) Opening - closing mechanism :

The stomata obviously act as a channels for the exit of water vapour but their opening and closing are under physiological control, in response to environmental stimuli. In many species stomata show a diurnal rhythm opening by day and closing by night. Light stimulating stomatal opening. Accordingly the pores are open during the period when light is available for photosynthesis, in the dark when, CO_2 can not be assimilated water loss is avoided.

Water stress however has an overriding effect over other stimuli causing stomatal closure. This occurs at quite moderate levels of water stress, before the leaf wilts i.e. stomata do not close because of an overall lack of water, but the decline in the plant water status acts as a stimulus for closure. A hormonal signal appears to be involved, the concentration of hormone ABA (Abscisic acid) rises rapidly in response to water stress, and ABA induces stomata to close. (Hsiao *et al*., 1976) The closing of stomata reduce water loss and is a vital mechanism for preventing desiccation. Photosynthesis is however drastically inhibited as a consequence.

Light has no direct effect on water loss, but through the control it exerts over stomatal opening.

It has profound effect on the water relations of plants. Atmospheric conditions thus tend to promote higher transpiration rates by day than by night and in summer than in winter.

The degree of opening of stomata is often the most important single factor controlling the rate of transpiration. The maximum amount of water is lost when there are maximum number of the stomata open. Transpiration is most rapid when stomata are fully open; and slowest when they are fully closed.

According to Stalfelt, (1932) if the atmospheric conditions do not favour rapid transpiration, the full transpiration rate may be reached when the stomata are only partly open. But when external factors favour rapid transpiration, the rate increases with increasing stomatal aperture right upto maximum opening.

Stomata are highly sensitive to water stress and react by partial closure at quite low levels of water deficit, protecting the plant from further water loss. In wilted plants the stomata are usually shut. The early stages of wilting are however, often accompanied by a widening of the stomatal aperture, the guard cells being pulled apart by the shrinking of surrounding epidermal cells, which lose water more rapidly. In extreme wilting too, the protective mechanism may break down as shrinking epidermal cells again pull the pores open.

The result of various workers upon the influence of temperature on stomatal behaviour are not in agreement and divergent views have been expressed upon the subject. According to Scarth (1932) relatively high temperatures (35°C to 40°C) accentuate opening of stomata of Zebrina pendula in the light and prevent closure or even induce opening in the dark. Relatively low temperature (8°C) prevent opening of stomata of this species even in the light. There is more evidence that the pH of the cell sap of the guard cells increases with rise in temperature and that this change in pH concentration is accompanied by the hydrolysis of starch to sugar. Presumly the reverse transformation occurs at certain lower temperatures.

ii) Size and Distribution of Stomata :

The size of stomatal pore varies greatly according to the species of plant and somewhat even among the individual stoma on any one plant. They are always very minute, however their dimentions being expressed in terms of microns (µ). Measurements of the average length and breadth of the fully open stomatal pore and average number of stomata which have been found per square centimeter on the leaves of number of representative species are listed in the following table given by Eckerson S.F. (1908).

S.No.	Name of the plant species	Average No. of stomata per Cm^2		size (length x breadth) of pore when fully open (lower epidermis)
		upper epidermis	lower epidermis	
1.	Bean (*Phaseolus vulgaris*)	4000	28100	7 x 3 µ.
2.	Castor Bean (*Ricinus communis*)	6400	17600	10 x 4 µ.
3.	Geranium	1900	5900	19 x 12 µ.
4.	Maize (*Zea mays*)	5200	6800	19 x 5 µ.
5.	Oat (*Avena sativa*)	2500	2300	38 x 8 µ.
6.	Sunflower (*Helianthus annus*)	8500	15600	22 x 8 µ.
7.	Tomato (*Lycopersicum esculantan*)	1200	13000	13 x 6 µ.
8.	Wheat (*Triticum sativum*)	3300	1400	38 x 7 µ.

In general the number of stomata present in the epidermis of leaves may range from a few thousand to over a hundred thousand per square centimeter, the exact number depending upon the species and upon the environmental conditions, under which the leaf has developed. A single maize plant has been estimated to bear from 140 to 240 million stomata. However, marked deviation from such average values are possible for any species, depending upon the environmental conditions.

The number of stomata per unit area of leaf surface may be quite different on leaves of two plants of the same species, Generally number of stomata are more on lower epidermis than in upper epidermis. The number of stomata per unit are usually varies on different leaves of the same plant. (Street, 1984).

iii) Daily Periodicity of Stomatal Opening and Closing :

The stomata of all species of plants which have been studied exhibit a more or less regular daily periodicity of opening and closing, although the behaviour of the stomata upon the plant of any one species varies often markedly, depending upon the pattern of daily cycle of environmental factors.

It is probable that the stomatal mechanism of every species of plant exhibit certain distinctive features in the way in which it reacts to various combinations of envoronmental factors. Hence, only broad generalizations can be formulated regarding the daily periodicity of stomatal behaviour. The result of number of investigators indicate that as a rule under the conditions prevailing on a standard day, the stomata of most species of plants are open all or most of the day light period and closed at night. The stomata open in the morning under the influence of light factor and soon attain nearly their maximum diffusive capacity, under "standard day" conditions however, the water content and turgor of the leaf cells usually decrease progressively, during most of the day light period. Because of this internal water deficit which develops in the leaf, stomatal closure usually begins about noon or a little before. Virtually complete closure of the stomata often takes place considerably before the advent of darkness because of the predominant effect of the water factor over the light factor during the afternoon hours.

Innumerable other types of daily cycles of stomatal behaviour are possible. The diffusive capacity of the stomata sometime rises to a mid or late morning maximum decreases markedly during the mid'day hours, rises to a secondary maximum during the afternoon, and finally falls to a virtually zero value at approximately the termination of the daylight period.

The stomata apperantly behave in this way when a water deficit develops in the leaves somewhat earlier in the day than under "standard day" conditions partial closure of stomata result during the morning hours. The resultant reduction in the water content of the leaf and for a time the stomatal aperture again widen. Subsequently the water deficit of the leaf increases again due to increased transpirational loss, and the stomata enter upon a second cycle of closing which continues throughout the remainder of the daylight period.

When the soil water supply is distinctly inadequate the stomata usually open incompletely and seldom remain open for the entire daylight period. Although with the advent of daylight period the light factor favours stomatal opening, especially on clear days, the water content of the leaf is so low that opening is seldom complete. Furthermore the effect of water factor usually begins to predominate over the light factor relatively early in the day and stomatal closure may be complete by mid'day or even sooner. During prolonged droughts the stomata generally close progressively earlier and earlier each day and ultimately matinal opening may cease almost entirely.

iv) Factors Influencing Opening and Closing of Stomata :

There are three principle factors which influence the opening and closing of the stomata are —

a) Light -

The most familiar of all the stomatal reactions is their response to light. Unless other conditions to be discussed later, are limiting, the stomata of most species open when exposed to light and close upon the failure of illumination. Most commonly therefore the stomata are open in the day time and closed at the night. Although there are many exceptions to this statement. The sensitivity of the stomata to the light factor probably varies considerably according to species. Within limits the stomata appear to respond quantitatively to the amount of light absorbed. Stomatal opening apperantly will occur in all wavelengths of the visible spectrum; although the influence of radiations in the red region appears to be weaker than the influence of other wavelengths of the viside spectrum. (Sierp, 1933).

Upon the cessation of illumination the stomata usually begin to close generally, this is gradual process and according to Stalfelt (1929) the greater the quantity of light, which has been absorbed during the course of day, the longer it takes for the completion of stomatal closure.

The work of Sayre (1926), Scarth (1932) and others indicates that, the mechanism whereby light brings about stomatal opening and the mechanism whereby its absence causes stomatal closure are primarily osmotic, but are conditioned by change in the H - ion concentration of the guard cells. Scarth (1932) found that the p^H of the guard cells of the <u>Zebrina</u> pendula to range from 5.0 or less in the dark and 6.0 to 7.4 in the light.

The guard cells apperantly always contain starch, but the quantity present is not constant from one hour of the day to the next. Sayre (1926) has shown that the starch content of the guard cells is maximum during the night, decrease rapidly during the day light hours; and increases again towards evening. The sugar content of the guard cells bear a reciprocal relationship to the starch content, when the latter is high the sugar content is low, and vice versa. These reciprocal changes are apperantly the result of reversible reactions in which the total amount of carbohydrate involved does not vary greatly. Conversion of starch to sugar and sugar to starch results from the action of complex enzymes known as "diastase". Increase in the p^H of guard cells occurs upon the incidence of light, appears to favour the hydrolytic action of diastase. On the contrary a decrease in their p^H , such as occurs in the evening, favours the synthetic action of this enzyme whereby, sugar is converted into starch.

Increase in the sugar concentration of guard cells results in their increase in their osmotic pressure while a decrease in their sugar concentration has the opposite effect. That such changes in the osmotic pressure of the guard cells actually occur has been shown by many investigators. Beck (1931) shown that changes in osmotic pressures at incipient plasmolysis of the guard cells and epidermal cells of the English Ivy (Hedera helix). In general the osmotic pressure of guard cells is usually relatively high during the day light hours and relatively low at night.

b) Internal Water Relations :

A shrinkage in the total volume of water in a plant results in general in a diminution in the volume of water in each individual cell, although all the cells will not necessarily be affected equally. Such a decrease in the water content of the leaf cells, not sufficient to induce visible wilting, is often called incipient wilting. Under such conditions the guard cells usually decrease in the turgor as a result of osmotic movement of water into contiguous cells. Reduction in the turgor pressure of the guard cells as a result of diminution of the volume of water in them will bring about a partial to complete closure of the stomata. There is also some evidence that diminution in water content of the guard cells induces a decrease in the p^H of their cell sap and a correlated conversion of sugar to starch. The resulting diminution in the osmotic pressure of guard cells may lead to further loss of water from them into adjucent epidermal cells.

c) Temperature :

The result of various workers upon the influence of temperature on stomatal behaviour are not in agreement and divergent views have been expressed upon the subject. According to Scarth (1932) relatively high temperature (35°C to 40°C) accentuate opening of stomata of *Zebrina pendula* in the light and prevent closure or even induce opening in dark. Relatively low temperature (8°C) prevent opening of the stomata of this species, even in the light. There is some evidence that the p^H of the guard cell sap increases with rise in the temperature and that this change in H - ion concentration is accompanied by hydrolysis of starch to sugar. Presumely the reverse transformulations occur at certain lower temperature.

v) Effect of Water Stress on Stomatal Behaviour in SPV-504 and RSV-10R varieties of sorghum :

Stomatal resistance is the major physiological control for reducing water loss and preventing the development deleterious water deficits. Further more, it exerts a predominant influence over net photosynthesis of grasses during water stress (Doley and Trivett, 1974; Ludlow, 1976). Therefore it is of keen interest to study the response of stomata of plant to water stress, the effect of water stress on stomatal behaviour in SPV-504 and RSV-10R varieties of sorghum has been recorded in Table No. IV. 5 and IV. 6 and Fig. No. 4.13 and 4.14.

In general width of the stomatal aperture varies with the species as well as varies with leaf to leaf of the same plant our results depicted in Table IV. 5 and Iv. 6 show that in case of SPV-504 variety of sorghum the width of stomatal aperture observed on lower epidermis is more than the width of stomatal aperture on upper eipidermis. Similar type of results were also found in case of RSV-10R variety. But if we compare the width of stomatal aperture in SPV-504 and RSV-10R , it is found that dimensions of width are more in SPV-504 than in the RSV-10R variety. This is supposed to be the varietal character. But we think that it is a adaptive feature of SPV-504 which is subjected to water stress.

It is evident from the readings that in SPV-504 and RSV-10R varieties of sorghum stomata open at a maximum level in between 12.00 noon to 1.00 p.m. range during hours of a day. Our graphical results recorded in Fig. No. 4.11 and 4.12 also show highest peak point in 12.00 noon and 1.00 p.m. this peak is because of the highest light intensity during that period, to which the stomatal opening widened at its maximum level. It is happened due to the direct response of light intensity.

Table No: IV.5 Effect of water stress on stomatal behaviour in SPV-504 variety of sorghum.

Hours of a day	Control		4-days stress		8-days stress		12-days stress		16-days stress	
	Upper epidermis width (μ)	Lower epidermis width (μ)	Upper epidermis width (μ)	Lower epidermis width (μ)	Upper epidermis width (μ)	Lower epidermis width (μ)	Upper epidermis width (μ)	Lower epidermis width (μ)	Upper epidermis width (μ)	Lower epidermis width (μ)
7.00 A.M.	2.0	2.5	1.0	1.5	1.0	1.5	1.0	1.5	0.5	1.0
8.00 A.M.	3.0	3.5	2.0	2.5	2.0	2.5	2.0	2.0	1.5	2.0
9.00 A.M.	4.5	5.0	3.5	4.0	2.5	3.0	3.0	3.5	3.0	3.5
10.00 A.M.	5.5	6.0	4.5	5.0	3.0	4.0	4.0	4.5	3.5	4.0
11.00 A.M.	6.5	7.0	5.5	6.0	4.5	5.0	5.5	6.0	4.5	5.5
12.00 Noon	7.0	8.0	6.0	7.0	5.5	6.0	4.5	5.0	4.0	4.5
1.00 P.M.	7.0	8.0	5.5	7.0	5.5	6.0	3.0	3.5	3.0	3.5
2.00 P.M.	6.5	7.0	4.5	6.0	5.0	5.5	2.5	3.0	2.0	2.5
3.00 P.M.	5.5	6.0	3.5	5.0	3.0	4.0	2.0	2.5	1.5	2.0
4.00 P.M.	4.0	5.0	2.5	4.0	2.5	3.0	2.5	3.0	2.0	2.5
5.00 P.M.	3.0	4.0	2.0	3.0	2.0	2.5	2.0	2.5	1.5	2.0
6.00 P.M.	2.5	3.0	1.5	2.0	1.5	2.0	1.5	2.0	1.0	1.5

* Values expressed are the mean of five readings.

Table No: IV.6 Effect of water stress on stomatal behaviour in RSV-10R variety of sorghum.

House of a day	Control		4-days stress		8-days stress		12-days stress		16-days stress	
	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis	Upper epidermis	Lower epidermis
	width (µ)		width (µ)		width (µ)		width (µ)		width (µ)	
7.00 A.M.	1.5	2.0	1.5	2.0	0.5	1.0	0.5	1.0	0.5	0.5
8.00 A.M.	2.0	2.5	2.0	2.5	1.0	1.5	1.5	2.0	1.0	1.5
9.00 A.M.	3.0	4.0	2.5	3.0	2.0	2.5	2.0	3.0	2.5	3.0
10.00 A.M.	4.5	5.5	3.0	4.0	2.5	3.0	3.0	4.0	3.5	4.0
11.00 A.M.	5.5	6.5	4.5	5.0	3.5	4.5	5.0	5.5	4.5	5.0
12.00 Noon	6.5	7.0	5.0	6.0	4.5	5.5	4.0	4.5	3.5	4.0
1.00 P.M.	6.5	7.0	5.0	6.0	4.5	5.5	3.5	4.0	3.0	3.5
2.00 P.M.	5.5	6.0	4.5	5.0	3.0	4.5	2.5	3.0	2.0	2.5
3.00 P.M.	4.0	5.0	4.0	4.5	2.5	3.0	1.0	1.5	1.5	1.0
4.00 P.M.	3.5	4.0	3.0	3.5	2.0	2.5	2.0	2.0	2.0	1.5
5.00 P.M.	3.0	3.5	2.0	2.5	1.5	2.0	1.5	2.0	1.0	1.0
6.00 P.M.	2.0	2.5	1.0	1.5	1.0	1.5	0.5	1.5	0.5	1.0

* Values expressed are the mean of five readings.

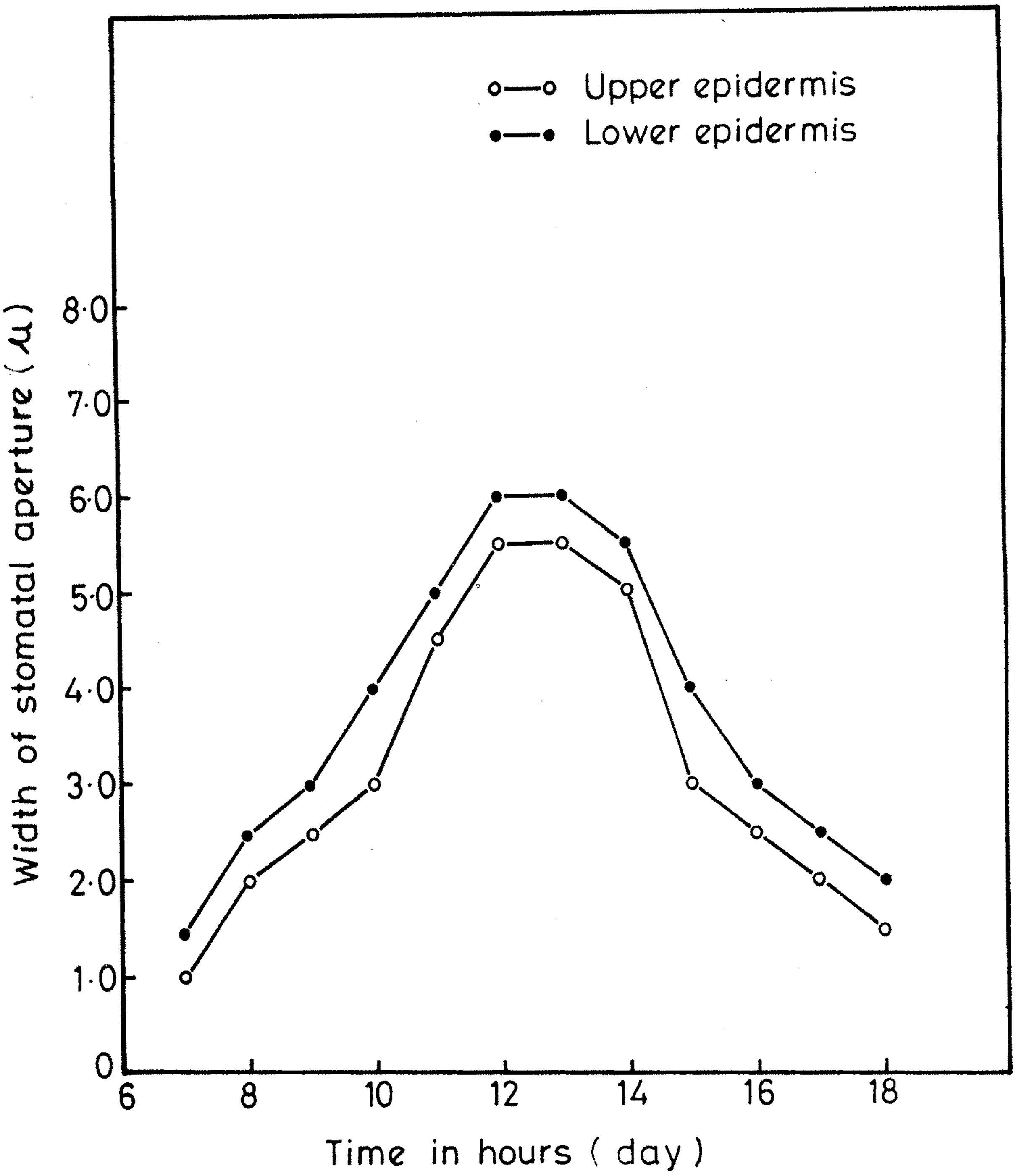

FIG. 4·11 STOMATAL BEHAVIOUR IN SORGHUM (VAR. SPV-504). DURIG WATER STRESS.

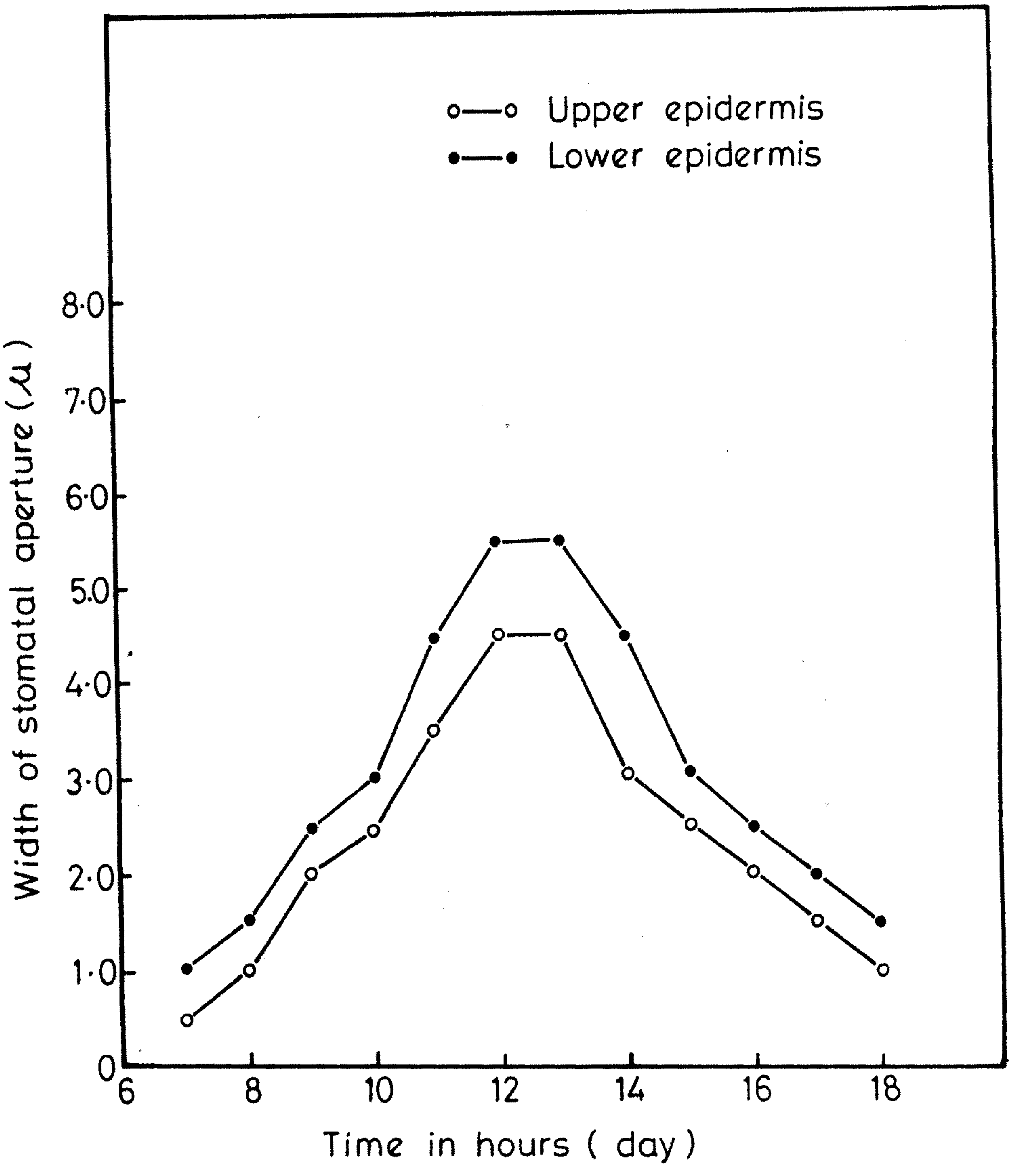

FIG. 4·12 STOMATAL BEHAVIOURS IN SORGHUM (VAR. RSV-10R), DURING WATER STRESS.

It is also noted from the Fig. No. 4.9 and 4.10 that the width of stomatal aperture goes on decreasing as the water stress is increased. So in the plants subjected to the 4, 8, 12 and 16 days water stress the width of stomatal aperture goes on decreasing. The stomatal width reaches its maximum value 7 µ to 8 µ in control plants at 12.00 noon but it is minimum 3 µ to 5 µ at same period in the plants under 16 days water stress.

There is another evidence has been noted from the Table No. IV. 5 and IV. 6 that the width of stomatal aperture is least 0.5 µ at 7.00 a.m. while it is slightly larger 1.0 µ at 6.00 p.m. during the hours of a day. This is due to the very low light intensity at the morning and minimum illumination at evening. So it proves that intensity of light plays an important factor in controlling the opening of stomatal pore.

From our results it is also found that in SPV-504 and RSV-10R varieties show two peak points in the width of stomatal aperture which are subjected to 12 days and 16 days water stress. First the stomata attain their maximum width between 12.00 noon

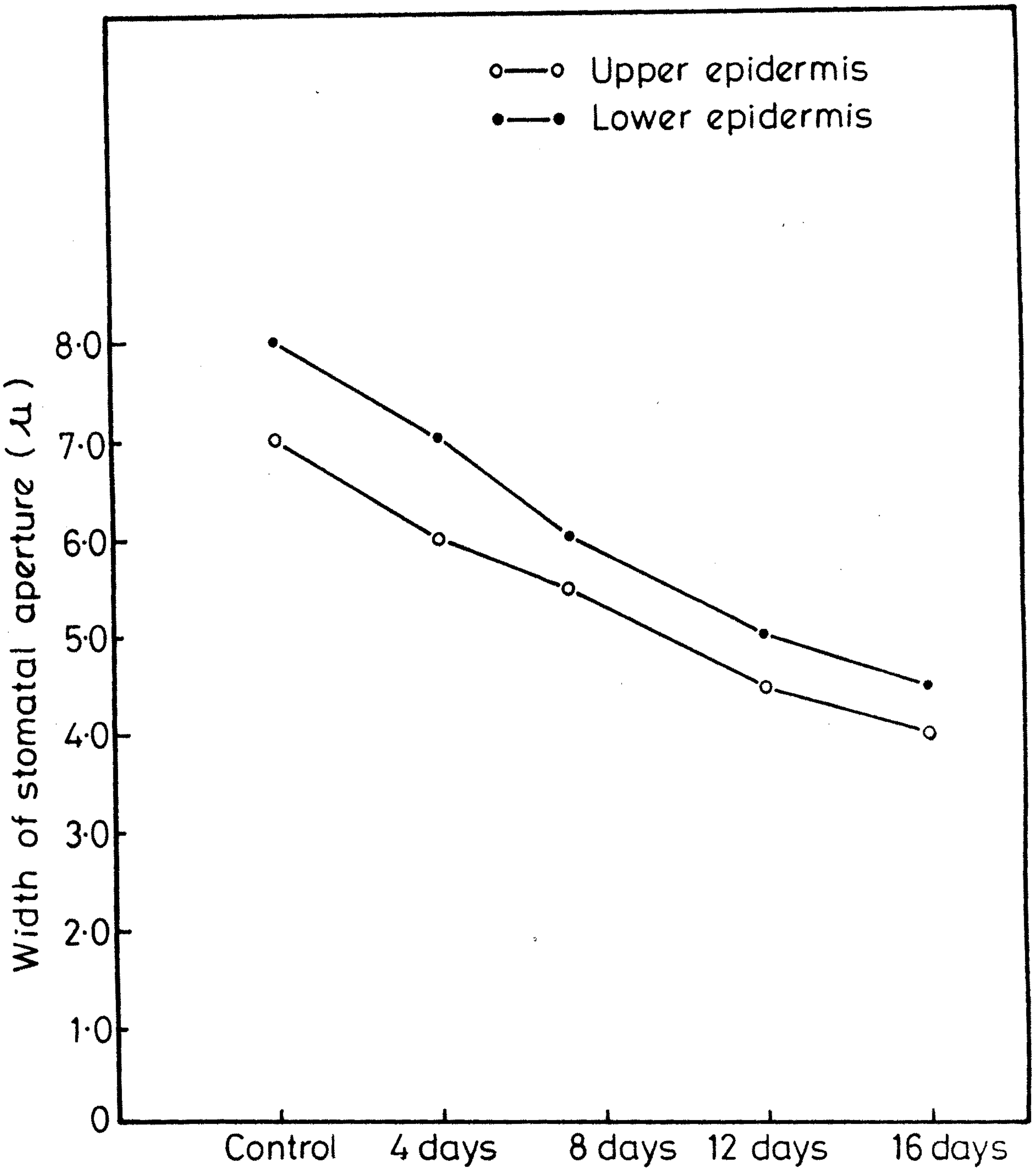

FIG. 4·9 EFFECT OF WATER STRESS ON STOMATAL APERTURE IN SPV-504 VAR. OF SORGHUM.

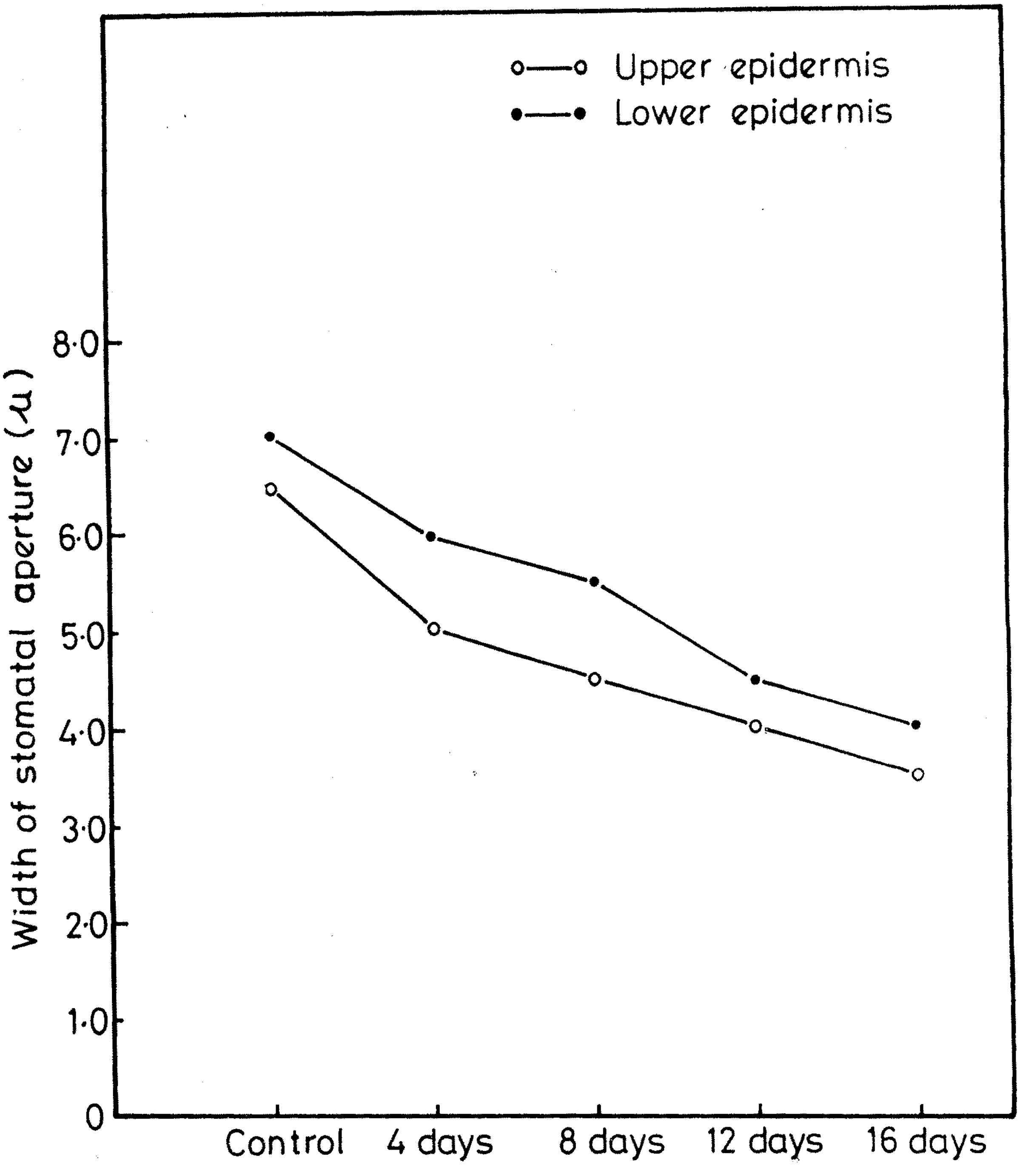

FIG. 4·10 EFFECT OF WATER STRESS ON STOMATAL APERTURE IN RSV-10R VAR. OF SORGHUM.

to 1.00 p.m. then again at 4.00 p.m. they attain more width as compare to 2.00 p.m. and 3.00 p.m. observation. This may be probably due to the change in water deficit of the leaves and the change in the turgidity of the guard cells.

E. Effect of Water Stress on Inorganic Constituents :

i) Potassium :

The Table No.IV. 7 and IV. 8 and Fig. No. 4.15 and 4.17 show the effect of water stress on the potassium content in the leaves of SPV-504 and RSV-10R varieties of sorghum respectively. It is observed that in both the varieties the potassium content of the leaves is increased in 4 and 8 days water stressed plants but decreased in 16 days stressed plants.

Potassium is one of the important indispensible macro nutrients playing an important role in water relations of a plant during growth. The element appears to be highly mobile in and its deficiency is usually noted in older leaves which become chlorotic and develop dark nactotic zones. Potassium plays significant role in plant metabolism.

According to Hartt (1969) translocation of sugars in sugarcane was found to be closely linked to potassium. Potassium deficient sugarcane was demonstated to have a lower

Table No. IV.7

Effect of water stress on inorganic constituents in SPV-504 var. of sorghum.

Inorganic Constituents		Water Stress (days)			
	Control	4	8	12	16
1) K	2.56	2.80	3.17	2.75	2.40
2) Ca	0.71	0.78	0.86	0.68	0.54
3) Mg	0.538	0.430	0.420	0.396	0.370
4) Na	0.14	0.17	0.29	0.32	0.37
5) Fe	0.15	0.18	0.22	0.12	0.07
6) Mn	0.021	0.026	0.030	0.017	0.013

* The values expressed in $g\ 100^{-1}\ g$ dry tissue.

* Each value is mean of three determinations.

Table No. IV.8

Effect of water stress on inorganic constituents in RSV-10R var. of sorghum.

Inorganic	Water Stress (days)				
Constituents	Control	4	8	12	16
1) K	2.53	2.75	3.14	2.64	2.42
2) Ca	0.76	0.84	0.92	0.70	0.50
3) Mg	0.622	0.542	0.410	0.399	0.360
4) Na	0.15	0.26	0.32	0.36	0.41
5) Fe	0.17	0.20	0.23	0.14	0.09
6) Mn	0.015	0.023	0.027	0.015	0.011

* The values expressed in g 100 g^{-1} dry tissue.

* Each value is mean of three determinations.

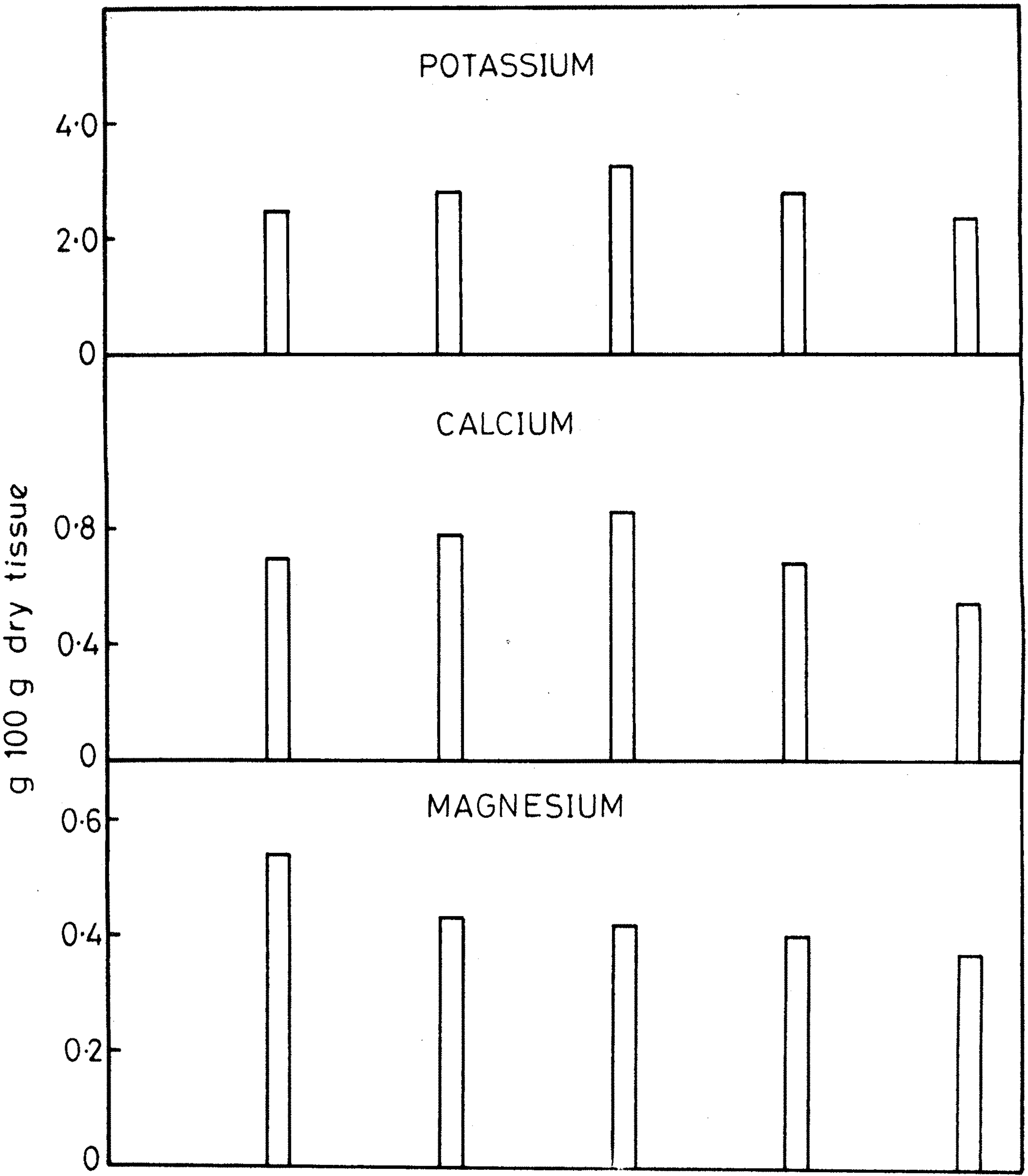

FIG. 4·15 EFFECT OF WATER STRESS ON POTASSIUM CALCIUM AND MAGNESIUM CONTENTS OF LEAVES OF SORGHUM (VAR <u>SPV-504</u>).

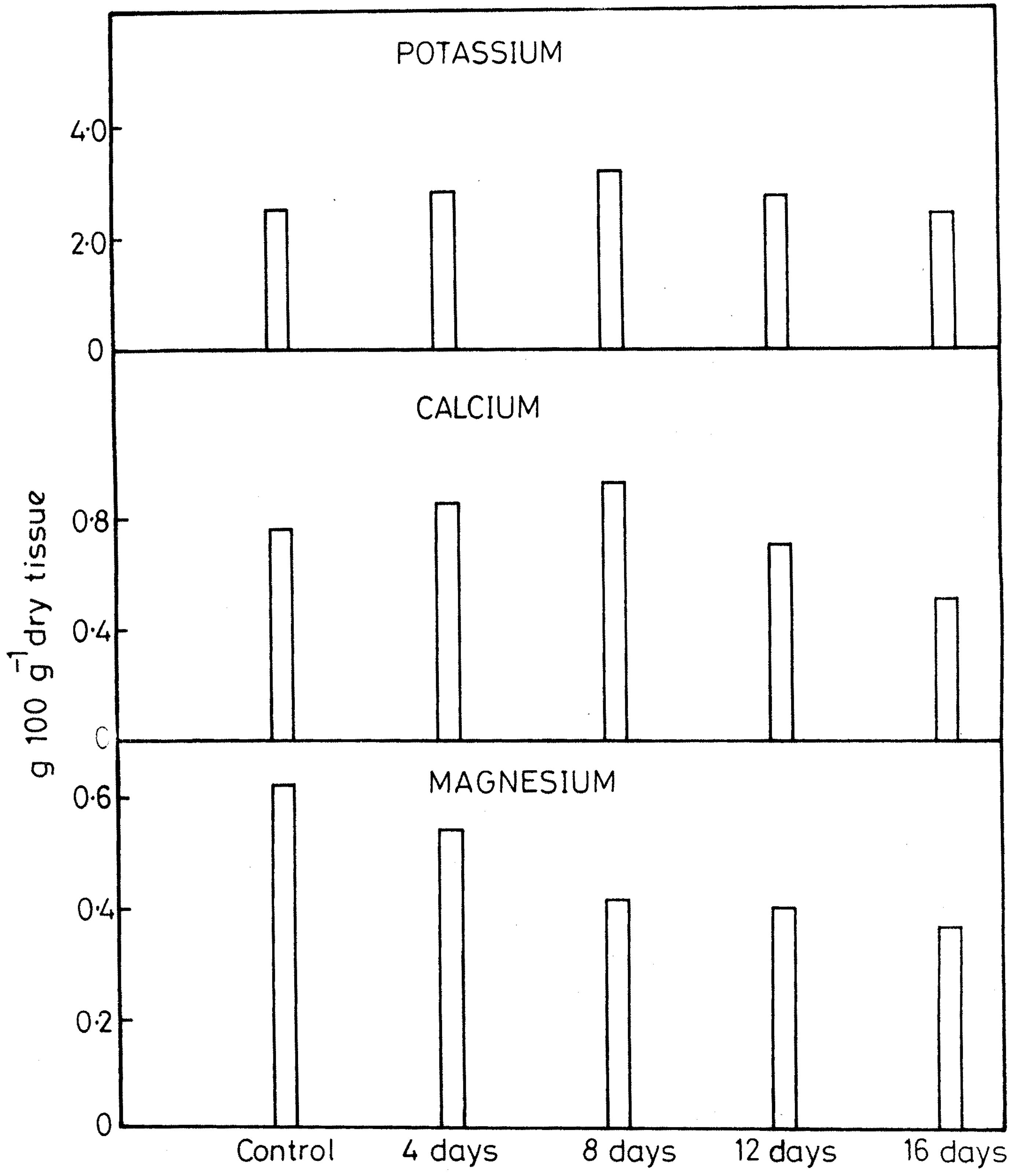

FIG. 4·17 EFFECT OF WATER STRESS ON POTASSIUM, CALCIUM AND MAGNESIUM CONTENTS OF LEAVES OF SORGHUM (VAR. RSV – 10R) sugar concentration even though the photosynthetic activity was not altered. The experiment of Stewar~~d~~l and Hungata (1966) and Shimomura (1967) indicated that potassium uptake is only slightly reduced by water stress. Kongstrud (1969) reported a varietal difference regarding potassium uptake during water deficiency. Singh and Singh (1970) reported an increase in potassium content in the first period of growth of rice due to depleted soil water but latter the trend was reversed. The deficiency in moisture content is associated with increase in potassium content during all stages of their growth (Rahman *et al*., 1971). Khatri and Mehta (1962) obsevered the accumulation of potassium in stem and leaf parts in ragi.

Bernstein (1963); Rains (1972) found that potassium was selectively absorbed by the plants under water stress and it is one of the main ions involved in preventing the plant from loosing water and becoming physiologically dry. Halbrook *et al*. (1980) observed an increase in potassium uptake in tomato along with growth and finally its accumulation in the fruit. Schere *et al*. (1982) observed in wheat (*Triticum aestivum*) that inadequate potassium supply resulted in a lower water content and decreased growth rate as compared with plants sufficiently supplied with K^+. Ford *et al*. (1981) observed accumulation of potassium, sodium and chloride in Panicum maximum; and this accumulation of inorganic ions was accounted for osmotic adjustments.

Jadhav (1984) reported 2.5% increase in the level of potassium in stem and leaves of prosomillet. Bildusas, Pfleger, Stewart and Dixon (1986) observed controversy exists regarding increased uptake of potassium by mycorrhizal plants in response of Bromus inermis inoculated with Glomus fasciculatum to potassium fertilization and drought stress. Gaikwad (1987) observed the accumulation of potassium in the leaves of Phaseolus aconitifolius upto three to seven days water stress plants. But after seven days water stress potassium decreases slightly. He reported that the accumulation of potassium in water stressed moth bean, may be considered as an adaptive feature.

In both sorghum varieties SPV-504 and RSV-10R the potassium increases upto 12 days water stress, but in 16 days stressed plants potassium decreases slightly. The accumulation of potassium upto 12 days water stressed jowar cultivars may be for osmotic adjustments. While potassium content decreases after 12 days water stress may be due to exploitation of soil water due to drought.

ii) Calcium :

The Table No. IV.7 and IV.8 and Fig. No. 4.15 and 4.17 shows the effect of water stress on the calcium content in the leaves of SPV-504 and RSV-10R varieties of sorghum respectively. It is observed that in both the varieties the calcium content is increased in the 4 and 8 days water stressed plants, but the calcium content of the leaves is decreasing in plants which are exposed to 12 and 16 days of water stress.

Calcium is playing an important role in the metabolic processes of plants calcium is rather an immobile element and plays an important role in cation transport by plant cells (Epstein, 1961). Due to its immobile nature, calcium accumulate in the phelem in older parts of the plants.

According to Richards and Wadleigh (1952) water stress causes variable effects on calcium concentration in plants. Takeshi (1966) reported that in *Brassica rapa* and *Vigna sinensis* water stress was found to increase calcium content in the leaves. Rahman *et al*. (1971) observed that the calcium content rises with deficiency in soil moisture at different stages of development of some *Panicum* species. Calcium is found to be involved in mechanism of heat resistance in thermophilic bacteria (Ljunger, 1973). Calcium content also increases in sugarcane due to water stress (Samuels 1972).

Kunno *et al*. (1964) reported that the inhibition of calcium and magnesium absorption was one of the reasons for increased flower and pod shedding in soybean caused by water deficit. Gillev (1969) recorded symptoms of calcium deficiency in groundnut crop subjected to drought. Calcium was greatly reduced in wilting rice leaves was observed by Singh and Singh (1970). Vander Boon (1973) noticed that drought lowers calcium content and raises the K/Ca ratio in tomato fruits. But Stewart and Hungate (1966) employing ^{45}Ca found that there is no effect of soil moisture on calcium uptake in *Phaseolus vulgaris*. Similarly Eck *et al*. (1981) observed that water stress did not affect calcium concentration in the leaves of *Sorghum bicolor*.

Jadhav (1984) recorded that the calcium contents in flag leaves of proso millet increases in first stages of water stress but it again decreases in the later stages of water stress. Gaikwad (1987) also reported the same results in *Phaseolus aconitifolius*. He added that like potassium, calcium may be involved in drought resistance mechanism in moth bean plant.

In both the varieties of sorghum the accumulation of calcium content in the 4 and 8 days water stressed plant may be accounted for osmotic balance like potassium. However, this divalent cation declines due to 12 and 16 days severe water stress. Like potassium, calcium may be involved in drought resistance mechanism.

iii) Magnesium :

The Table No. IV.7 and IV.8 and Fig. No. 4.15 and 4.17 shows the effect of water stress on the magnesium content in the leaves of SPV-504 and RSV-10R varieties of sorghum, respectively. It is observed that in both the varieties the magnesium level goes on decreasing gradually as the water stress is increased.

As magnesium is essential element for chlorophyll synthesis the green leaves of the plant become pale yellow due to its deficiency. It is also an important cofactor involved in plant metabolism. Sakanaue and Iguchi (1968, a,b,c) found that magnesium uptake is greatly reduced in rice plant under water stress. On the other hand Kongstrud (1969) observed an increase in the magnesium content in black current but not in apple. According to Gilmore (1971) there is a decrease in the amount of magnesium in the leaves of loblolly pine due to water stress.

Georgieva *et al.* (1982) have recorded that magnesium deficiency in chloroplast lipids of maize leaves reduce the phospholipids, phosphotydyl glycerol and galacto-syldiglycerides.

The decrease in the magnesium content. Jadhav (1984) observed that the decrease in Mg content in root and stem and its accumulation in leaves indicate possibly it is translocated towards the leaf to reduce losses in lipids of chloroplast during water stress. It was also observed that the chlorophyll content of the leaves of proso millet is unaflected due to water stress.

Gaikwad (1987) reported that there is linear increase of magnesium in the **Phaseolus aconitifolius** due to water stress. He considered it as an adaptive feature in drought resistance.

It is clear from the data depicted in Table No. IV.7 and IV.8 both the cultivars of sorghum the magnesium content decreases as the period of water stress increases. Thus the decline of magnesium level in water stressed varieties of sorghum, may be an adaptive feature in drought resistance.

iv) Sodium :

The changes in sodium level in the leaves of SPV-504 and RSV-10R varieties of sorghum during water stress have been recorded in Table No. IV.7 and IV.8 and Fig. No. 4.16 and 4.18. It is evident from the values of sodium content that there is a gradual increase of sodium in the leaves when the plants are subjected to 4, 8, 12 and 10 days of water stress.

The sodium is also found to be an important element because

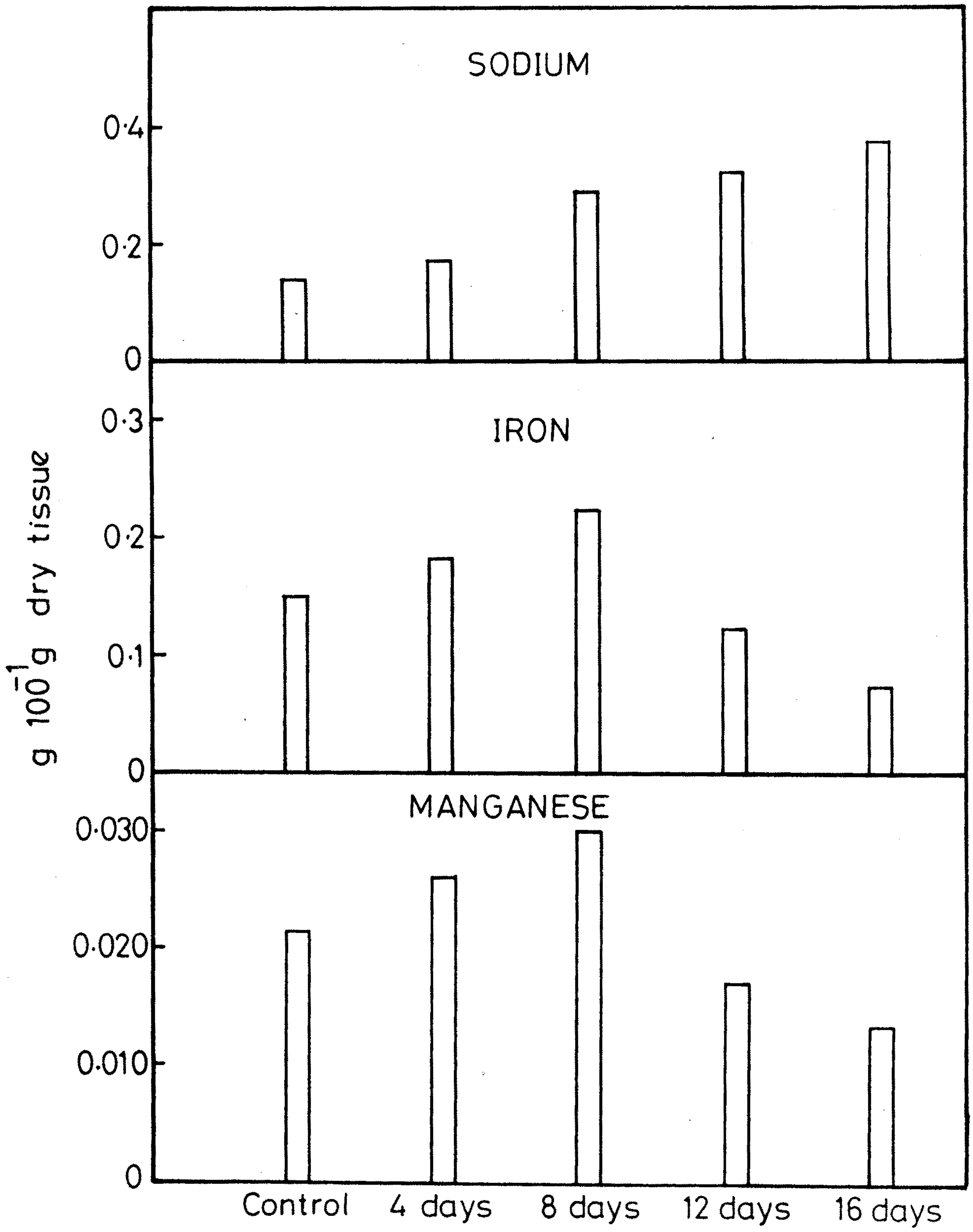

FIG. 4·16 EFFECT OF WATER STRESS ON SODIUM, IRON AND MANGANESE CONTENTS OF LEAVES OF SORGHUM (VAR. SPV-504).

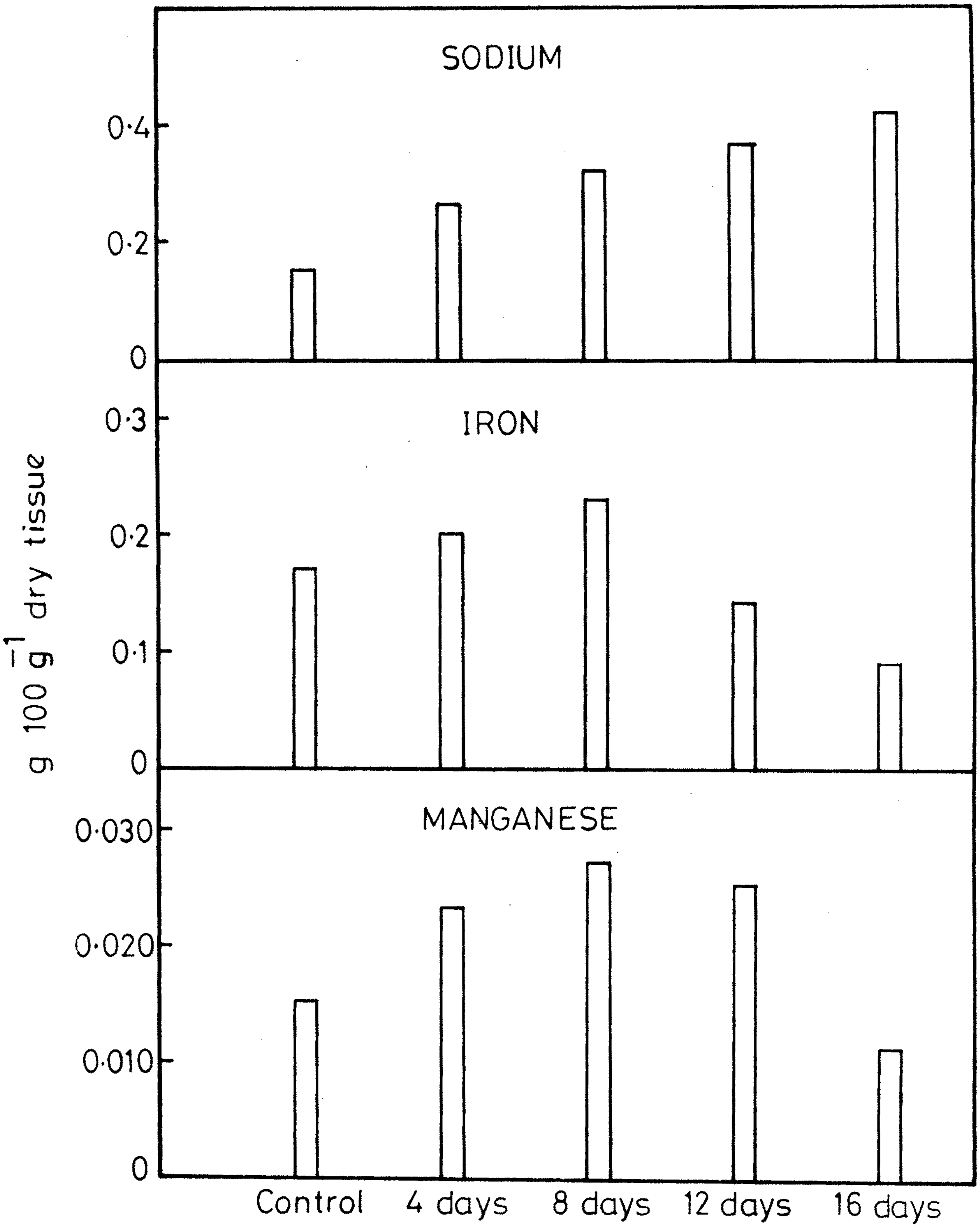

FIG. 4·18 EFFECT OF WATER STRESS ON SODIUM IRON AND MANGANESE CONTENTS OF LEAVES OF SORGHUM (VAR. RSV-10R).

in some metabolic activities sodium can replace potassium and acts in the process of water relations in plants. There is a little work on the effect of drought on sodium uptake. Formerly it was believed that sodium is a non-eesential element for glycophytes (Epstein, 1972). However Brownell and Crossland (1974) suggested its essentiality in C_4 and CAM metabolism.

Takeshi (1966) observed very little difference in sodium contents leaves of _Brassica_ _rapa_ and _Vigna_ _sinensis_ when grown under water stress. Rahman _et_ _al_. (1971) reported that moisture stress causes a rise in the plant sodium content of each stage of development in different grass species. According to these workers, such increase may be attributed to the great reduction in dry matter at low moisture levels. Sodium increases drought resistance of water stressed sugarbeet by altering leaf water balance (Lawlor and Malford, 1973).

Ramati _et_ _al_. (1979) and Ford (1981) reported the accumulation of sodium, during water stress in _Panicum_ _ripens_. They considered that the _Panicum_ grass leaves adjust osmotically to water stress apparently through accumulation of solutes so that there is a decrease in osmotic potential at full turgor.

Jadhav (1984) showed that the sodium content in root, stem and leaves of proso millet is increased as the amount of water stress is increased. Gaikwad (1987) also had shown the same results in the stem and leaves of *Phaseolus aconitifolius*. He predicted that the increase of sodium in moth bean may be an adapting feature.

The accumulation of cation sodium in the leaves of water stressed SPV-504 and RSV-10R varieties of sorghum may contribute to osmotic balance which is an adaptive feature for drought.

v) Iron :

The Table No. IV.7 and IV.8 and Fig. No. 4.16 and 4.18 show the effect of water stress on the iron content in the leaves of SPV-504 and RSV-10R varieties of sorghum respectively. It is seen that iron content of leaves in both varieties increases upto 8 days water stress and then declines towards 16 days water stress.

As iron is essential for chlorophyll synthesis and a co-factor in the number of enzymatic reactions; it is also important element. It is a type of minor element in the plant nutrition. The adequate value of iron according to Epstein (1972) in higher plants is 0.01 percent of dry weight. Iron is considered as an immobile element in plants (Brown, 1961),Basionny and Biggs (1971) and Rahman *et al*. (1971) observed that uptake and translocation of iron in citrus are hindered due to water stress.

There is less research about the behavior of iron in plants exposed to water deficit. Ivanov and Karakash (1965) observed that soil moisture stress increases the content of soluble iron in roots of apple trees. There is some work on the physiology of water stress in proso millet. Jadhav (1984) observed that iron content continuous decreases in stem and leaves upto grain filling stage and increases further in the leaves at maturity. It was seen that iron content of the root continuously increases as growth proceeds, but falls down after heading stage. During water stress iron accumulates almost in all parts of proso millet due to negative influence of water stress on iron translocation. Gaikwad (1987) observed the increase of iron content in the stem and leaves of P. aconitifolius as the amount of water stress in increased.

Increasing iron content of the leaves in both the cultivars of jowar upto 8 days water stress may be due to the soil moisture stress. However in 12 and 16 days water stress in both varieties there is linear decrease in the iron level. This may be attributed to hindered up take of iron due to severe water stress.

vi) Manganese :

The Table No. IV.7 and IV.8 and Fig.No. 4.16 and 4.18 shows the effect of water stress on the manganese content in the leaves of SPV-504 and RSV-10R varieties of sorghum respectively. It is observed that manganese content of leaves in both varieties increases upto 8 days water stress and then declines towards 16 days water stress.

Manganese is one of the important trace elements. Manganese play, an important role in the activation of enzymes in plants, According to Viets, (1972) it is equally important to study the effect of water stress on the major elements (Nitrogen, phosphorus potassium) secondary elements (calcium, magnesium, silicon) as well as minor elements like manganese, iron, boron. Sakanoue and Iguchi, (1968) carried out extensive investigation to study the effect of low soil moisture on growth and nutrient absorption of rice at various stages of growth. They reported that drought causes to increase the absorption of manganese in rice. Working with the same crop Pande and Singh (1969) however, found reduction in manganese content due to water stress.

Jadhav (1984) reported the slight decrease in manganese content in the water stressed proso millet leaves. He supposed that it may not cause any metabolic disorder. The manganese content of the stem and leaves of moth bean increases upto three days water stress and then declines towards 15 days water stress (Gaikwad 1987).

In the leaves of SPV-504 and RSV-10R varieties of sorghum the level of manganese increases upto 8 days water stress. The absorption of manganese is more due to the sudden shock of drought. But on the other hand manganese content decreases towards 16 days water stress which may be attributed to soil moisture stress.