Chapter III

RESULTS AND DISCUSSION

A. Effect of Water Stress and NaCl Salinity on Growth and Development :

The growth and development of Dodonaea viscosa L. under drought and saline conditions (respectively plate I and II) have been recorded in Tables 1, 3 and 2, 4 respectively. The observations have also been depicted in figures 1, 2 & 3, 4 respectively. The tables show the effect of water stress for 4, 8, 12 and 16 days and NaCl salinity at various salt concentrations such as 25, 50, 100 and 200 mM on root growth, shoot growth, root to shoot ratio, number of leaves per plant, leaf area per plant and biomass (fresh as well as dry matter) production in the species after about three months growth.

It is evident that with increasing level of drought the linear growth of D. viscosa L. is only slightly affected. This is quite clear from the values for total length per plant. It can be seen that the total length of well irrigated plant is about 36 cm which is reduced to about 34 cm only even after 16 days water stress. More reduction in the length of the plant is observed in case of 8 days water stress. Thus, it appears that drought has almost a negligible effect on the linear growth of D. viscosa L. Root to shoot ratio, however, is affected by some measurable margin due to drought condition. This is suggestive of some adverse effect of water stress on linear growth of root system. This is also evident from the values recorded for root length. It can be seen that the root length of daily irrigated plants is about 24 cm which is reduced to about 17 to 18 cm due to water stress. On the other hand the shoot length of the plant seems to be unaffected by water stress. It is also observed that the number of leaves per plant is continuously declined with

Plate-1 Effect of water stress on growth and development of D. viscosa L.

Plate-II Effect of NaCl salinity or growth and development of D. viscosa L.

increasing the intensity of drought. It can be seen that the control plants have on an average 28 leaves per plant, while the plants stressed for 16 days have only 13 leaves. This is as a result of early senescence, abscission, drying of the leaves and leaf fall in the plants exposed to drought. It may be true that new leaf formation in water stressed plants is affected.

As far as linear growth of D. viscosa L. plant under saline conditions is concerned, salinity seems to be detrimental, particularly at the higher salinity levels (100 and 200 mM NaCl). It can be seen that there is almost 50 % reduction in the total length of the plant when grown under saline conditions at 100 and 200 mM NaCl in the medium. It is also evident from Table 2 that the root to shoot ratio is slightly affected upto 50 mM NaCl level. However, it is strongly affected at the highest salinity level (200 mM NaCl). This is indicative of strong inhibition of root growth in this species under saline conditions, particularly at higher salinity levels. This is quite evident from the values recorded for root length. It can be seen that there is slight increase in the root length from about 23 cm in the plants grown under nonsaline conditions to about 24 cm in the plants grown at 25 mM NaCl level. However, with further increase in the salinity level there is rapid fall in the length of root system. There is more than 60% reduction in the root length in the plants grown at 200 mM NaCl level. Shoot growth seems to be relatively less affected by salinity. It appears that root growth in D. viscosa L. is highly sensitive to saline conditions as compared to that under drought. Leaf area per plant is also affected remarkably due to NaCl salinity. It can be seen that the photosynthetic area in the plants grown under non-saline conditions, which is about 86 cm^2, drops down sharply to about

Table:1 Effect of water stress on growth of D. viscosa L.

Water stress (days)	Root length (cm)	Shoot length (cm)	Total length (cm)	R/S	No. leaves plant^{-1}
0 (control)	24.23±9.95	12.83± 3.54	36.06 ± 13.49	1.89	28
4	17.84±4.72	13.86± 3.62	31.70 ± 8.34	1.29	20
8	18.27±5.35	12.11± 4.49	30.38 ± 9.84	1.51	15
12	18.34±3.24	13.53± 3.11	31.87 ± 6.35	1.36	19
16	21.92±6.60	12.01± 4.05	33.93 ± 10.65	1.83	13

± SD

Table:2 Effect of NaC1 salinity on growth of *D. viscosa* L.

NaC1 treatment (mM)	Root length (cm)	Shoot length (cm)	Total length (cm)	R/S	Leaf area (cm^2)
00 (Control)	23.20 ± 5.25	7.80 ± 1.89	31.00 ± 7.14	2.97	85.59
25	24.16 ± 5.93	7.97 ± 2.75	32.13 ± 8.68	3.03	53.45
50	17.45 ± 5.32	6.80 ± 2.14	24.25 ± 7.46	2.57	53.42
100	10.60 ± 7.74	4.52 ± 0.65	15.12 ± 7.39	2.35	35.82
200	8.78 ± 3.81	5.90 ± 1.49	14.68 ± 5.30	1.50	23.16

± SD

53 cm^2 even at the lower salinity level (25 and 50 mM NaCl). It is still further strongly affected by higher salinity levels. It can be seen that there is as much as 60 and 74 % reduction in the photosynthetic area in the plants grown at 100 and 200 mM NaCl levels respectively.

The biomass production by D. viscosa L. plants under drought and salt stress conditions is recorded in Tables 3 and 4 and figures 5 and 6 respectively. It is evident that fresh weight of a plant is considerably reduced due to water stress. About 50 % reduction in the fresh weight of a plant is observed in case of the plants exposed to 16 days water stress. This significant reduction in the fresh biomass can be attributed to that of leaf, as the leaf fresh weight is significantly reduced due to water stress. The biomass produced by the stem is not at all affected by water stress. There is only a slight reduction in the fresh weight of roots in the plant exposed to water stress. Almost the same pattern can be seen for dry matter production by the plant under drought conditions. It can be seen that the dry matter produced by daily irrigated plants after about three months growth is 0.31 g $plant^{-1}$. It decreases continuously with the severity of water stress and declines upto 0.1 g $plant^{-1}$ after 16 days water stress. It appears that water stress strongly influences the biomass production in the foliage probably affecting the photosynthetic processes. Decrease in the number of leaves due to water stress may be the reason for decreased biomass production in the foliage.

It is interesting to note that the fresh biomass production in D. viscosa L. is only slightly affected by salinity. It can be seen that the fresh weight of a plant grown under non-saline conditions is 0.63 g $plant^{-1}$ which is maximally reduced upto

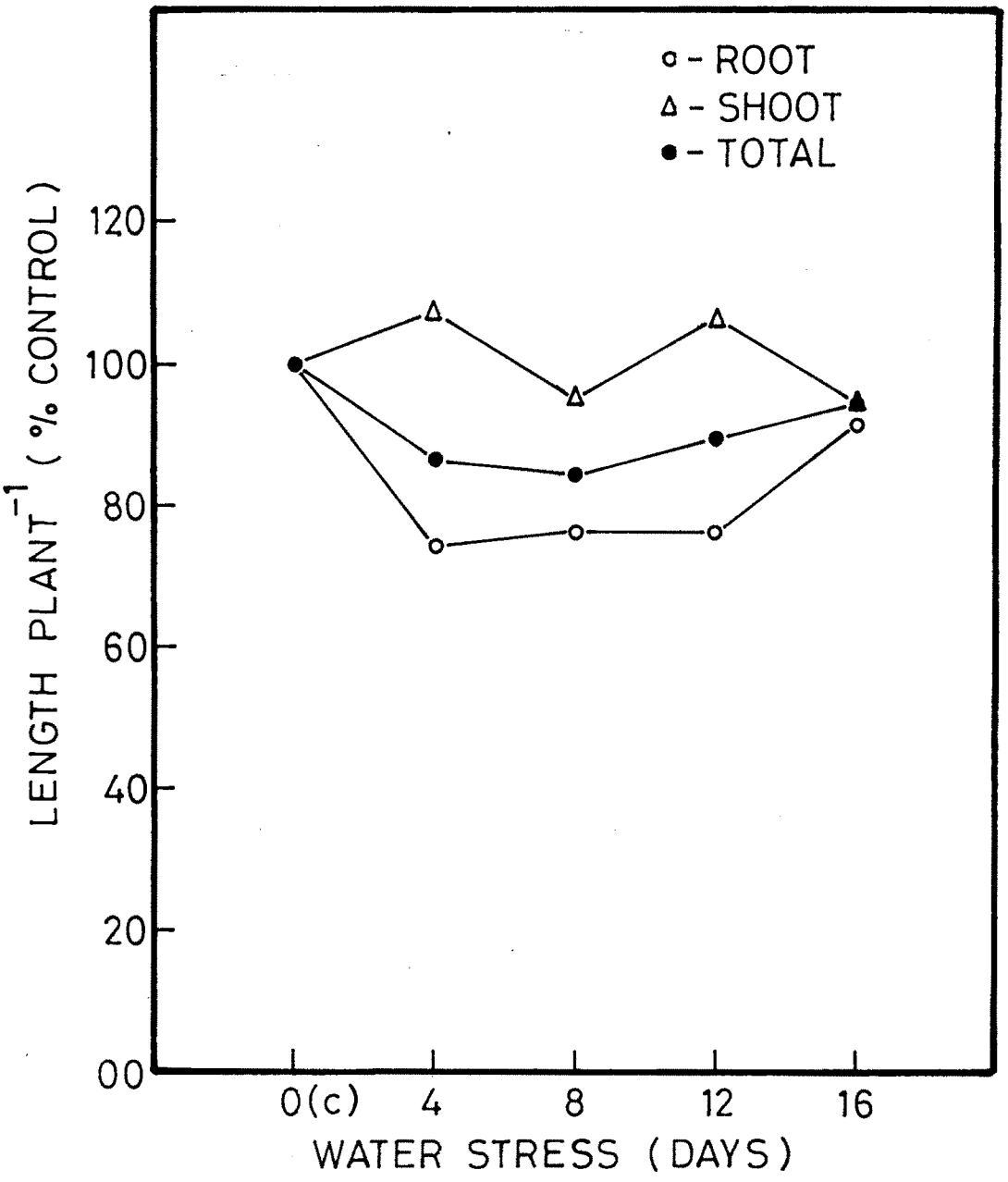

FIG.1. EFFECT OF WATER STRESS ON GROWTH OF D. viscosa L.

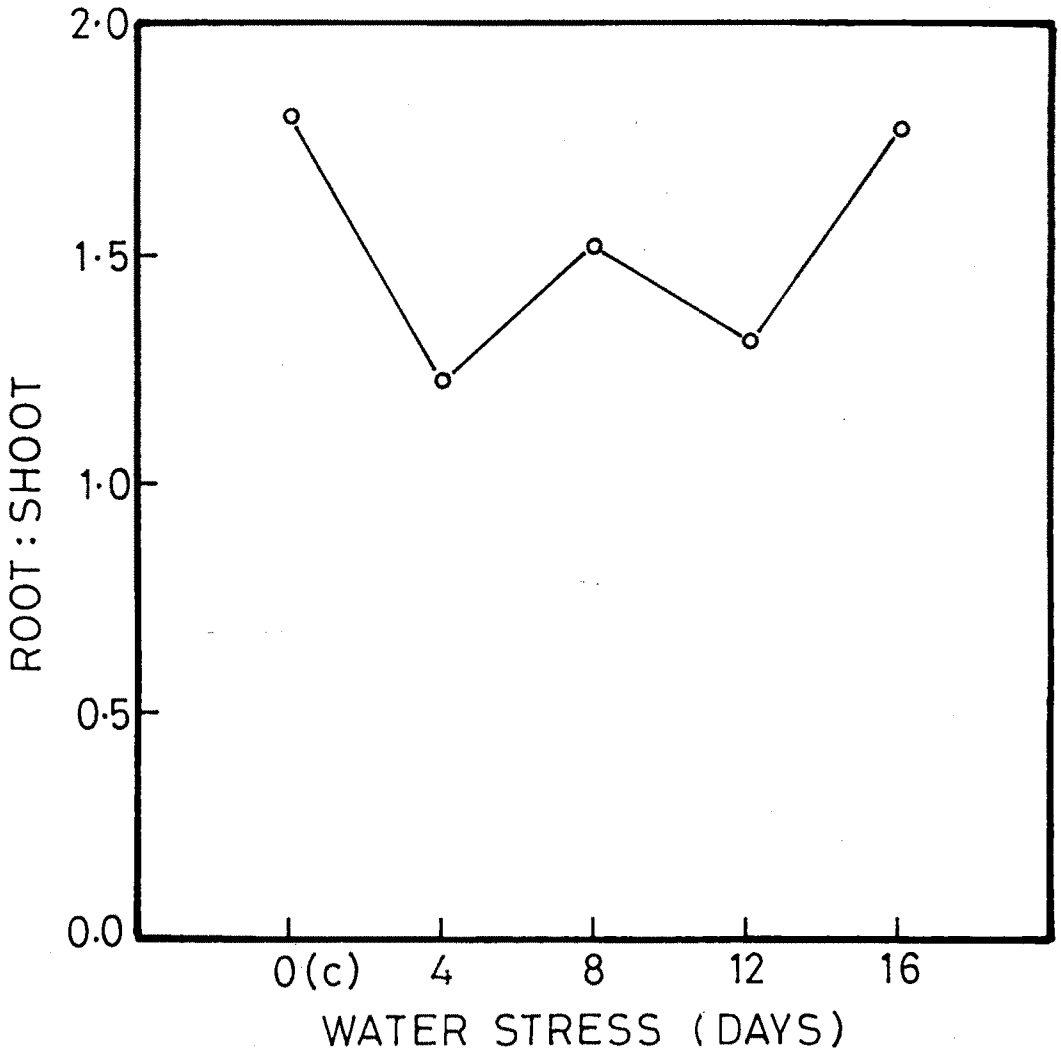

FIG.2. EFFECT OF WATER STRESS ON ROOT:SHOOT RATIO IN D. viscosa L.

0.59 g plant^{-1} at 50 mM NaCl level. The higher salinity levels have shown only a slight effect on fresh weight of the plant. It is also evident that each and every part of a plant like leaf, stem and root responds almost alike to the salinity stress. Dry matter production in the plant, however, is affected by NaCl salinity. It can be seen that with increasing concentration of salt in the medium, there is continuous and linear decrease in the dry weight of a plant. This decrease in dry weight plant^{-1} seems to be due to sharp decrease in the dry weight of stem. Dry weight of leaf and roots is only slightly affected. Thus dry matter production in D. viscosa L. seems to be sensitive to salinity stress.

Drought has generally been accepted as a deficiency of available soil moisture which produces water deficits in the plant sufficient to cause a reduction in growth. The drought condition may be due to absence of water or moisture in the soil, the physical drought, or may be due to saline conditions, due to which the salt concentration in the soil medium is highly increased, rendering unavailability of rather plenty of water in the medium, to the plants, a physiological drought. Response of plants to drought however, varies from plant to plant and species to species. Some of the plants have well developed mechanism to resist water stress and make use of available water efficiently. Xerophytes and succulents are some of the good examples of drought resistant plants. Greenway and Munns (1980), while reviewing the mechanisms of salt tolerance in nonhalophytes, have categorised the plants into three groups. The first group being that of halophytes which continue to grow rapidly at 200 to 500 mM NaCl, include the plants such as Suaeda maritima,

Atriplex numularia, A. nastata, Spartina townsendie and sugarbeet. The second one of both halophytes and non-halophytes which grow very slowly above 200 mM NaCl include halophytic monocotyledons, cotton, barley and tomatoes. The third group comprises of very salt sensitive non-halophytes and include fruit trees such as citrus, avocado and stonefruit.

Water deficits in meristematic regions reduced growth materially (Loomis, 1934; Wilson, 1948). Richards and Wadleigh (1952) have presented a thorough review of many investigations which shows that slight to moderate water stress decreased plant growth. Growth is suspended during moisture stress and resumed upon its elimination. The extent of the damage caused to the plants depends on their physiological ages, the degree of water stress and the species concerned (Gates, 1968). Generally the organ growing most rapidly at the time of stress is most affected (Aspinall et al., 1964). Aspinall et al. (1964) found that all stages of plant development are affected but the most sensitive stage is between the completion of spikelet formation and anthesis in most of the crop plants. Parao et al. (1976) have found that drought resistance in rice cultivars is related to ability to develop a deep well proliferated root system. The effect of water stress on growth, water relations and proline metabolism in Phaseolus vulgaris has been studied by Jaeger and Meyer (1977). They found that water stress causes to decrease the water potential and fresh and dry weights of leaves and the plants. Karamanos (1978) has recorded more than 50 % reduction in the total leaf area of field beans (Vicia faba L.) grown in the field for 46 days under water stress conditions. Water stress to pot grown groundnut (Arachis hypogea L. cultivar C - SS-437) plants suppressed dry weight, extension and expansion

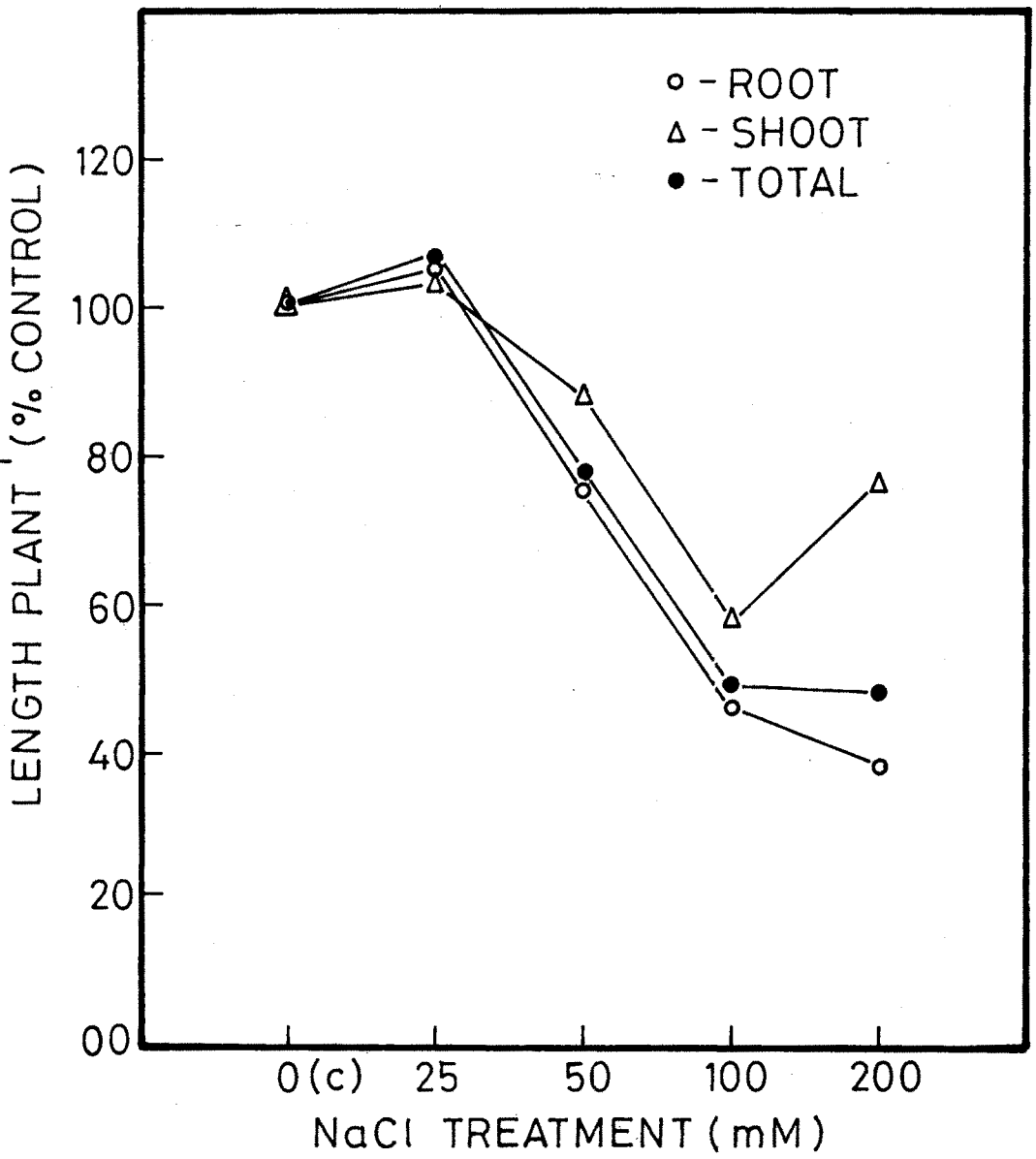

FIG.3. EFFECT OF NaCl SALINITY ON GROWTH OF D. viscosa L.

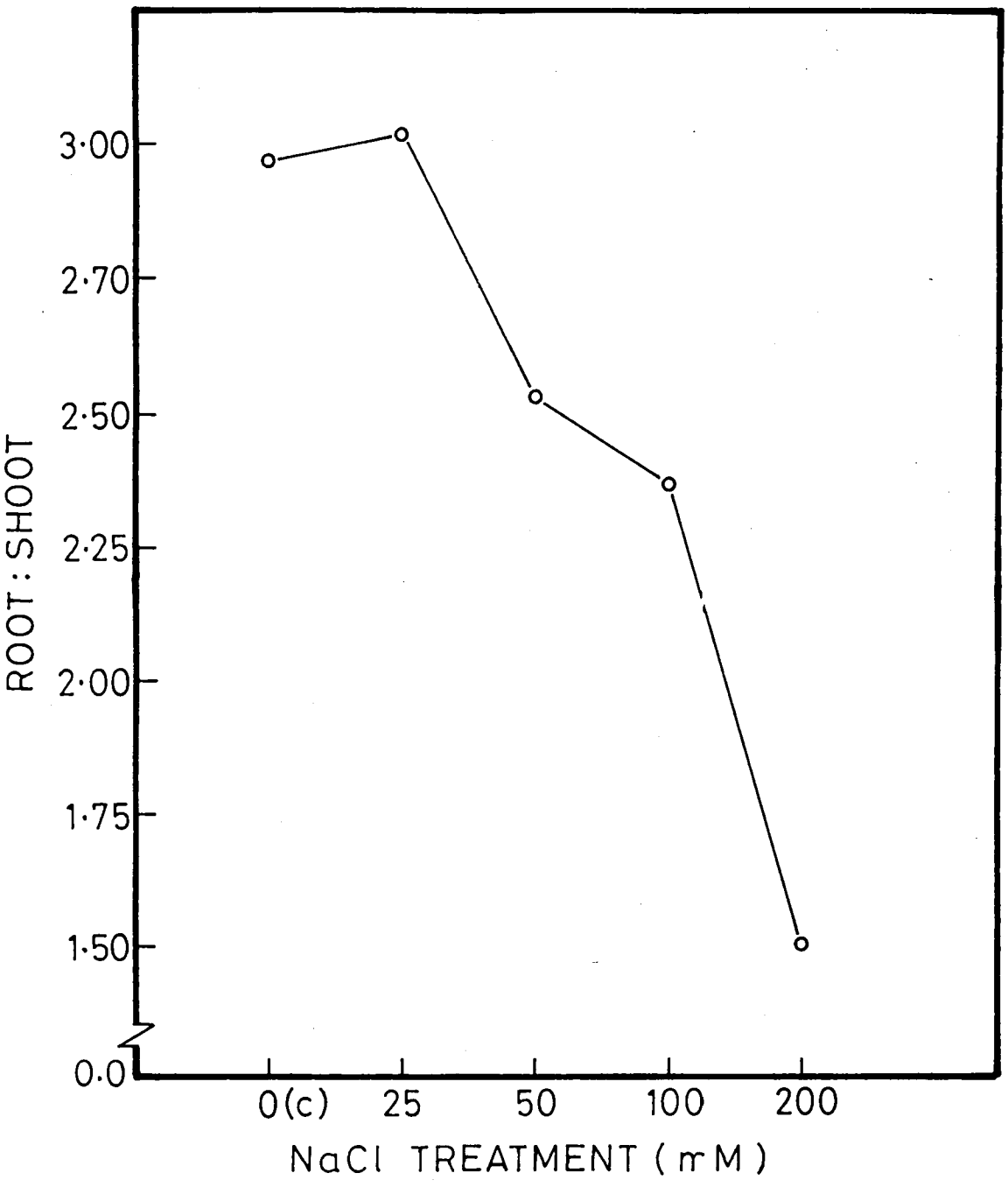

FIG.4. EFFECT OF NaCl SALINITY ON ROOT:SHOOT RATIO IN D. viscosa L.

growth. Tesha and Paul (1983) observed that as water stress increased the dry matter production was decreased in case of sweet corn. Osonubi (1984) has made an interesting observation in Gmelina arborea seedlings. He found that leaf and root growth of this species was not affected until the later part of the water stress period. As the severity of water stress increased, root growth was prolific in all soil segments. Thakur and Rai (1984) have reported that the detrimental effects of water stress are more severe on above ground parts as compared to underground parts in case of Maize. Joshi (1985) found that water stress adversely affected total biomass, biomass of shoots and roots, net production and relative growth rate of Poa pratensis.

The response of plants to salinity stress varies from plant to plant and species to species. Several workers have reported that salinity adversely affects growth and dry matter production in plants (Heikal, 1976; Frota and Tucker, 1978; Joolka and Singh, 1979; Chavan and Karadge, 1980 ; Ahmed et al., 1980; Makrides and Goldthwaite, 1981; Mukharjee et. al., 1982). Shourbaggy and Missak (1975) studied the effect of salinity on growth, mineral composition and seed lipid characteristics of some Ricinus communis varieties and found that growth rate in each cultivar was reduced with progressive increase of NaCl concentration. It was also observed that leaf area in each cultivar decreased with increasing level of salinity. Abdul-Wahab and Al-Juboory (1975) studied the development of salt tolerance in cotton plants. They observed that increasing the salt concentration in different treatments, decreased the length and dry weight of a plant, flowering was delayed and fruiting was inhibited when NaCl concentration was increased gradually up to 16 ECe. Shoot growth was found to be more sensitive to NaCl salinity than root

Table:3 Effect of water stress on biomass (fresh and dry weight) production in *D. viscosa* L.

Water stress (Days)	Fresh weight (g plant^{-1})				Dry weight (g plant^{-1})			
	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total
Control 0	0.37	0.16	0.12	0.65 ± 0.04	0.11	0.10	0.10	0.31±0.02
4	0.15	0.16	0.09	0.40 ± 0.03	0.06	0.11	0.08	0.25±0.02
8	0.19	0.16	0.08	0.43 ± 0.03	0.07	0.09	0.06	0.22±0.01
12	0.20	0.15	0.07	0.42 ± 0.04	0.07	0.08	0.05	0.20±0.03
16	0.12	0.15	0.07	0.34 ± 0.02	0.05	0.09	0.05	0.19±0.01

± SD

Table:4 Effect of NaCl salinity on biomass (fresh and dry weight) production in *D. viscosa* L.

NaCl treatment (mM)	Fresh weight (g plant^{-1})				Dry weight (g plant^{-1})			
	Leaf	Stem	Root	Total	Leaf	Stem	Root	Total
00 Control	0.29± 0,016	0.17± 0.04	0.17± 0.02	0.63± 0.03	0.17± 0,07	0.14± 0.03	0.06± 0.02	0.37± 0.4
25	0.28± 0.01	0.14± 0.02	0.17± 0.03	0.59± 0.02	0 19± 0.07	0.05± 0.03	0.07± 0.03	0.31± 0.4
50	0.28± 0.03	0.17± 0.04	0.17± 0 04	0.62± 0.5	0.17± 0.08	0.05± 0.024	0.06± 0.03	0.28± 0.44
100	0.29± 0.012	0.16± 0.018	0.17± 0.036	0.62± 0.02	0.13± 0.08	0.03± 0.012	0.06± 0.028	0.22± 0.39
200	0.28± 0.05	0.16± 0.02	0.17± 0.03	0.61± 0.3	0.12± 0.04	0.03± 0.01	0.04± 0.02	0.19± 0.03

growth in wheat (Ashour *et al.*, 1977). Laszlo and Kuiper (1979) have reported salt sensitive nature of *Plantago media* as compared to salt tolerant nature of *P. coronopus*. It was found by them that *P. media* was sensitive to very low concentration of NaCl in the medium (25 mM). Karadge and Chavan (1981) have reported that both NaCl and Na_2SO_4 affected growth and yield of groundnut cultivar TMV-10. They (1983) performed a pot culture experiment to evaluate salt tolerance potential of *Sesbania aculeata* poir and it was observed that the plant could tolerate salinity levels upto the electrical conductivity of 10 mS cm^{-1} and at 15 mS cm^{-1} there was about 40% reduction in dry matter production. A stimulation of growth by low levels of salinity in case of a halophytic forage grass, *Chloris gayana*, has been reported by Waisel (1985). However, growth of the species was found to be inhibited by higher salinity in the medium. Flowers *et al.* (1986) have described the effect of salinity on growth and ion concentrations in a number of tobacco cultivars. It is reported that sodium chloride at the concentration of 200 mol m^{-3} hardly affected the fresh weight of the plants but significantly reduced the dry weight. The difference in the response of fresh and dry weight to salt was reported to be due to change in succulence. Gupta *et al.* (1986), while studying salt tolerance in some tree species at seedling stage concluded that *Acacia nilotica* and *Eucalyptus camaldulenss* could be grown with less than 50 % growth reduction upto 5 mS cm^{-1} salinity. Jeschke *et al.* (1986) have studied the effect of sodium chloride salinity on growth, development, ion transport and ion storage in *White lupina*. They observed that the dry matter gain of shoot and root was almost linearly decreased with increasing external NaCl, the relative growth rate of roots being more

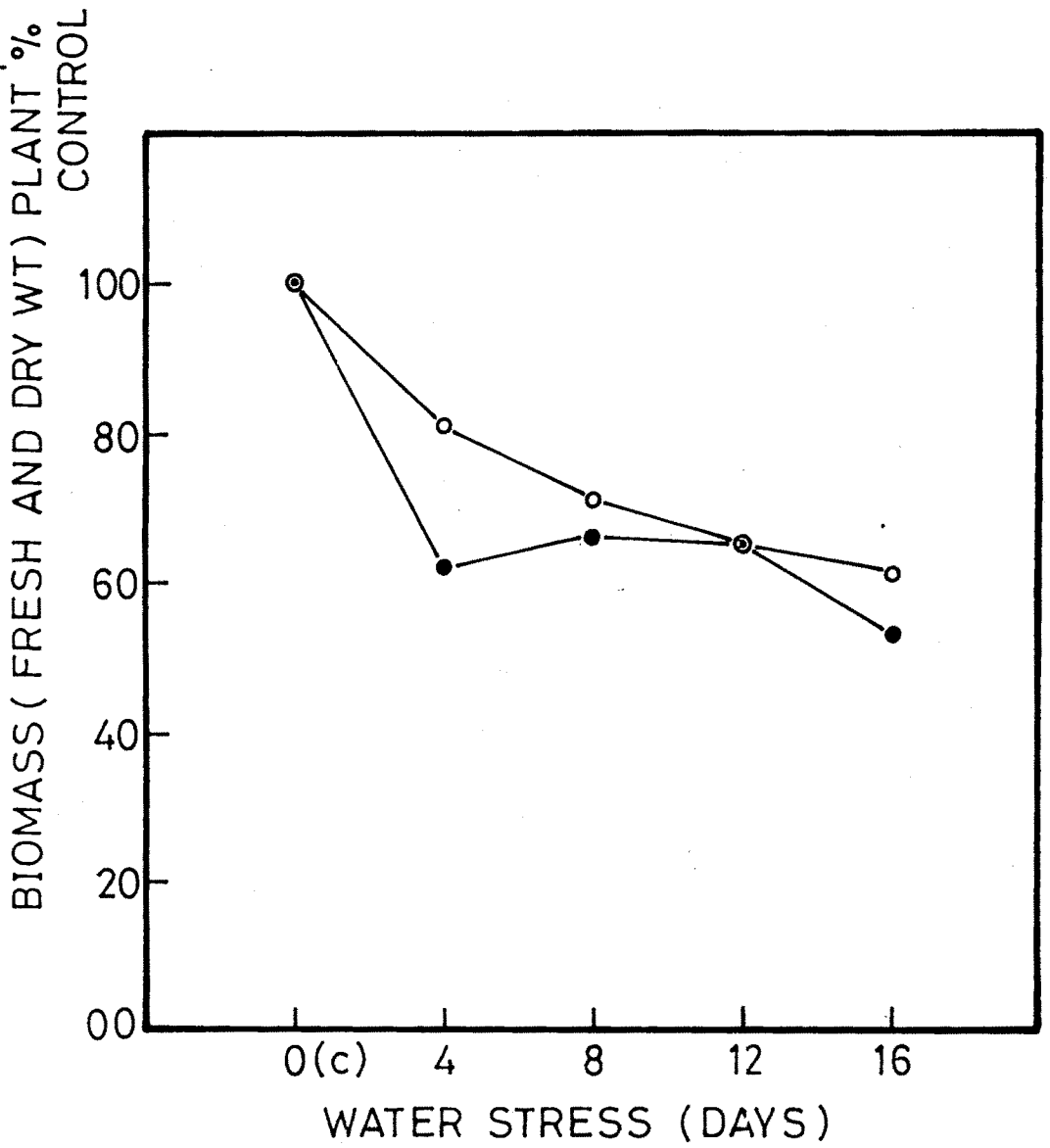

FIG.5. EFFECT OF WATER STRESS ON BIOMASS (FRESH-• AND DRY-o WT.) PRODUCTION IN D. viscosa L.

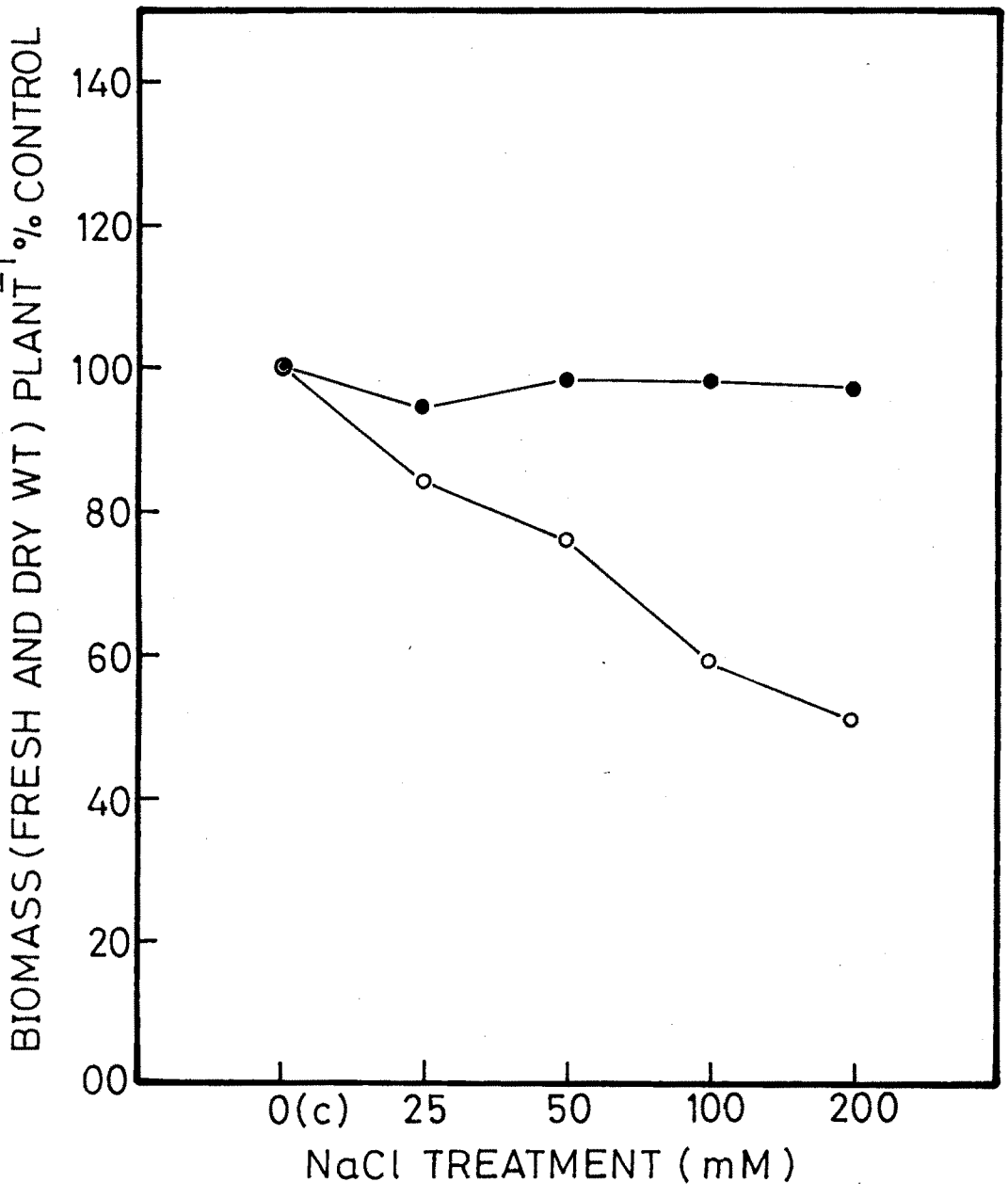

FIG.6. EFFECT OF NaCl SALINITY ON BIOMASS (FRESH-• AND DRY-∘ WT) PRODUCTION IN D. viscosa L.

effected than that of shoot. Malik and Shaukat (1986) have reported that higher NaCl concentrations retarded the root and shoot growth of Triticum aestivum cultivar chanaf-70. It was further observed that the suppression of root growth was more than that of shoot presumably due to accumulation of ions. Curtis and Lauchlii (1987), have reported that increase in leaf area in Hibiscus cannabinus was more sensitive to salinity than either leaf emergence rate or dry matter accumulation. Dry weight was reduced only above threshold of approximately 37 mM NaCl. Zahid et al. (1986) studied salt tolerance in wheat and observed that the number of tillers and plant height decreased highly significantly as the salinity levels increased.

Contrary to these observations a stimulation in growth and development by NaCl salinity has been reported by several workers. Hamid and Talibudeen (1976) showed that grater sodium uptake promoted an increase in dry matter yield of all parts of barley and sugarbeet indicating that sodium plays a specific role in their metabolism. Matar et al. (1975) obtained differential response by spinach and lettuce. It was found that with increasing sodium supply dry matter production was decreased in lettuce while that increased in spinach. Recently, Winter and Lauchli (1982) have compared the response of two Trifolium spp. for their salt tolerance. It was found that T. alexandrinum survived at all salt treatments. Salt induced growth reductions of 30 and 47% occurred respectively at 50 and 100 mM NaCl concentrations. They considered this species as moderately salt tolerant. Very recently Khalid and Malik (1987), have studied the effect of different levels of salinity on seed germination, plant growth and chemical composition of Atriplex rhagodioides in gravel culture experiments. They have found that increased biomass yields were obtained in saline

treatments upto the electrical conductivity 15 mS cm^{-1}.

From the present studies it can be suggested that D. viscosa L. is no doubt a drought tolerant plant as its biomass is only slightly affected due to even a pretty long duration water stress. The plant also shows an ability to tolerate the moderate levels of NaCl salinity. However, the response shown by the plant to stress conditions varies with the type of stress. It is observed that root growth of the species is more sensitive to drought than to salinity stress. On the other hand leaf development seems to be highly sensitive to the salinity stress. This differential response by D. viscosa L. plants to water stress and salinity stress indicates the probable different mechanisms for drought resistance and salinity tolerance. However, the plant can be safely considered to be drought resistance as well as moderately salt tolerant species.

Further discussion with the organic constituents, the behaviour of various enzymes and the uptake and distribution of various inorganic nutrients will throw some more light on mechanisms of stress tolerance in the species.

5. Effect of Water Stress and NaCl Salinity on Organic Constituents.

Moisture content:

The reduction in moisture level in plant tissue is essentially the first detectable change caused by water deficits. However, this reduction in moisture uptake varies from plant to plant and species to species. Usually, eventhough there is a reduction in moisture level in drought tolerant plants, still they show high percentage of moisture indicating thereby that they have an ability to conserve water in the tissue under

adverse environmental conditions.

The effect of water stress and NaCl salinity on uptake of moisture by D. viscosa L. has been recorded in Table 5. It is evident that there is a remarkable decrease in the moisture content of 4 days water stressed plants. However, it appears to be maintained in the plant at more intense drought conditions. This high moisture content shown by the plant after 8, 12, and 16 days water stress is mainly due to an ability of root and stem of the plant to retain more water. The moisture content of the leaf, however, falls down with increasing intensity of drought. It appears that the plant is able to conserve sufficient amount of water during drought. It may be due to immediate response to stomata which might have remained closed, particularly at the time when the rate of transpiration is very high. This can be considered as an adaptive feature of D. viscosa L. under drought conditions.

It is also evident from Table 5 that there is significant accumulation of moisture in the plant grown under saline conditions at all levels. This increase in the plant moisture content is mainly due to that in the stem tissue followed by, to some extent, to that in the leaves and roots. The more uptake of moisture under saline conditions can be considered as an adaptive feature of the species towards salinity tolerance.

Water deficits cause dehydration of protoplasm (Levitt, 1956) and this results in loss of turgor. May and Milthorpe (1962) reported that growth of number of crop plants is reduced by a decrease in relative turgidity to below 90 % . According to Levitt (1972) severe dehydration leads to a pronounced decrease in respiration rate but it is found only after the degree of dehydration becomes severe. Iljin

Table:5 Effect of water stress and NaC1 salinity on the moisture content* of different parts of D. viscosa L.

Plant part	Water stress (Days)					NaC1 treatment (mM)				
	O(Control)	4	8	12	16	OO(Control)	25	50	100	200
Leaf	70	60	63	65	58	41	32	39	55	57
Stem	38	32	44	47	40	18	64	71	81	81
Root	17	11	25	29	29	65	59	65	65	76
Total	52	38	49	52	44	41	47	55	65	69

* Values are expressed as moisture percentage.

(1923) reported that the first effect of water stress is a partial or complete stomatal closure. This leads to decreased rate of photosynthesis. Such water shortage, particularly in the leaves, not only reduces the photosynthetic rate but also retards translocation. As there is almost no loss of water from D. viscosa L. plants under the conditions of water deficits, the species can be said to have very well developed mechanism of drought resistance.

Increase in the level of moisture in stem and leaves of D. viscosa L. may induce succulence in the plant parts. This change may be an adaptive feature as accumulated water in the tissue dilutes the cell sap thereby decreasing toxic effects, if any, of accumulated sodium.

2. **Acidity status:**

The effect of water stress and NaCl salinity stress on the acidity status of the leaves of D. viscosa L. has been recorded in Tables 6 and 7 respectively. The acidity status of the leaves is determined by measuring TAN (Titratable Acid Number) and pH of water extract of the fresh leaves.

It is evident from the observations that both water stress as well as salinity stress have a considerable effect on the acidity status of the leaves of D. viscosa L. Water stress, however, has shown a profound influence on the acidity status of the leaves. It can be seen that due to water stress, the TAN increases significantly and linearly with the dessication of plants. The pH values also well agree to the TAN values. However, under saline conditions TAN of the leaves is increased markedly upto 50 mM NaCl concentration and decreased considerably at the higher salt concentrations in the medium. The values recorded for

Table:6 Effect of water stress on acidity status (TAN* and pH) of the leaves of D. viscosa L.

Water stress	TAN*	pH
0 (Control)	66.87	6.1
4	89.70	5.9
8	97.13	5.95
12	135.57	6.25
16	130.57	6.1

* Values are expressed as ml 0.1 N NaOH required to neutralise the acids present in 100 g fresh tissue.

pH show the similar trend. Thus, it appears that when D. viscosa L. plants are exposed to stress conditions the accumulation of free organic acids or acidic substances, takes place, particularly in the leaves.

There are only a few reports available describing the influence of water stress on the acidity status of a plant. Ramati et al. (1979) and Ford et al. (1981) have reported an accumulation of organic acids in Panicum ripens and P. maximum respectively, when grown under water stressed conditions. They have also reported that organic acids like malate and succinate accumulate in the stressed leaves but there is decrease in the level of aconitate. No change in oxalate content was observed due to increase in water stress. Jadhav (1984) has recorded an increase in the acidity status of the leaves of Panicum miliaceum when stressed for 4, 8, 12 and 16 days. A general increase in the level of organic acids was observed by Singh and Prasad (1980) in groundnut cultivar C-SS-437 plants when grown in pots under water stress.

There are quite a large number of reports which describe the effect of NaCl salinity on the acidity status of the plants. Strogonov (1964) has observed an increase in organic acid content due to NaCl salinity in maize. Similar increase in the organic acid level in the leaves of salt stressed plants has been reported by many workers (Rush and Epstein, 1976; Downton and Loveys, 1978). Contrary to these observations some workers have noted decreased level of organic acids in the plant due to salinity. Flowers and Hall (1978) have shown that organic acid content was maximum in Suaeda maritima kept in tap water and decreased in the salt treated plants. Kulkarni (1984) has made similar observations in case of moth bean (Phaseolus aconitifolius).

The maintenance of turgur pressure as plant water potential declines is crucial for cell expansion

Table:7 Effect of NaC1 salinity on acidity status (TAN* and pH) of the leaves of *D. viscosa* L.

NaC1 treatment (mM)	TAN*	pH
00 (Control)	46.33	5.63
25	53.20	5.51
50	52.34	5.48
100	42.90	5.50
200	34.32	5.37

* Values are expressed as ml 0.1 N NaOH required to neutralize the acids present in 100 g fresh tissue.

for growth and for many of the associated biochemical, physiological and morphological processes (Hsiao,1973; Hsiao et. al., 1976). The ability of a tissue to maintain turgor pressure as water potentials decline in response to decreasing water contents is an important mechanism of drought resistance. Two processes maintain turgur pressure as water potential declines, a low osmotic potential due to either a naturally high solute concentration or an accumulation of solutes or a high tissue elasticity. Low osmotic potential is beneficial under drought and that the less resistant species are unable to lower their osmotic potential by osmotic adjustment (Jones et al., 1981). There are number of species, with naturally low solute concentration, which have the capacity to accumulate additional solutes in response to water stress and to achieve, to some extent the osmotic adjustment.

Organic acids have been shown to play a prominent role in osmotic adjustment in plants (Osmond, 1963; Bernstein, 1975). But, according to Ford and Wilson (1981) the role of organic acids in osmotic adjustment is relatively smaller than solute accumulation. Lawlor and Fock (1977) observed an increase in labeling in succinate, fumarate and aconitate in water stressed sunflower leaves.

The increase in acidity status of the leaves of D. viscosa L. exposed to water stress and that exposed to salinity stress is probably due to an increase in the level of organic acids in the leaf tissue. Further, it appears that these organic acids probably play some decisive role in osmotic adjustment during stress conditions in D. viscosa L. Organic acids by their accumulation in the desiccated tissue may play a primary role in the drought resistance capacity in the species.

3. Chlorophylls:

The effect of water stress and NaCl salinity on chlorophyll a, chlorophyll b, total chlorophylls and chlorophyll a:b ratio in the leaves of D. viscosa L. has been shown in Tables 8 and 9 respectively and depicted in figures 7 and 8. It is evident that the photosynthetic pigments accumulate in the leaves of this plant under stress conditions. It can be seen that with increasing level of water deficit in the soil medium, as well as in the tissue, there is remarkable increase in the level of green pigments. The chlorophyll content of about 103 mg $100g^{-1}$ fresh tissue in the control plants (daily irrigated) is elevated by about 25 % in the leaves of 8 days water stressed plants and about 15 to 20 % increase in the chlorophyll content of the leaves of D. viscosa L. plants is observed when water stressed for 12 and 16 days respectively. This increase in total chlorophyll content is probably more due to chlorophyll 'a' which is synthesized or accumulated in the desiccated plant leaves. Chlorophyll `b' seems to be least affected by draught. Chlorophyll a:b ratio also supports the observation. It can be seen that chlorophyll a:b ratio which is 2.29 in the irrigated plants increases to 3.50 in the 8 days desiccated plants and 2.47 in the 12 days desiccated plants. However, this ratio is slightly declined in 16 days water stressed plants.

Almost similar trend has been shown by the chlorophylls in the plants exposed to salinity stress. It can be seen that there is gradual increase in the level of total chlorophylls with increasing level of NaCl salinity in the soil medium. Eventhough chlorophyll 'a' as well as ' b' show almost similar trend in responding to salinity stress, chlorophyll 'a' appears to be more influenced than chlorophyll `b'. This is quite clear from chlorophyll a:b ratio in the leaves of D. viscosa L.

Table:8 Effect of water stress on chlorophyll contents* of the leaves of D. viscosa L.

Water stress	Chl. 'a'	Chl. 'b'	Total (a+b)	Chl. a:b
0 (Control)	71.33	31.29	103.02	2.29
4	74.31	28.35	102.66	2.62
8	98.64	28.15	126.79	3.50
12	83.40	33.77	117.17	2.47
16	82.86	38.35	121.21	2.16

* Values are expressed as mg 100^{-1} g fresh tissue.

The stability of chlorophyll molecules has long been considered as an essential parameter of stress resistance. The synthesis of chlorophyll can be highly sensitive to low leaf water potentials. Vergin (1965) and Borque and Naylor (1971) reported that water deficit caused significantly slower accumulation of chlorophylls in greening leaves. In their experiments it was found that the small water deficit induced by low humidities was enough to cause a significant response. Maranville and Paulsen (1970) also found that drought reduces chlorophyll contents as well as light absorption in corn. Singh et al. (1973) observed a decrease in the chlorophyll content of the leaves due to water stress in wheat and barley. Volodarskil and Bystrykh (1974) have reported some changes in the pigment composition of the leaves during ontogenesis in sunflower under drought conditions. It was observed that in presence of an insufficient water supply there was change in the quantity of green pigment which was lowered. Alberte et al. (1975) studied the effect of water stress on the development of photosynthetic apparatus in the greening leaves in Canavalia enciformis. They reported that low relative humidity or polyethylene glycol induced root water stress resulted in a three to four hour lag in chlorophyll accumulation, reduced the rate of chlorophyll 'b' accumulation and reduced the formation of rate of the light harvesting chlorophyll a/b protein. Jaeger and Meyer (1977) have reported necrosis of the foliage in Phaseolus vulgaris grown under water stressed conditions. Alberte et al. (1977) found that the loss of chlorophylls from maize leaves upon water stress amounted, falling to almost 60 % of control, 8 days after irrigation. This loss of chlorophylls occurred mainly from mesophyll cells and could be accounted for by the loss of

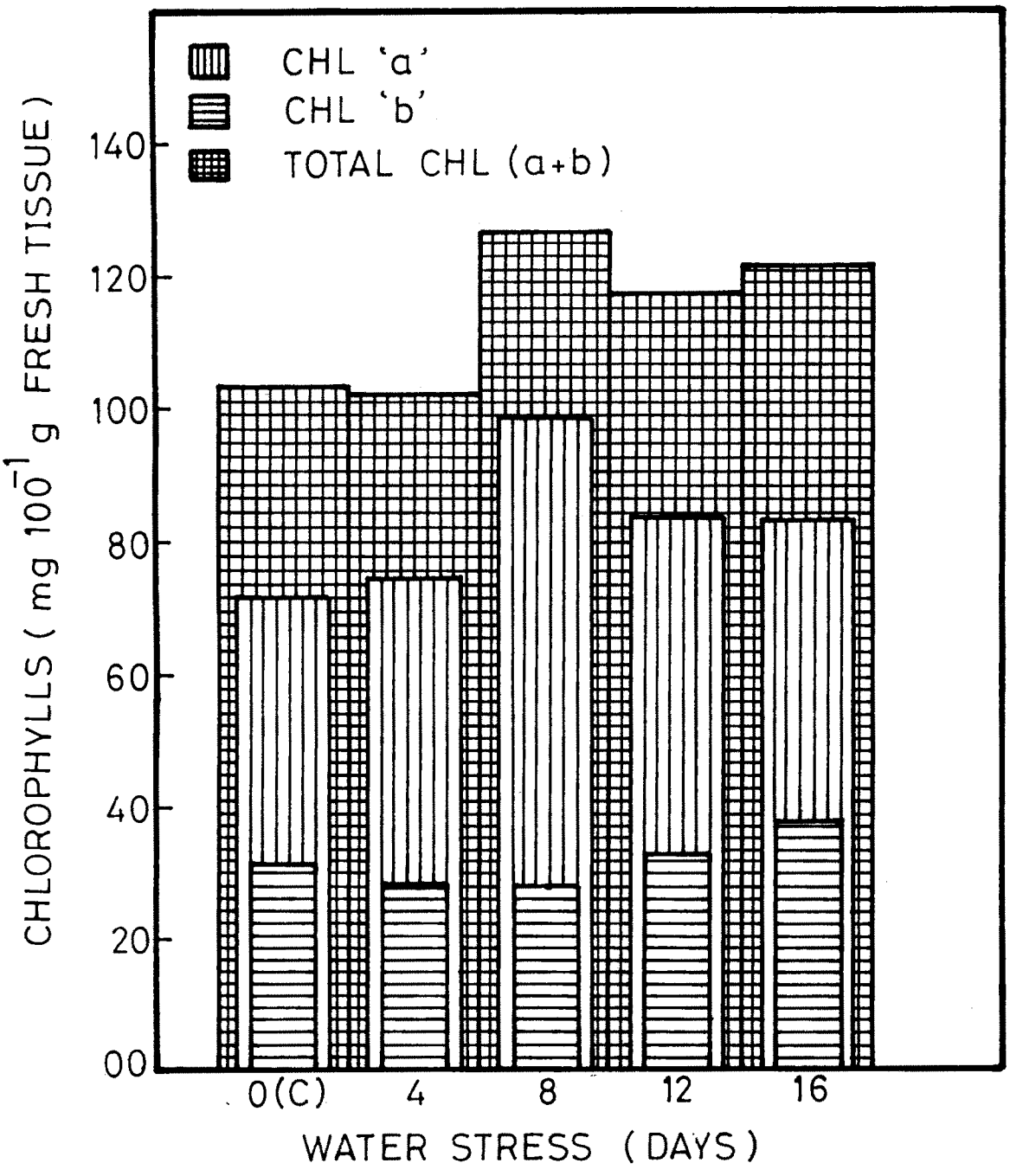

FIG.7. EFFECT OF WATER STRESS ON CHLOROPHYLL CONTENTS OF THE LEAVES OF D.viscosa L.

chloroplast membranes. In cotton, a loss of chloroplast membrane integrity under stress was correlated with increased phosphatase activity localized on or near the chloroplast membrane (Nir and Poljakoff-Mayber, 1966; Vieira de Silva et al., 1974). Spyropoulos and Mavrommatis (1978) studied the effect of water stress on three Quercus species belonging to different habitat. They found that the chlorophyll concentration was decreased in all Quercus species with greatest decrease occuring in Q. robur. Sanchez et al. (1983) studied the effect of water stress on the chlorophyll content, nitrogen level and photosynthesis in both the cultivars. While summarizing the ultrastructural consequences of drought in the chloroplast caused by water stress, Poljakoff-Mayber (1981) has stated that these changes include the structural changes resulting from excessive swelling, distortion of the lamellae, vesiculation and the appearance of lipid droplets. The appearance of osmiophillic droplets in stress damaged chloroplasts suggests a separation of lipid and protein phases in the membrane structure damaging the chloroplast structure functional integrity. Recently, Joshi (1985) has shown that the chlorophyll concentration in the leaves of Poa pratensis was not affected by water stress.

From the foregoing discussion it appears that in most cases the chloroplast membrane system is distructed and the degradation of chlorophylls takes place which may be taken as a sign of drought sensitivity. On the other hand the drought resistant species have well developed capacity of chlorophyll retention even under the adverse drought conditions. An increase in chlorophyll content in the leaves of D. viscosa L. under water stress conditions may be due to a slight decrease in moisture content due to dehydration of the leaf tissue. However, it is certain that this species has a remarkable ability to maintain chlorophylls.

Table:9 Effrect of NaC1 salinity on the chlorophyll contents* of leaves of D. viscosa L.

NaC1 treatment (mM)	Chl.'a'	Chl.'b'	Total (a+b)	Chl. a : b
00 (Control)	58.39	25.27	83.66	2.31
25	68.83	27.30	101.13	2.52
50	69.74	26.88	96.62	2.59
100	74.02	31.88	105.90	2.32
200	90.09	39.07	129.16	2.31

* values are expressed as mg 100^{-1} g fresh tissue.

even under severe drought and hence D. viscosa L. can be considered as a drought resistant plant.

There are number of reports available which describe the effect of soil salinity on pigment composition of the leaves of number of plants. A decrease in chlorophyll content due to salinity is observed by great a many number of workers like Karadge and Chavan (1980) in Arachis hypogea, Ahmed et al. (1980) in number of leguminous plants, Rao and Rao (1981) in pigeon pea and Gingelley, Hegde and Patil (1982) in Parthenium hysterophorus, Karadge and Chavan (1981) in Sesbania, Patil and Patil (1983) in Syzygium , Patil (1984) in Sesbania, Ahmed et al. (1986) in Azadirachta indica and Melia azedarach, Ball (1986) in Avicenia and Pisum sativum, Doering Ludder (1986) in Punica granatum and El-Sharkawy et al. (1986) in Cotton, Hibiscus, Sabdariffo and Sorghum. From their observations it is also evident that chlorophyll 'a' is more sensitive to salinity than chlorophyll 'b' resulting in decreased chlorophyll a:b ratio. According to Strogonov et al. (1970) salinity affects the strength of forces binding the pigments. protein. lipid complex, which in turn reduces the chlorophyll content. It is reported that peanut plants exposed to salinity show a decrease in chlorophylls which can be recovered by the application of phosphorous (Malakondaiah and Rajeshwar Rao, 1980) indicating that disturbed ionic balance is responsible for reduction of the chlorophylls, especially due to toxic effect of Na. Reddy and Vora (1986) have correlated this decrease in chlorophyll content due to salinity in case of Pennisetum typhoides and wheat leaves to increased level of enzyme chlorophyllase.

Contrary to the above reports, an increase in chlorophyll content of the plants grown under saline conditions has also been recorded by number of workers. Ahmed et al. (1979) observed an increase in

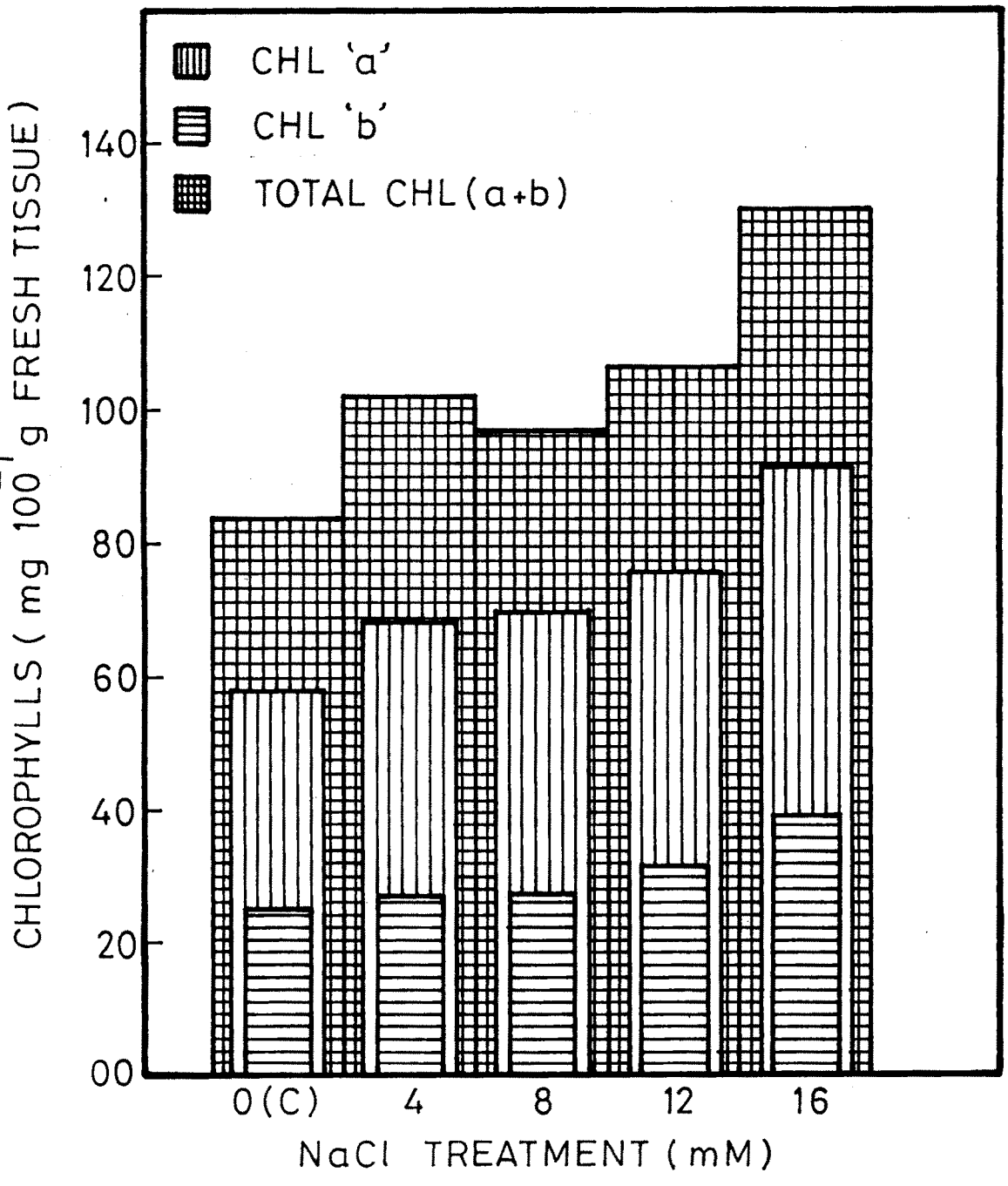

FIG.8. EFFECT OF NaCl SALINITY ON CHLOROPHYLL CONTENTS OF THE LEAVES OF D. viscosa L.

chlorophyll content in castor bean, flax and sunflower. Chavan (1980) in Eleusine coracana and Wadkar (1989) in Crotalaria verrucosa, a plant naturally growing on coastal lines, have also made similar type of observations. Passera and Albuzio (1978) have also recorded an increase in chlorophyll content of two wheat cultivars, when grown under saline conditions. Recently, Krishnamoorthy et al. (1987) have found that the sodium chloride treatment causes to increase the chlorophyll content upto 4 weeks in nine varieties of rice. There are certain reports where chlorophylls are found to be insensitive to salinity (Kale and Singh, 1987; Gaikwad, 1989). The capacity to retain or accumulate chlorophylls under saline conditions is considered as an adaptive feature.

From the present observations it appears that D. viscosa L. has a good capacity to retain the chlorophylls even under saline conditions. This is suggestive of a salt tolerant nature of D. viscosa L.

From the foregoing discussions it appears that D. viscosa L. has a well developed capacity to retain chlorophylls under stress conditions. In this regard the plant shows relatively a better tolerance to salinity as compared to that to water stress. As far as the response of photosynthetic pigment to drought and salt stress is concerned the mechanism seems to be almost the same.

4. Carbohydrates:

Effect of water stress and NaCl salinity on the carbohydrate contents of D. viscosa L. leaves has been recorded in Tables 10 and 11 respectively and figures 9 and 10. The leaves of D. viscosa L. have been analysed for reducing sugars, total soluble sugars and starch contents.

Table:10 Effect of water stress on carbohydrate and polyphenol contents* of the leaves of D. viscosa L.

Water stress (days)	Reducing sugars	Total soluble sugars	Starch	Total carbody drates	Polyphenols
0 (Control)	0.89	2.34	6.00	8.34	1.43
4	0.89	2.08	5.88	7.96	1.84
8	0.68	2.30	6.38	8.68	1.63
12	0.73	1.73	8.63	10.36	1.63
16	0.83	1.82	8.75	10.57	2.24

* Values are expressed as g 100^{-1} g fresh tissue.

It is evident that as the intensity of water stress increases there is increase in the level of total carbohydrates. This is very significant in the plant stressed for 12 and 16 days. Starch, the major contributor of carbohydrates, is mainly responsible for the accumulation of carbohydrates in the leaves. It can be seen that due to severe drought starch is accumulated in the leaves of D. viscosa L. Contrary to this the level of reducing sugars as well as total soluble sugars is decreased with increasing the intensity of drought. The soluble sugar content is markedly affected by water stress.

It is evident from table 11 and figures 9 and 10, that there is no definite pattern observed with respect to total carbohydrate contents of the leaves due to salinity. It can be seen that at lower salinity level (25 mM NaCl) there is a decrease in the carbohydrate contents of the leaves. However, at the higher salinity levels (50 and 100 mM NaCl) there is some measurable increase in the total carbohydrates. The carbohydrate content of the leaves at 100 mM NaCl level, however, still remains below to that in control plant. Among the carbohydrates, starch seems to be accumulated significantly in the leaves at 25 as well as 50 mM NaCl salinity. At the highest salt concentration the starch level in the leaves remains unchanged. The level of total soluble sugars in the leaf tissue is decreased due to salinity at all salt concentrations. However, there seems to be a little effect of salinity on reducing sugar contents of the leaves. From the observations recorded here it can be said that there is accumulation of starch and decrease in the level of soluble sugars in the leaves of D. viscosa L. when exposed to stress conditions.

Carbohydrate metabolism is affected by drought through direct and indirect effect on photosynthesis and through several intermediate

Table:11 Effect of NaCl salinity on carbohydrate and polyphenol contents* of the leaves of *D. viscosa* L.

NaCl treatment (mM)	Reducing sugars	Total soluble sugars	Starch	Total carbohydrates.	Polyphenol
00 (Control)	0.73	1.17	5.00	6.17	1.66
25	0.73	0.91	5.58	5.49	1.75
50	0.52	1.04	5.83	6.87	1.58
100	0.73	0.91	5.00	5.91	1.54

* Values are expressed as g 100^{-1} g fresh tissue.

components of the processes (Slatyer, 1969). The role of soluble sugars in drought tolerance has been explained by number of workers. Maximov (1929) suggested two possible mechanisms to explain the role of sugars. 1. The accumulation on sugars might protect the protoplasm from coagulation and desiccation and 2. the high concentration of sugars in the tissue might prevent visible wilting for a long time, inspite of increasing water deficit. Maranville and Paulsen (1970) found that water stress decreased the starch concentration markedly in the corn seedlings. They suggested that this was due to acceleration of starch hydrolysis and not due to impairment of starch synthesis. The observations made by Chang and Wetmore (1986) also support these findings. They found that the starch content of cotton leaves decreased during the initial decline in water potential from - 1.1 to -1.4 MPa and this change was related to an increase in soluble -amylase activity and decrease in bound glucon synthetase activity. They have also reported that further decline in the water potential with further reduction in leaf water potential. There was a sharp increase by about 200 % in the starch content with a decline in the level of bound glucon synthetase as well as α -amylase. Their enzymatic data demonstrated that the effect of water stress on cotton is adverse because starch degradation products are not translocated but accumulated as reassembled starch in the source leaves. In their subsequent publication (1987), they reported that water stress decreases cotton leaf starch content directly by enhancing α-amylase activity and indirectly by altering sucrose metabolism and in this altered metabolism, an inhibition of sucrose synthetase causes an accumulation of sucrose (soluble sugar) in cytoplasm. Lee et al. (1974) reported that drought stress decreases reducing sugar, sucrose and starch concentrations in both

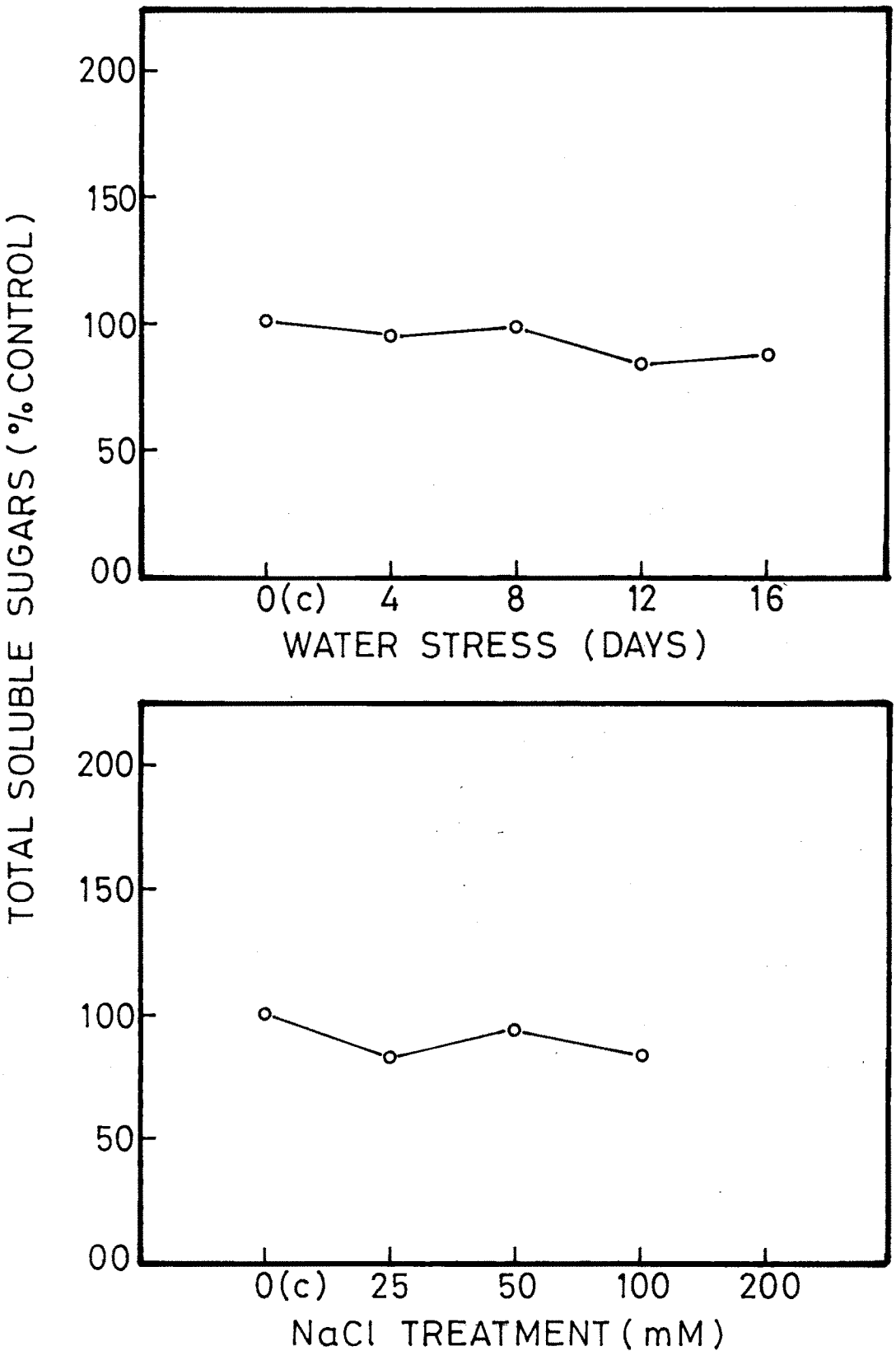

FIG. 9. EFFECT OF WATER STRESS AND NaCl SALINITY ON TOTAL SOLUBLE SUGARS CONTENT OF THE LEAVES OF D. viscosa L.

drought tolerant as well as susceptible varieties of pea. Barlow et al. (1976) found that in corn seedlings suffering from induced water stress the increase in soluble carbohydrate concentration was inversely related to both rate of leaf elongation and total dry matter accumulation. Parker (1970) and Stewart (1971) have reported a decrease in starch content due to water stress. Thakur et al. (1980) studied the effect of water stress on carbohydrate metabolism in resistant and susceptible cultivars of Zea mays. They observed that at 1st leaf stage, starch content of the resistant cultivar was lower than that of susceptible cultivar but reducing sugar content was much higher. At the 3rd leaf stage, starch contents were similar in both the cultivars but sugar contents were higher in the resistant cultivar. Differential changes in root and shoot carbohydrates as affected by increased levels of stress were also observed. Similar type of studies were conducted by Singh and Rai (1983) in Cicer arietinum cultivars. It was found by them that the total and non reducing sugars accumulated with increased levels of water stress in cultivar C-214 shoots and roots, while, in cultivar G-130 shoots and roots a reduction was indicated. The shoots of resistant cultivar C-214 showed higher concentration of non-reducing and total sugars than those in the cultivar G-130. Schmid and Feucht (1986) found that all carbohydrates increased in the leaves of Prunus species with ascending stress symptoms. Timpa et al. (1986) studied the effect of water stress on the organic acid and carbohydrate compositions of cotton plant, selected to study the mechanism of poor and enhanced performance under field water stress conditions. It was observed that in all cultivars, the water stressed plants showed 2 to 5 times greater amounts of organic acids and carbohydrates over the values determined for the irrigated samples. Under

stress, sucrose accumulation was observed in wilting strains which showed poor performance under field water stress. Recently, Bunce (1982) has studied the effect of water stress on photosynthesis in relation to diurnal accumulation of carbohydrates in source leaves of soybean and sunflower in a controlled environment. He could not find any difference in carbohydrate contents in sunflower, after two days of stress. Free proline and reducing sugars in water stressed sunflower leaves were studied to know their relationship and differences due to drought tolerant plant characteristics (Muriel and Guerra, 1984). It was reported that a high rate of free proline accumulation and low yield of reducing sugars represents a very poor water stress adaptation.

From the forgoing discussions, it can be suggested that the response of the plant to water stress with respect to carbohydrate metabolism varies from plant to plant and species to species. According to Vora *et al*. (1974) accumulation of sugars in the tissue under water stress indicates a protective role of sugars. Ackerson (1981) found that increase in leaf carbohydrates helps osmotic adjustment during water stress in cotton. Ford *et al*. (1981) observed accumulation of reducing and total sugars in the stressed leaves of *Panicum maximum* and suggested that the contribution of carbohydrates to the osmotic adjustment is relatively small than to accumulation of solute. In *D. viscosa* L. the soluble as well as reducing sugars seem to contribute a little, in osmotic adjustment of the plant during drought. The accumulation of starch in the leaf tissue may be either due to inhibition of activity of enzymes like α-amylase or may be due to a feedback inhibition by water stress. Thus, carbohydrates in *D. viscosa* L. seem to play a minor role in the adaptation of plants to stress.

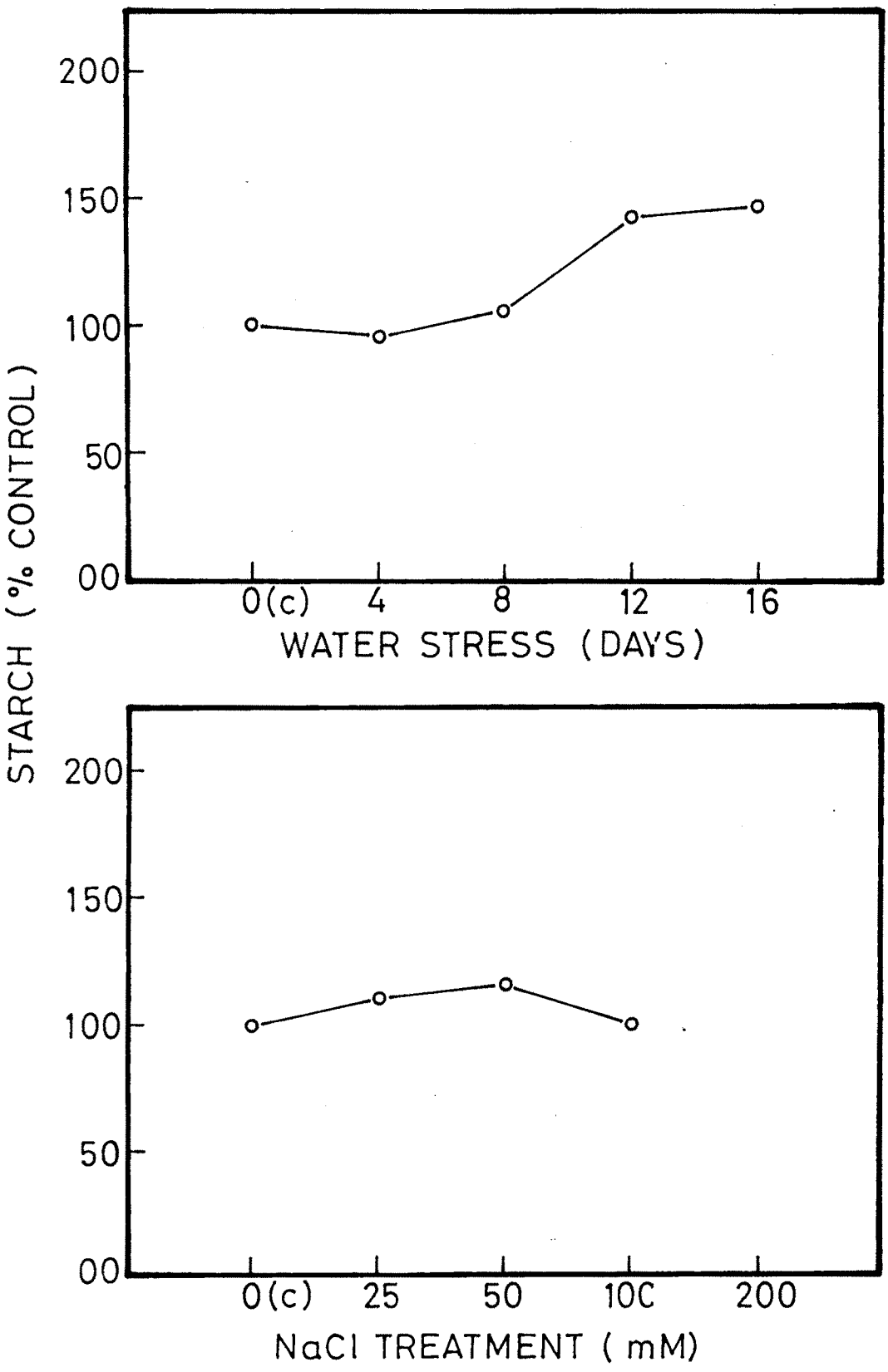

FIG. 10. EFFECT OF WATER STRESS AND NaCl SALINITY ON STARCH CONTENT OF THE LEAVES OF D. viscosa L.

It is suggested by Matar et al. (1975) that even a small increase in sodium content can cause a considerable change in carbohydrate metabolism and this is as a result of influence of sodium on both synthesis and translocation of carbohydrates. Ahmed and Abdullah (1979) observed that total sugar content of potato tubers increased with increasing concentration of salt in most of the varieties which were claimed as salt tolerant ones on the basis of their yield. Kabuzenko and Ponomareva (1980) found that in relatively more salt resistant tomato, under maximum salinization (0.5 % for chloride) the starch content considerably increased as compared to that in the control. Karadge and Chavan (1981) have reported that total carbohydrate content of the leaves of groundnut cultivar TMV-10 decreased considerably, indicating reduced dry matter production, under saline conditions.

Steiner (1935) and Flowers et al. (1977) have expressed a serious doubt about role of sugars in osmotic adjustment by the plants under saline conditions. Contradictory opinions have been given by several workers. Strogonov et al. (1970) and Maas and Nieman (1978) have suggested that increased level of soluble sugars in all parts of a plant grown under saline conditions may add to the osmotic balance. While investigating osmometabolic adjustment in flax, cotton and wheat under salinity stress, El-Sharkawi (1977) suggested that increased synthesis of sugars and probably nitrogen metabolites are the means of adjustment to salinity. The carbohydrate metabolism in D. viscosa L. seems to play a minor role in the mechanism of salinity tolerance. As NaCl salinity has caused no significant alterations in the carbohydrate composition of the leaves probably the plant is showing a kind of resistance to salinity by keeping intact the metabolic activity like carbohydrate metabolism under saline conditions. As discussed earlier, organic acids

which accumulate during salinity stress and proline to some extent, may add to the salinity tolerance of the species.

5. Polyphenols:

The effect of water stress and NaCl salinity on polyphenol contents of the leaves of D. viscosa L. has been recorded in Tables 10 and 11 respectively and figure 11.It is evident from the observations that total polyphenol content of the leaves increases remarkably due to water stress. About 57 % increase in the phenolics has been recorded in the plants water stressed for 16 days. On the other hand NaCl salinity has shown almost no effect on the amount of phenolic compounds of the plant. It can be seen that there is only a slight increase in the level of polyphenols ((about 6 %) due to lower salinity level (25 mM NaCl). However, there is a slight decrease in the phenol content at higher salinity levels.

Increase in the level of polyphenol content due to water stress in D. viscosa L. is in agreement with the findings of Brachet and Bichaut (1972), who recorded that simultaneous action of atmospheric and edapic moisture deprivation prcduces an increase in the synthetic rate of phenols. Talha et al. (1975) have also reported considerable increase in the alkaloid content of Carthamus roseus due to moisture deficit. The anatomical structure of the leaves of Impatiens balsamica suffering from water stress has a grater number of tannin and rhaphide sacs (Todd et al. 1974). Contrary to these observations, a decline in the level of phenolics due to water stress has also been reported. Tsai and Todd (1972) observed about 25 % decline in the phenolic contents of both resistant as well as susceptible varieties of wheat due to water stress.

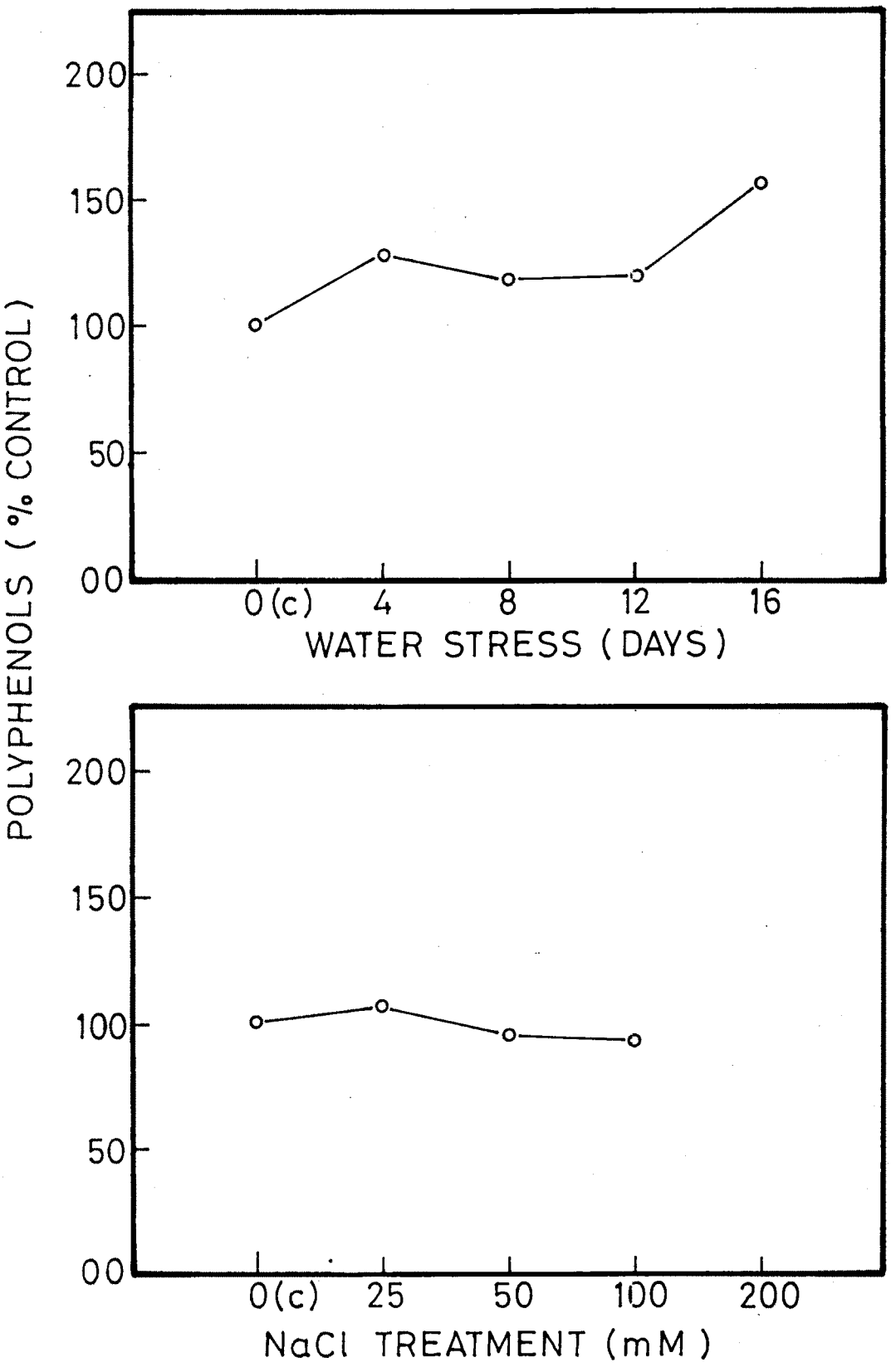

FIG.11. EFFECT OF WATER STRESS AND NaCl SALINITY ON POLYPHENOL CONTENT OF THE LEAVES OF D. viscosa L.

Eventhough there are very few reports available which discuss the effect of salinity on polyphenol metabolism, those are relatively more than those with water stress. A decrease in the level of leaf phenolics has been recorded by Karadge (1981) in Portulaca oleracea, Patil (1984) in groundnut and Krishnamoorthy and Siddique (1985) in cowpea due to saline Conditions. Similar observations are made by Gaikwad (1989) in Panicum miliaceum cultivar MS-1307 and Pennisetum typhoides cultivar GHB-81, which are considered by him as salt sensitive cultivars. Wadkar (1989) observed that the polyphenol content of the leaves of Crotalaria juncea and C. verrucosa was decreased due to salinity stress. Contrary to these observations, an increase in polyphenol content due to salinity in groundnut cultivar TMV-10 leaves to a considerable extent is observed by Karadge and Chavan (1980), while, it decreases in groundnut cultivar SB-11. They have suggested that probably NaCl salinity induces secondary metabolism in the leaves of cultivar TMV-10 resulting in synthesis and accumulation of polyphenolics. An increase in polyphenol content has been noted by Chavan (1980) in the leaves of 'ragi' exposed to NaCl salinity. Sesbania grandiflora has shown an interesting response to salinity stress. It has been found by Patil (1984) that in young leaves the higher salt concentration was inhibitory while an opposite trend was shown by the mature leaves. A marked increase in polyphenols, especially at the low salt regimes, is observed in Crotalaria retusa by Wadkar (1989). From these reports it is clear that the response shown by polyphenol metabolism to salinity varies from plant to plant and species to species.

Polyphenols are secondary metabolites which are known to play a protective role in plants under stress conditions. Phenolic compounds are also known to accumulate during fungal infection of plants. Their

role in disease resistance has also been demonstrated. However, it is difficult to generalize the exact role of polyphenols in plants. Probably polyphenols which are already found rich in D. viscosa L. may be playing a protective role against desiccation by still further increasing their level in the tissue. It can be concluded, therefore, that the secondary metabolism in D. viscosa L. probably responds differently to different types of stresses.

5. **Proline:**

Many organisms, including species adapted to mesic or arid habitat accumulate substances which are normal cell constituents, particularly free amino acids, during a period of water deficit. A range of amino acids accumulate to a greater or lesser degree in different organisms but the most frequent and extensive response is an increase in the concentration of the amino acid, proline. Accumulation of proline upon dehydration due to water deficit or increasing osmotic pressure has been recorded in bacteria, algae and higher plants (Aspinall and Paleg, 1981).

The phenomenon of proline accumulation by plant tissue during water deficit has attracted considerable attention since it was first described. But, the precise role of proline in metabolism of the stressed plant remains to be elucidated. There is considerable evidence, however, from range of sources which suppose the proposition that proline accumulation is positively correlated with drought resistance. A correlation between proline content and salt tolerance has been proposed by Goas (1968) . Later, number of reports have strengthened the propositions.

The exact role of proline in the mechanism of drought resistance or salt tolerance is not clear. According to Palfi et al. (1974), proline is highly

water soluble and most stable amino acid as regards resisting oxidative acid hydrolysis. According to them proline causes to increase considerable amount of bound water in the leaves. It is suggested by Stewart and Lee (1974) that proline may be functioning as a source of solute for intracellular osmotic adjustment under saline conditions. According to Savitskaya (1976) proline may be the single source and precursor of hydroxy proline in the structural protein of the cell wall participating in the cell extension process and may serve as reserve or energy material for respiration. Schobert (1977) has suggested two mechanisms, quiet different from osmotic regulation, for the regulatory function of proline. It is assumed that these regulatory pathways are connected with the hydrophobic groups of biopolymers in the cell cytoplasm. Proline is postulated to associate via its hydrophobic part with hydrophobic side chains, thereby converting them into hydrophillic groups by exposure to the carboxylic acid and amino groups verses water molecules. The advantage is due to the fact that water associated with hydrophillic group is found via hydrogen bonding forces contrary to hydrophobic groups. In addition the number of water molecules adjoining hydrophillic groups is far less than those involved with hydrophobic, reduces. By these mechanisms complete hydration of the biopolymers is maintained even with a reduced number of available water molecules. However, Chu et al. (1976) have suggested that proline has only a minor contribution to osmotic regulation in plants.

The effect of water stress and NaCl salinity on proline content of the leaves of D. viscosa L. has been recorded in Tables 12 and 13 respectively and figure 12. It is evident from the results that with increasing the intensity of water deficit in the rooting medium there is linear and gradual accumulation of free proline in the leaves. It can be seen that more

Table:12 Effect of water stress on proline contents* of the leaves of D. viscosa L.

Water stress(days)	Proline
0 (Control)	84 (100)
4	167 (200)
8	209 (250)
12	226 (270)
16	209 (250)

* Values are expressed as ug g^{-1} fresh tissue values in parathesis are percent content.

than 150 % increase in the level of free proline is observed in the plants stressed for more than 8 days. The highest level of proline accumulated is recorded in 12 days water stressed plants.

D. viscosa L. plants grown under saline conditions also show some tendency of accumulation of free proline in the leaves due to salinity stress. However, the rate at which proline accumulation takes place in the salt stressed plants is definitely less than that observed in water stressed plants. There is some measurable accumulation of free proline in the plants grown at 50 mM NaCl concentration.

There are number of reports which record accumulation of free proline in the plants exposed to water stress. Barnett and Naylor (1966) noticed a 10 to 100 fold increase in proline content due to water stress in Cynadon dactylon. Baskin and Baskin (1974) reported a 115 % increase in total amount of amino acids due to water stress in Astragales species of which proline accounted for about 30 % increase. Palfi et al. (1974) have reported that among the 60 plants studied by them, majority of herbaceous mesophytic cultivated plants, belonging to family solanaceae, leguminoceae, cruciferae, umbeliferae, compositae, and graminae, accumulate proline under water deficit. Blum and Ebercon (1976) in Sorghum, Boggess and Steward(1976) in barley, Boggess et al. (1976) in barley, Mcmichael and Elmore (1977) in cotton, Levy (1980) in citrus trees, Rao and Nainawatee (1980) in wheat seedlings, Singh and Rai (1981) in Bengal gram, Fukutoku and Yamada (1981) in soybean, Tan and Halloran (1982) in spring wheat cultivars, Ilahi and Doeffling (1982) in maize varieties, Ho-liu (1984) in sugarcane, Goyal et al. (1985) in rice genotypes and Chaudhary and Chaudhary (1986) in jute have reported tremendous accumulation of free proline. Accumulation of free proline in the leaves of D. viscosa L. under water

Table:13 Effect of NaCl salinity on electrical conductivity of the leaves and roots and proline contents of the leaves of *D. viscosa* L.

NaCl treatment (mM)	Electrical conductivity (mmhos cm^{-1})		Proline $ug\ g^{-1}$ fresh tissue
	Root	leaves	
00 (Control)	0.671	1.285	94 (100)
25	0.604	1.687	87 (92)
50	0.584	1.848	149 (160)
100	0.641	2.28	102 (109)
200	0.691	3.11	102 (109)

stressed condition is not an exception to the above findings.

Accumulation of free proline in plants exposed to salinity stress has been observed by several workers (Chu et al., 1976, Dreier, 1983; Gorham et al., 1985; Reddy and Vora, 1985; Chandra and Chauhan, 1985; Kishore et al., 1986). It is suggested that accumulation of free proline is dependent on the concentration of monovalent caticns like potassium. The accumulated proline acts as osmoticum and helps the plant to osmotically adjust during salt stress.

Karadge (1981) has observed, however, no significant change in proline content of Portulaca under saline condition. Naik and Joshi (1983) reported that no stress condition could effectively stimulate proline accumulation in the leaves of sugarcane plants, which they have suggested to be salt sensitive in nature. Decreased level of proline due to salinity is observed by Coughlan and Wyn Jones (1982) in spinach leaves, Singh and Jain (1983) in Chickpea and Wadkar (1989) in Crotalaria juncea. These observations indicate that probably proline has only a minor or no role to play in salt tolerance in the plants studied. Chandra and Chauhan (1985) observed free proline accumulated in barley, pearlmillet and chickpea does not show any positive correlation with growth and yield under saline conditions. According to them proline in the leaves is not related to salinity resistance and hence generalization regarding proline accumulation is not possible. Similar situation also prevails in D. viscosa L. It can be said, therefore, that proline has to play a minor role in salinity tolerance in the species. Tal et al. (1979) found that proline accumulation was smaller in two wild species of tomato which accumulated more chlorides and were more succulent. Under water stress the increase of proline

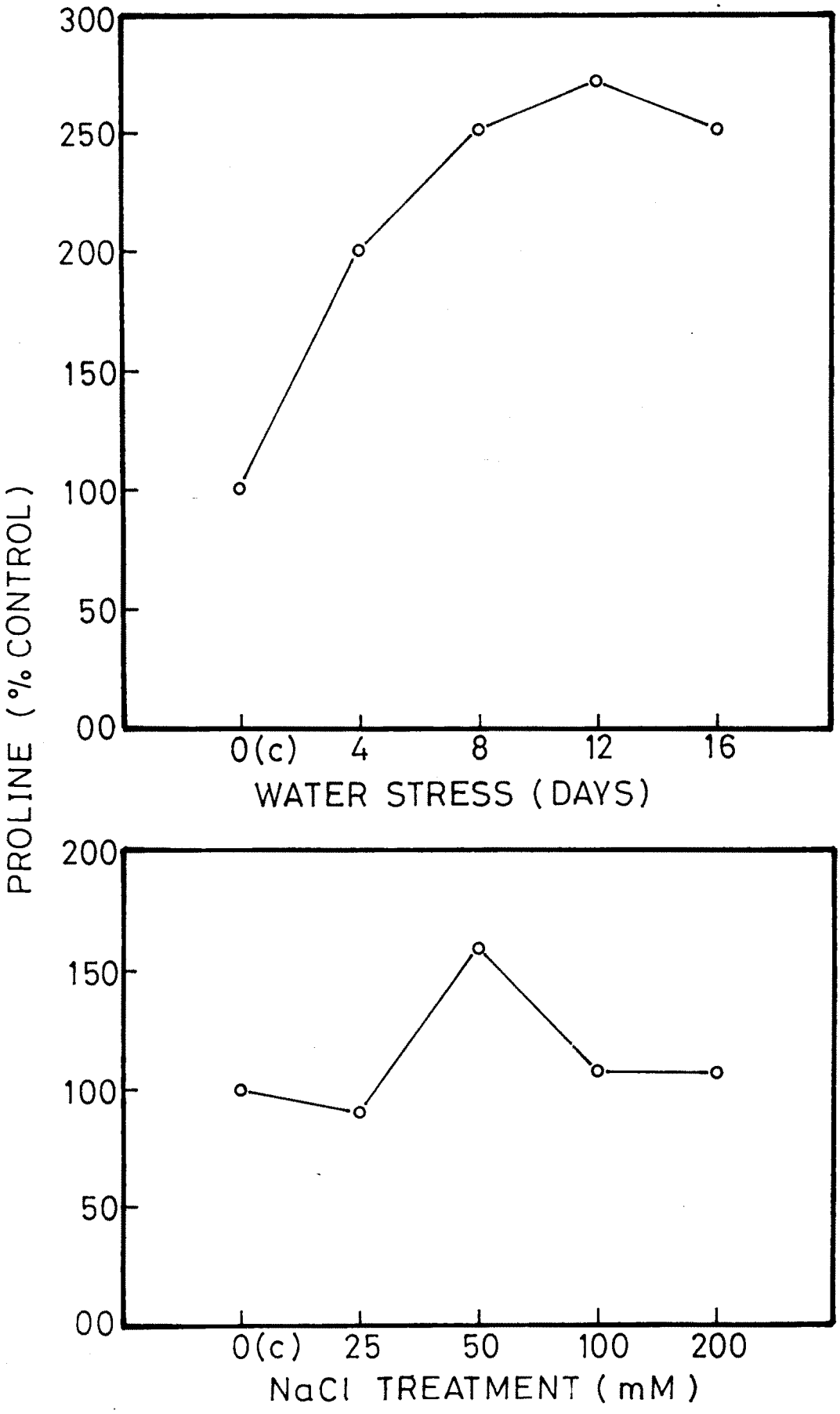

FIG.12. EFFECT OF WATER STRESS AND NaCl SALINITY ON PROLINE CONTENT OF THE LEAVES OF D. viscosa L.

level was greatest. Present observations with D. viscosa L. are also on similar lines.

7. Electrical conductivity:

The effect of NaCl salinity on electrical conductivity of the leaves and roots of D. viscosa L. has been recorded in Table 13. it is evident that with increasing level of NaCl salinity in the rooting medium there is remarkable and continuous increase in the electrical conductivity of leaf cell sap. It can be seen that the electrical conductivity of leaf cell sap is almost doubled at 100 mM NaCl level, while it is almost 3 times more at 200 mM NaCl level than that in the leaves of controlled plants. On the other hand, it appears that salinity has almost no effect on the electrical conductivity of root cell sap.

The electrical conductivity of a cell sap depends on the various solutes with different electrical charges such as various soluble salts, acidic or basic organic constituents and free cations as well as anions in the cell sap. The increase in electrical conductivity of leaf cell sap can be attributed to accumulation of cations and anions, particularly those of sodium and chlorine (this has been discussed in the next part of the thesis under, " Influence of salinity on uptake and distribution of various inorganic nutrients"). Increased electrical conductivity of leaf cell sap under saline conditions may be due to increased acidity status of the leaf tissue to some extent upto 50 mM NaCl concentration. Increased electrical conductivity may lead to the osmotic adjustment of the tissue as a mechanism towards salt tolerance. It is interesting to note that there is very little change in electrical conductivity of the root cells indicating less disturbances in the osmotic potential of root cells.

C. Effect of Water Stress and NaCl Salinity on Some Enzyme Systems :

1. Hydroxyperoxidases :

Effect of water stress and NaCl salinity on the activity of peroxidase and catalase in the leaves and roots of D. viscosa L. has been recorded in Tables 14, 15 and 16, 17 respectively and depicted respectively in figures 13, 14 and 15, 16.

The values recorded in table 14 indicate that with increase in the intensity of drought upto the moderate level, there is decrease in the activity of enzyme peroxidase in both leaf as well as root tissues, when the activity is expressed on fresh weight basis. Activity of the enzyme, however, is slightly elevated in the leaf tissue after 12 and 16 days water stress. This increase is quite remarkable in the root tissue. Activity of the enzyme when expressed on protein basis (specific activity) follows a different pattern. It can be seen that upto 4 days water stress there is almost no change in the activity of the enzyme. After 8 days, however, it sharply declines and with increasing the intensity of drought, activity of the enzyme is stimulated but it is still slightly lower than that in control, even after 16 days water stress. In the roots, activity of the enzyme is increased due to 8 days water stress. Further dessication of the plant strongly arrests the activity of the enzyme. The differential pattern observed here with respect to expression of enzyme activity cannot be fully explained. However, it may be possible that due to dessication there is accumulation of soluble proteins in the plant parts, particularly under severe drought in an attempt to increase the osmotic potential of cell sap. Due to dessication the enzyme protein activation

Table:14 Effect of water stress on the activity of peroxidase in the leaves and roots of D. viscosa L.

Water stress (days)	O.D.$min^{-1}g^{-1}$ Fresh tissue		O.D.$min^{-1}mg^{-1}$ Protein	
	Leaf	Root	Leaf	Root
'O'Control	18	13	1.002	1.06
4	17	9	1.004	1.06
8	09	7	0.44	1.81
12	21	18	0.65	0.55
16	16	26	0.99	0.38

Table:15 Effect of NaC1 salinity on the activity of peroxidase in the leaves and roots of D. viscosa L.

NaC1 treatment (mM)	O.D. $min^{-1}g^{-1}$ Fresh tissue Leaf	Root	O.D. $min^{-1}mg^{-1}$ protein Leaf	root
'00'(Control)	10	17	1.65	0.39
25	8	11	1.87	0.61
50	6	11	2.87	0.57
100	12	10	1.19	0.90
200	19	16	0.85	0.31

Table:16 Effect of water stress on the activity of catalase in the leaves and roots of D. viscosa L.

Water stress (days)	mg H_2O_2 broken down $min^{-1}g^{-1}$ fresh tissue.		mgH_2O_2broken $min^{-1}mg^{-1}$ protein	
	Leaf	Root	Leaf	Root
'O'control	21.86	9.8	1.25	0.56
4	33.18	9.8	1.85	0.81
8	26.39	4.52	1.33	0.28
12	27.90	6.78	1.63	0.54
16	11.31	8.29	0.56	0.67

Table:17 Effect of NaCl salinity on the activity of catalase in the leaves and roots of *D. viscosa* L.

NaCl treatment (mM)	mg H_2O_2 broken down $min^{-1}g^{-1}$ fresh tissue		mg H_2O_2 broken down $min^{-1}mg^{-1}$ protein	
	Leaf	Root	Leaf	Root
00 (Control)	8.29	9.04	0.39	1.05
25	10.55	10.55	0.56	1.25
50	8.29	8.29	0.38	1.17
100	12.81	11.31	0.71	0.998
200	14.32	9.8	0.70	1.58

in the leaf as well as root tissues might have been affected, resulting into reduction in the activity.

The level of hydroxypercxidases is higher in the leaf tissue of D. viscosa L. as compared to that in the root tissue. From table 16 it is evident that activity of enzyme catalase in the leaves, when expressed on fresh weight and protein basis, is markedly increased due to water stress upto 12 days duration of water stress, however, severe drought (16 days water stress) strongly affects it and brings down the level of the enzyme even upto less than 50 % that in control. The response shown by this enzyme from the root tissue to water stress is not so uniform. However, it can be said that except 8 days water stress, the drought conditions only slightly influence the activity of enzyme catalase.

From table 15 it is evident that activity of enzyme peroxidase in the leaf is affected by salinity upto 50 mM NaCl level. However, the higher salt concentrations (100 and 200 mM NaCl) are remarkably stimulatory for the enzyme. The specific activity of the enzyme, however, follows a reverse trend indicating accumulation of soluble proteins in the tissue due to salinity and inactivation of enzyme protein at the higher salinity levels. Almost same trend is maintained by root tissue of D. viscosa L. plants exposed to salinity stress.

From table 17 it is evident that enzyme catalase from leaves as well as roots shows a remarkable resistance to salinity. It can be seen that activity of the enzyme is increased due to salinity both in the leaf as well as root tissues. The specific activity of the enzyme and activity of the enzyme expressed on fresh weight basis have shown almost identical pattern.

Maintainance or stimulation of catalase in D. viscosa L. under both water as well as salinity

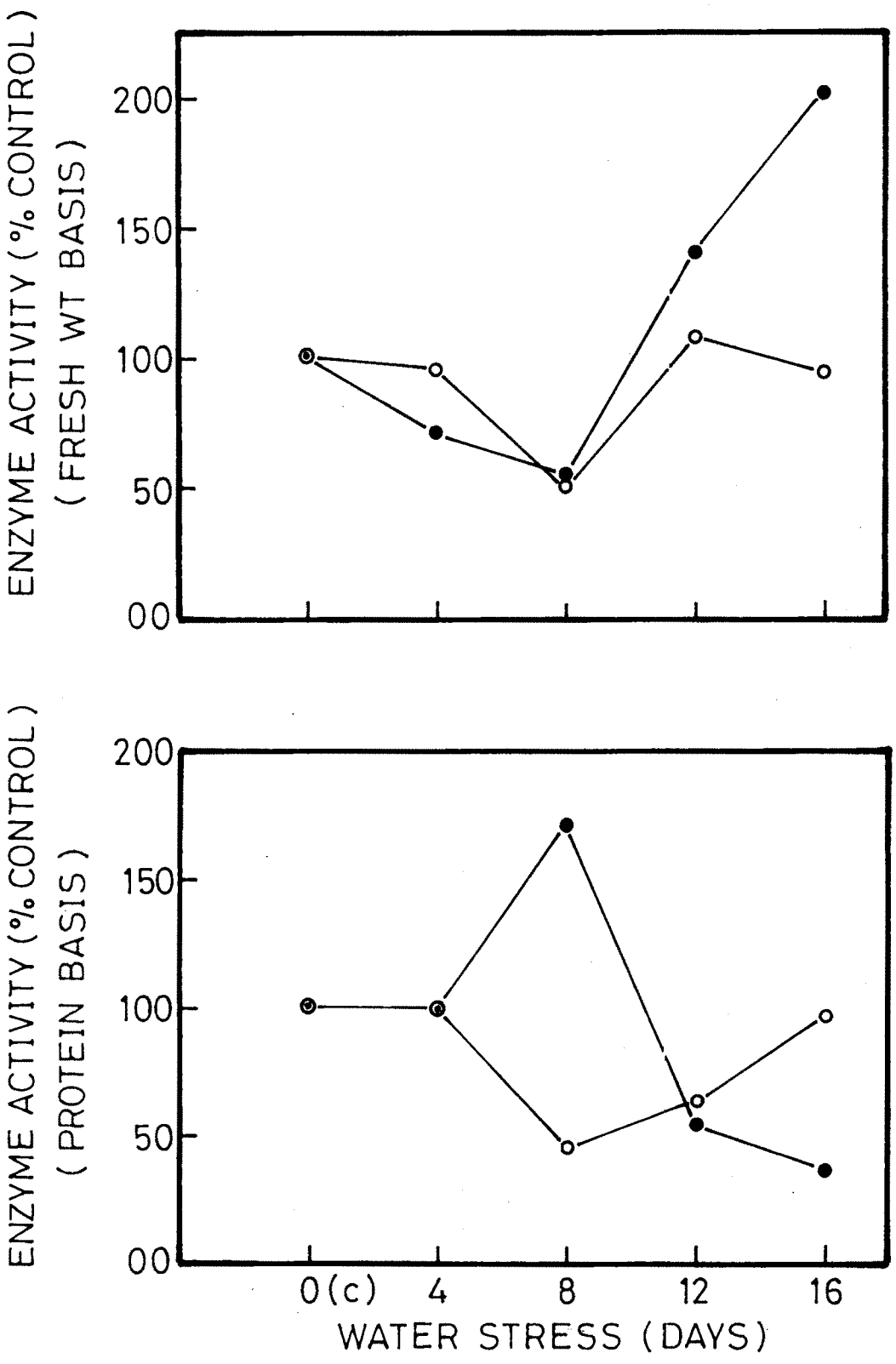

FIG.13. EFFECT OF WATER STRESS ON THE ACTIVITY OF PEROXIDASE IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L

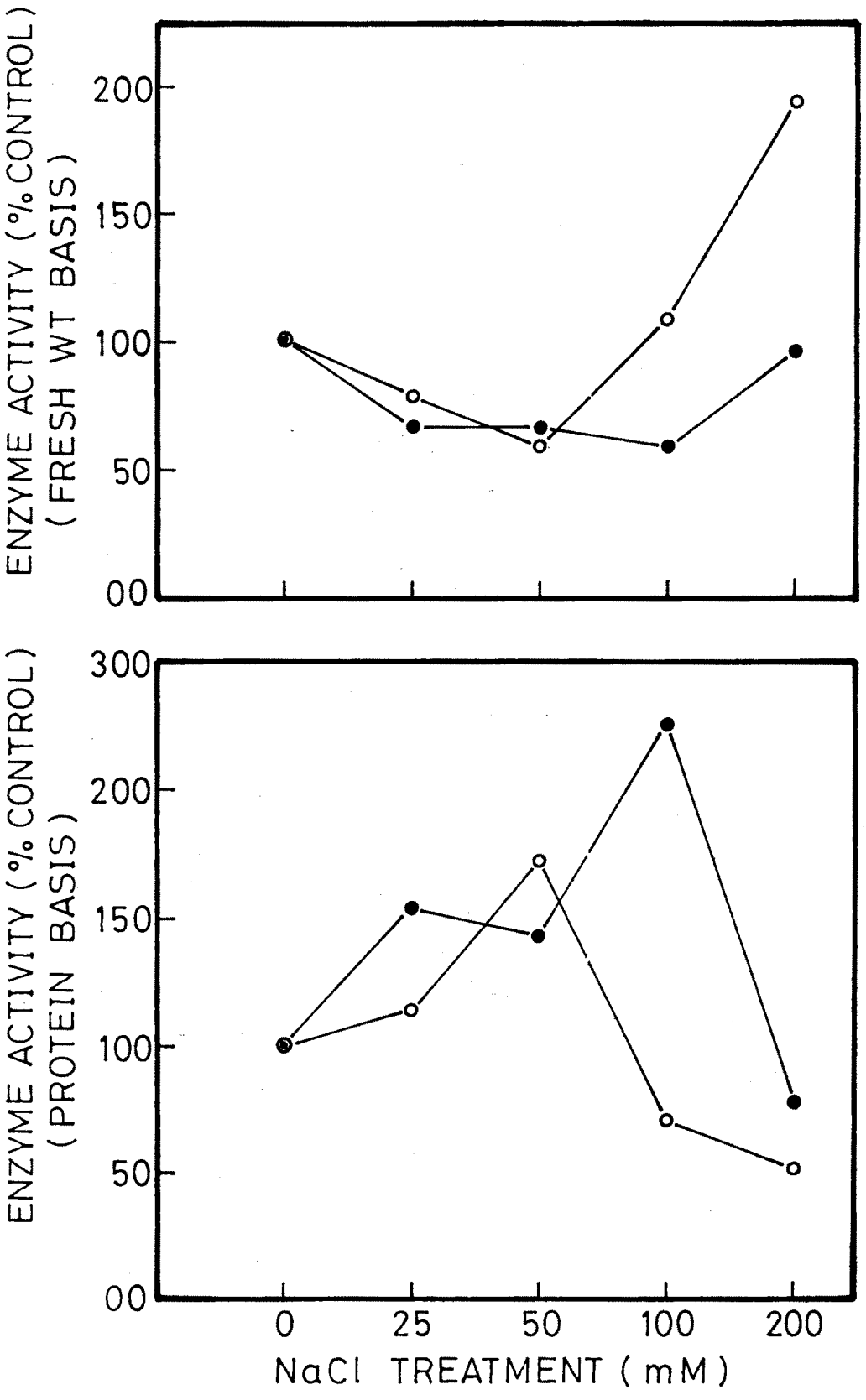

FIG.14. EFFECT OF NaCl SALINITY ON THE ACTIVITY OF PEROXIDASE IN THE LEAVES (○) AND ROOTS(●) OF D. viscosa L.

stressed conditions seems to be a protective mechanism for stress tolerance of the species.

There are only a few reports available which describe the behaviour of enzymes peroxidase and catalase under drought conditions. Thukral et al. (1985) have studied the effect of water stress on physiomorphological attributes in oil seed crop, Brassica. They reported that the activity of peroxidase in the leaves was higher in the tolerant than in the sensitive cultivars. They have emphasized a significant negative correlation between drought index and percent reduction in peroxidase activity and suggested that perusal of linear regression equation in the envisage usefulness of peroxidase activity in predicting water stress. From the present studies it can be said that even though, there is increase in the level of peroxidase due to high intensity of water stress in the leaves, simultaneously, the level of enzyme catalase is remarkably increased due to water stress, which may be playing a protective role against the toxic affects of peroxidase in the tissue. Thus, stimulation of catalase under drought conditions can be taken as an adaptive feature of D. viscosa L. for its drought resistance capacity.

Flowers (1972) observed a significant inhibition of peroxidase in salt tolerant Suaeda maritima. However, Strogonov (1964), Weimberg (1970), Aleshin et al. (1971) and Molokov et al. (1973) have reported an intensification of peroxidase activity due to salinity.

From the present studies it is clear that as both the enzymes, namely peroxidase and catalase are stimulated due to salinity, the overall balance in between destructive and protective functions is maintained under salinity stress. Increased level of catalase in particular, may be taken as an adaptive feature of the species towards salt tolerance. In

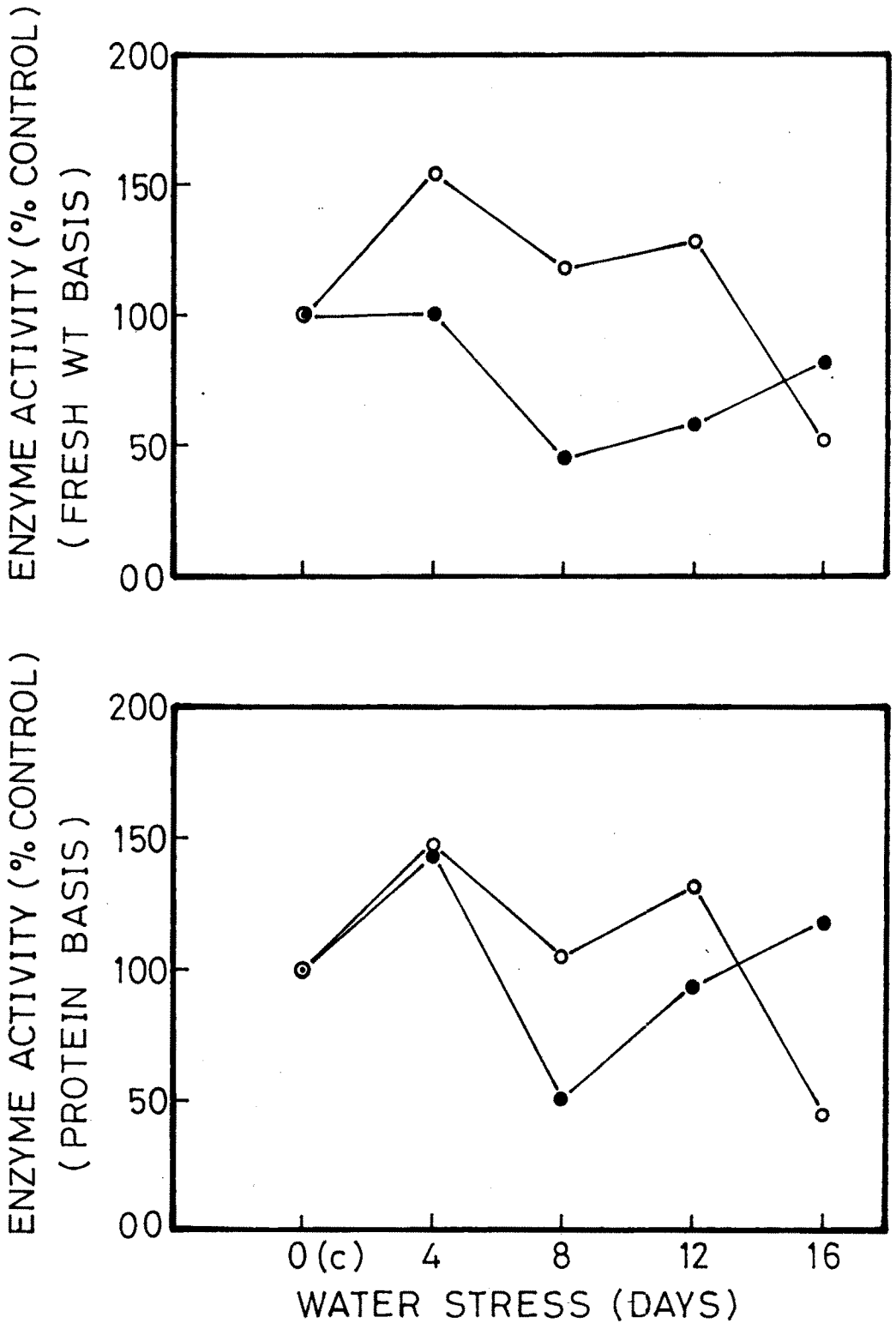

FIG.15. EFFECT OF WATER STRESS ON THE ACTIVITY OF CATALASE IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L.

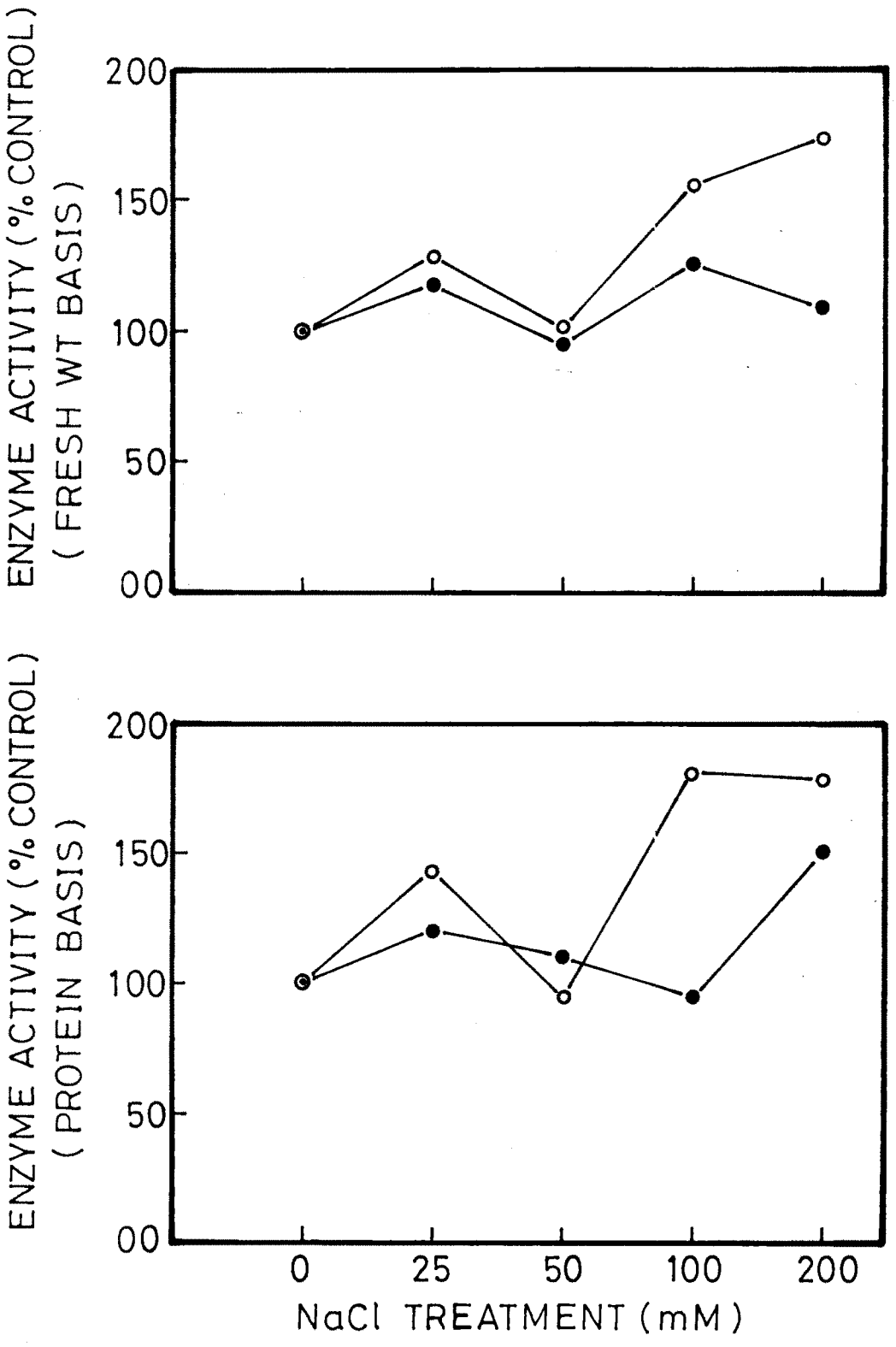

FIG.16. EFFECT OF NaCl SALINITY ON THE ACTIVITY OF CATALASE IN THE LEAVES (o) AND ROOTS (•) OF D. viscosa L.

conclusion, it can be said that D. viscosa L. has a good capacity to elevate the level of protective enzyme catalase as against peroxidase under stress conditions which contributes for stress tolerance in the species.

2. Acid Phosphatase:

Acid phosphatase is an enzyme involved in non-specific breakdown of a variety of phosphate compounds including ATP (De-Leo and Sacher, 1970). It also plays an important role in mobilization of nutrient reserves (Flin and Smith, 1967) and in several other processes in germinating seeds (Arbestain Ribas, 1977). Kar and Mishra (1975) suggest that total acid phosphatase is associated with the catabolic processes in the cells. Acid phosphatase is hydrolytic type of enzyme. It is also considered to be a marker enzyme of Lysosomes.

The work done on this enzyme in plants under stress conditions is scanty. However, there are several reports which describe the behaviour of this enzyme during seed germination under saline conditions. The influence of water stress on the activity of acid phosphatase during germination of ragi seeds is studied by Kunjamma (1983) and she found that the developmental pattern of this enzyme is slightly altered due to water stress. Mishra et al. (1978) observed a continuous decrease in the activity of this enzyme in germinating rice seeds due to water stress. Narasgaudar et al. (1979) have observed an inhibition of acid phosphatase in the seeds of Sorghum during germination under saline conditions and suggested that it may affect the hydrolysis of various reserve phosphates thereby disturbing the phosphate metabolism during germination. Dua et al. (1986) have reported an increase in acid phosphatase activity due to diffusion of macromolecules from castor bean during soaking period.

Table :18 Effect of water stress on the activity of acid phosphatase in the leaves and roots of D. viscosa L.

Water stress (Days)	O.D.$h^{-1}g^{-1}$ Fresh tissue leaf	Root	O.D $h^{-1}mg^{-1}$ Protein Leaf	Root
'0' control	2.50	9.8	1.39	5.53
4	5.98	9.0	3.53	7.27
8	7.98	10.4	3.92	6.36
12	4.4	10.8	2.31	8.6
16	3.98	13.6	1.94	10.78

Table:19 Effect of NaCl salinity on the activity of acid phosphatase in the leaves and roots of *D. viscosa* L.

NaCl Treatment (mM)	O.D.$h^{-1}g^{-1}$ Fresh tissue		O.D.$h^{-1}mg^{-1}$ Protein	
	Leaves	Root	Leaves	Root
00(Control)	8.04	9.0	3.76	10.28
25	7.00	11.4	3.62	13.20
50	4.00	7.2	1.80	9.90
100	7.00	11.6	3.77	10.00
200	8.20	9.6	3.94	15.00

In cotton, a loss of chloroplast membrane integrity under water stress was correlated with increased phosphatase activity localised on or near the chloroplast membrane (Nir and Poljakoff-Mayber, 1966; Vieira de Silva et al., 1974). Stimulation of phosphatases in plants under saline conditions has been reported by Ahmed and Hauq (1974). Weimberg (1970), however, found no significant effect of NaCl and other salts on the phosphatase system in pea seedlings. Zhukovskaya (1971) observed that both chloride and sulfate salinities activated phosphatase system in the roots and leaves of barley, millet, sunflower and tomato. They further reported that some new phosphatases are induced by salinities which were inactive in control plant. Activity of acid phosphatase was found to be increased due to NaCl treatment in pollen of sunflower, maize and rape (Ivanov Tseko et al., 1983).

The effect of water stress and NaCl salinity on the activity of enzyme acid phosphatase in the leaves and roots of D. viscosa L. has been recorded in the tables 18 and 19 respectively and depicted in figures 17 and 18. Activity of the enzyme has been expressed both on fresh weight as well as protein bases. It is evident that root tissue of the plant exhibits a high level of acid phosphatase. It is obvious that it is the root system and, therefore, root hair cell membrane which is directly exposed to the nutrient medium, the soil. Phosphatase is known to play a key role in an ion uptake and translocation. It is also evident that with increasing the intensity of drought there is remarkable increase in the activity of this enzyme both in leaf as well as root tissues. In case of leaves the enzyme records the highest activity in the plants which were exposed to 8 days water stress. High degree of dessication, however, inhibits acid phosphatase in the leaves but still it is

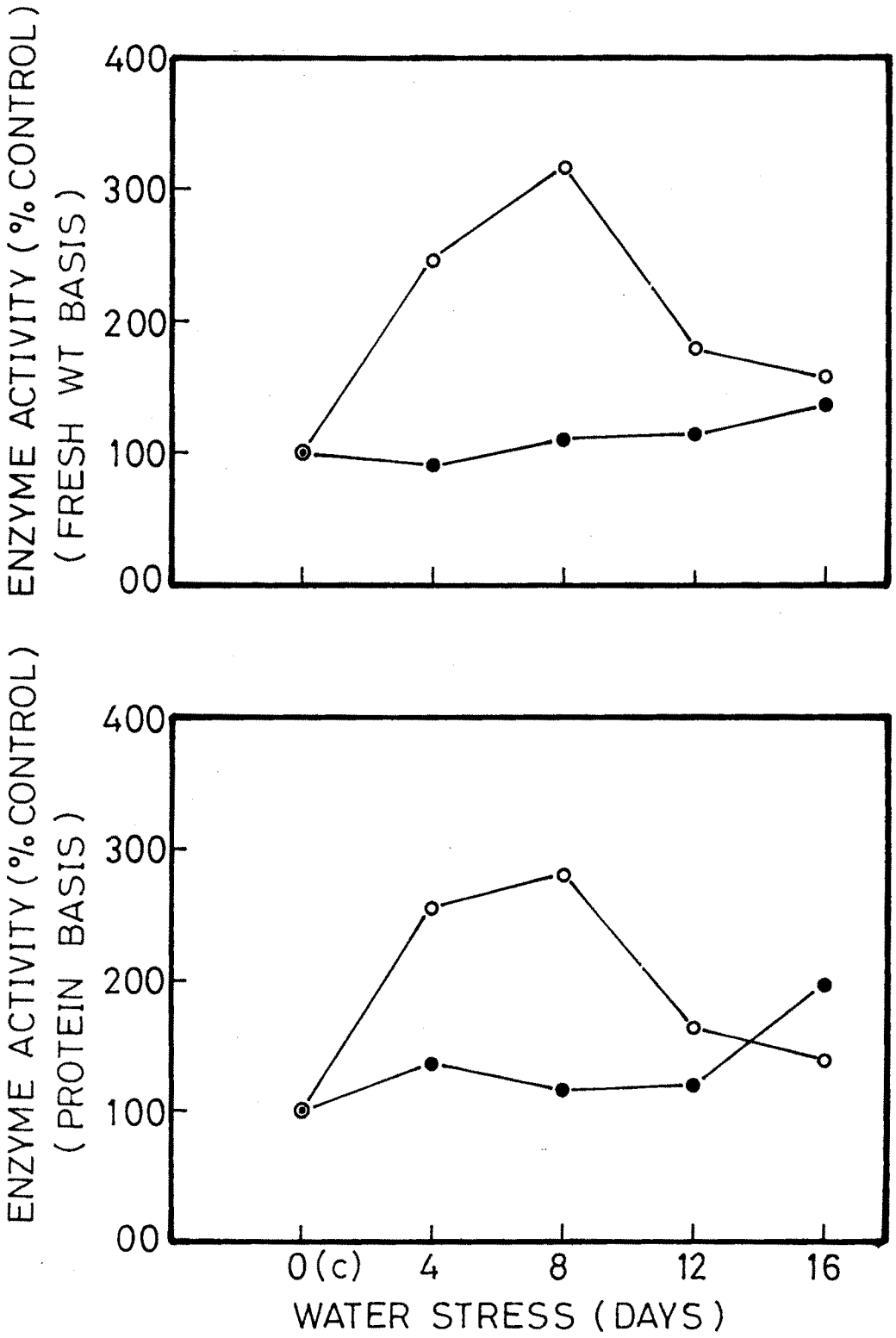

FIG.17. EFFECT OF WATER STRESS ON THE ACTIVITY OF ACID PHOSPHATASE IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L.

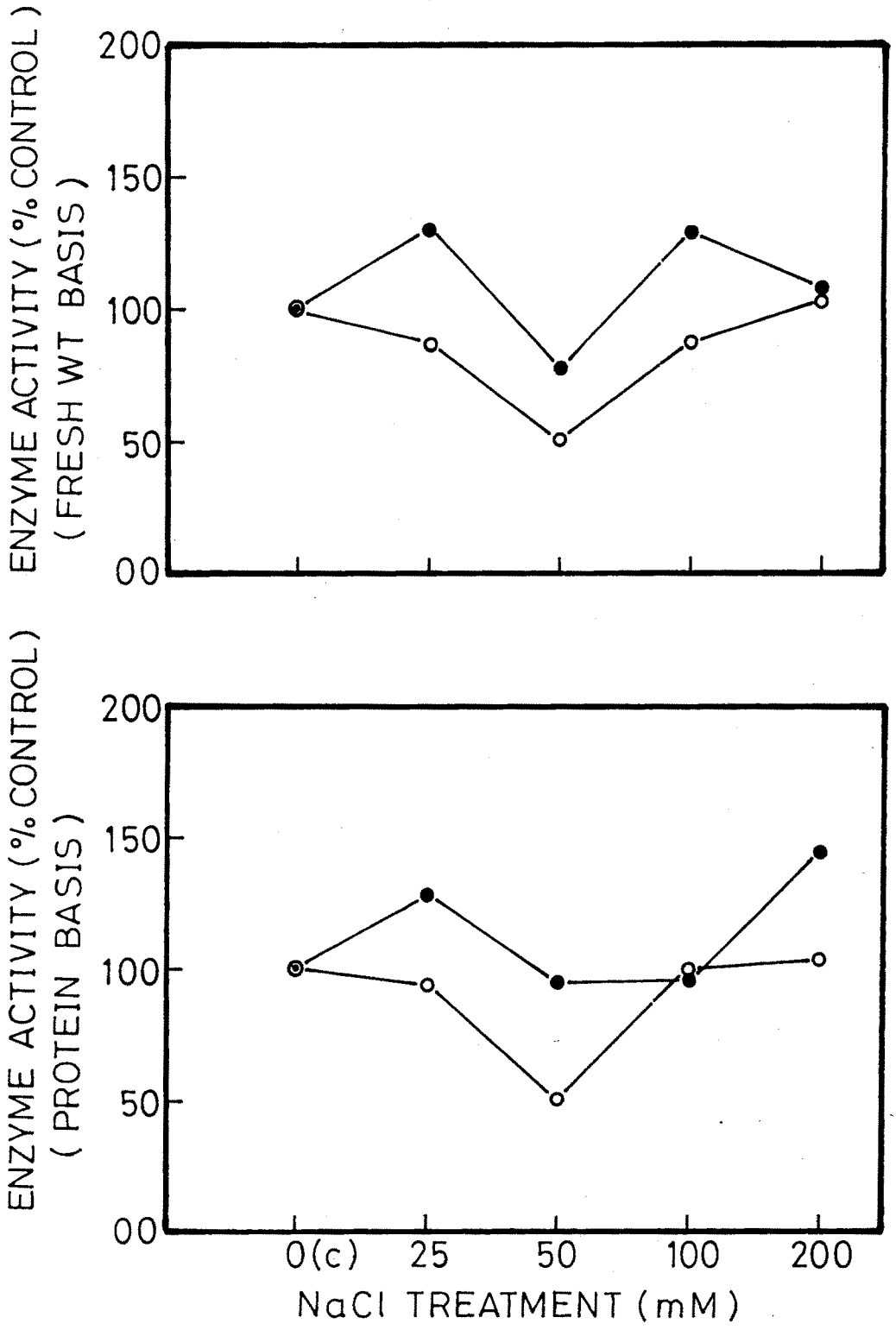

FIG.18. EFFECT OF NaCl SALINITY ON THE ACTIVITY OF ACID PHOSPHATASE IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L.

higher than that in the control plants. In case of roots, however, the highest enzyme activity has been recorded in the plants water stressed for 16 days. This stimulation in the activity of acid phosphatase may improve the phosphate metabolism to release more phosphorous for mobilization in the plants, a mechanism can be considered to be helpful in drought resistance. In fact, the phosphorous level of both leaf as well as root tissues is found to be increased due to water stress. This has been discussed in the later part of the thesis (Mineral Nutrition).

Table 19 and Figure 18 exhibit the effect of NaCl salinity on the activity of acid phosphatase in the leaves and roots of D. viscosa L. . It is evident that NaCl salinity has an adverse effect on the level of this enzyme in both plant parts. This is true upto 100 mM NaCl concentration in the medium. However, the highest salinity level (200 mM NaCl) stimulates the activity of acid phosphatase in the leaves as well as roots. It appears that phosphate metabolism under saline condition is only slightly influenced. It is observed that the phosphorous content of both plant parts is decreased due to salinity.

The differential response shown by acid phosphatase in D. viscosa L. shows a diversity in the mechanisms of the salinity tolerance and drought resistance.

3. Nitrate reductase:

Among the various biochemical factors limiting plant growth, Hageman et al. (1967) identified nitrate reductase as a rate-limiting step in nitrate assimilation. Nitrate reductase reduces nitrate to nitrite which is further reduced to ammonia which is assimilated for amino acid synthesis. Beevers and Hageman (1969) further suggested that nitrate reductase

first enzyme in the pathway, the rate limiting step, substrate inducible and relatively unstable because of its high turnover rate. It has been suggested that activity of nitrate reductase could be related to reduced nitrogen accumulation and possibly reduced dry matter production during stress with certain limitations (Sinha and Nicholas, 1981). Mattas and Pauli (1965) and Younis et al. (1965) studied the effect of water stress and temperature on growth and nitrogen metabolism in corn seedlings. It was observed that the growth of seedlings declined on the 4th day of stress and rate of increase in total nitrogen plant^{-1} also fell after the 3rd day and thereafter, remained low. During these experiments, nitrate content of the plant increased throughout and nitrate reductase activity declined even on the 1st day of water stress. They suggested that nitrate reductase is extremely sensitive to water stress. Huffaker et al. (1970) demonstrated that nitrate reductase in barley is strongly affected by even a mild water stress. A water deficit of 10 to 20 % was found to cause a 50 % reduction in the activity of nitrate reductase in maize seedlings (Bardzik et al., 1971) Shaner and Bayer (1976 -a, 1976 -b) suggested that nitrate reductase activity in maize was regulated by nitrate flux which was reduced in water stressed plants, leading to a lowering of enzyme activity. The response of nitrate reductase to water stress and salt stress was studied by Balasubramanian et al. (1974) to determine the stability of this enzyme in various crops. Enzyme activity was found to be susceptible to both salt and water stress. Brassica and Safflower, which are considered relatively more tolerant to water stress than wheat or barley in conditions of dry land agriculture showed the maximum loss of enzyme

activity, although some activity could always be detected. Rajgopal et al. (1977) observed that proline content in the un-irrigated wheat plants was maximal when the relative water content was lowest, which coincided with reduced nitrate reductase activity. Similar type of observations have been made by Goyal et al. (1985) in three genotypes of rice. The most likely explaination given by Sinha and Nicholas (1981) for the decrease in nitrate reductase activity during water deficit would seem to be that, changes in redox potential and energy change govern the responses of the enzyme. This regulation may be through inactivation or degradation of existing enzyme molecule or inhibition of further synthesis.

An inhibition of nitrate reductase by salinity in number of glycophytes has been reported by Weimer (1973), Plaut (1974) and Dwivedi et al. (1982). Karadge and Joshi (1983) have recorded overall decrease in the activity of this enzyme in Portulaca oleracea grown under saline conditions and have suggested that decreased activity of nitrate reductase affects the nitrogen content of the leaves producing nitrogen deficiency symptoms. Heuer and Plaut (1979) observed a decrease in nitrate reductase activity in sugarbeet due to salinity, which is attributed by them to the enzyme activity inhibition and inhibition of synthesis of enzyme. Even Billard and Boucaud (1982) observed a decrease in nitrate reductase activity in a halophyte Suaeda macrocarpa. Kabisheva et al. (1981) have suggested that dissociation of a molybdo factor from the enzyme apoprotein takes place which is responsible for decreased NR activity. Safaralliev et al. (1984) studied the causes of decrease in NR activity in legumes under salt stress and found that it may be dissociation of FAD in the leaves and molybdenum in root. Aslam et al. (1984) observed a severe inhibition

of NR when salt was added *invitro* while, *invivo* it was only slightly affected indicating that in situ NR activity is protected from salt injury. A decrease in nitrate reductase activity has also been reported by Patil (1984) in *Sesbania*, Rajmane (1984) in winged bean, Bottacin *et al*. (1985) in *Pennisetum* species and by Murumkar (1986) in chickpea which is considered by them to be due to the unavailability of substrate.

A stimulatory effect of salt on NR is also reported by number of workers. An increase in *invivo* activity of NR in *Phaseolus aconitifolius* seedlings exposed to saline conditions has been reported by Sankhla and Huber (1975). Chavan (1980) also observed similar trend in ragi and suggested that this increase enables the plant to cope with changes in nitrogen metabolism induced by salinity . Dias and Costa (1983) observed that nitrate reductase in sugarbeet leaves is stimulated by low salt concentration. Krishnamoorthy and Siddique (1985), Gaikwad (1989) and Wadkar (1989) have reported a stimulatory trend for NR activity in cowpea, millets and *Crotolaria* species respectively under saline condition.

The effect of water stress and NaCl salinity on the activity of nitrate reductase in the leaves and roots of *D. viscosa* L. has been recorded in tables 20 and 21 respectively and depicted in figures 19 and 20. It is evident that activity of the enzyme is more in the roots than that in the leaf. This is rather an unusual observation. A low activity of the enzyme in the leaf may be due to high level of phenolics present in the tissue which may be inhibiting the activity of the enzyme. From table 20 and figure 19, it is evident that NR in the leaf is only slightly affected due to water stress. It can be seen that there is some inhibition of enzyme activity in the plant exposed to 12 days water stress and

Table :20 Effect of water stress on the activity of nitrate reductase* (NR) in the leaves and roots of D. viscosa L.

Water stress(days)	Leaf	Root
0 (Control)	0.48	2.38
4	0.50	1.95
8	0.40	1.71
12	0.34	2.19
16	0.62	1.81

* Enzyme activity is expressed as mg NO_2 liberated $h^{-1}g^{-1}$ fresh tissue.

Table:21 Effect of NaCl salinity on the activity of nitrate reductase* (NR) in the leaves and roots of D. viscosa L.

NaCl treatment (mM)	Leaf	Root
00 (Control)	0.18	1.52
25	0.12	1.24
50	0.29	2.62
100	0.33	1.81
200	0.29	4.47

* Enzyme activity is expressed as mg NO_2 liberated $h^{-1}g^{-1}$ fresh tissue.

after 16 days water stress, there is some stimulation. However, in roots NR activity is markedly inhibited by water stress. Thus it appears that nitrate reductase in D. viscosa L. responds negatively to increasing intensity of drought. The present observation with NR is suggestive of drought resistant nature of D. viscosa L., as suggested by Maranville and Sullivan (1976), who established distinct classes of drought tolerance in Sorghum, ranging from tolerant to susceptible types. When they tested the effect of temperature and drought on a range of these genotypes, they observed that the most tolerant type lost nitrate reductase activity to the maximum extent. The mechanism of inhibition of nitrate reductase activity in drought resistant D. viscosa L. cannot be explained on the basis of present studies.

The response shown by nitrate reductase in D. viscosa L. to NaCl salinity is quite different from that shown to water deficit. It is evident from table 21 and figure 20 that with increasing salinity level in the medium, except 25 mM NaCl, there is remarkable increase in the activity of nitrate reductase from both leaves and roots. A decrease in NR activity at lower salinity level (25 mM NaCl) is probably similar to that observed in the water stressed plants. This indicates some adjustment of the plant against salinity stress at lower levels. It is difficult, however, to explain the stimulation of nitrate reductase in the leaf as well as roots at the higher salinity level. It is probable that stimulatory effect of salinity may be a secondary metabolic change adding to mechanism of salinity tolerance in D. viscosa L.

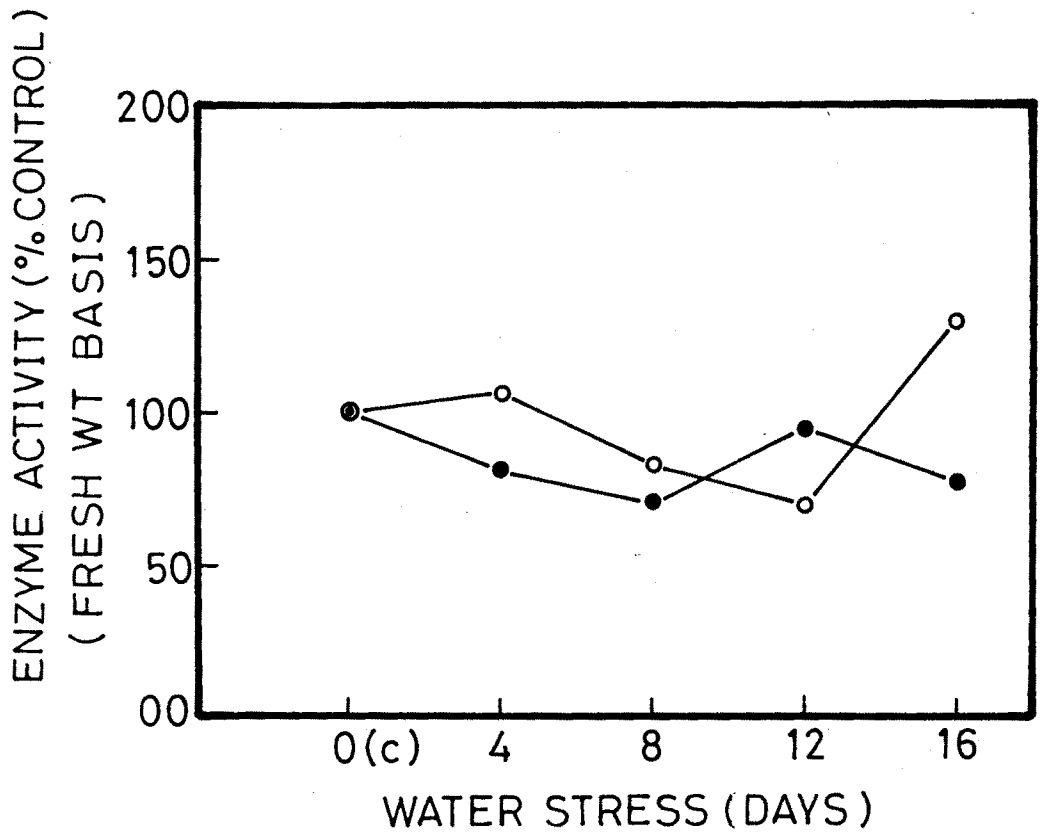

FIG.19. EFFECT OF WATER STRESS ON THE ACTIVITY OF NITRATE REDUCTASE (NR) IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L.

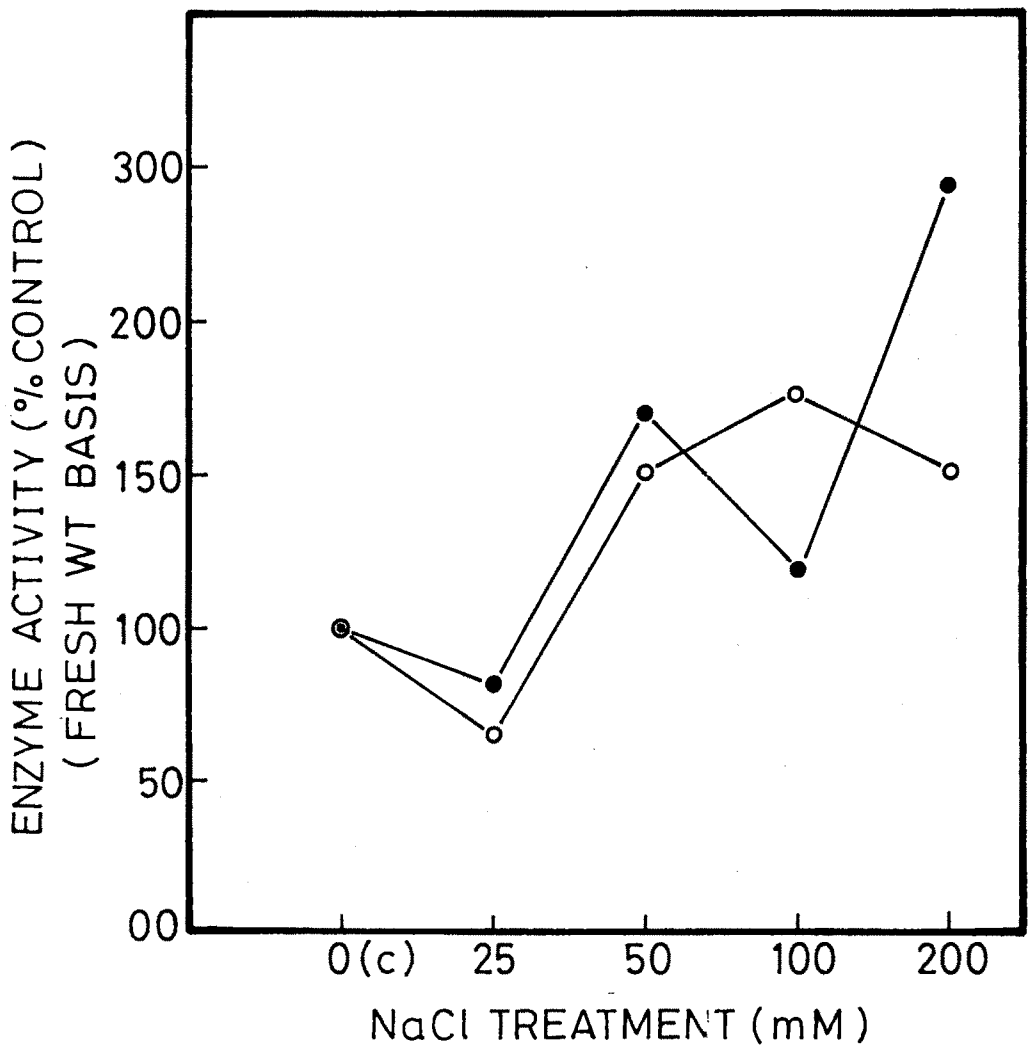

FIG.20. EFFECT OF NaCl SALINITY ON THE ACTIVITY OF NITRATE REDUCTASE (NR) IN THE LEAVES (○) AND ROOTS (●) OF D. viscosa L.

D. Effect of Water Stress and NaCl Salinity on Mineral Nutrition

Uptake and distribution of various inorganic constituents such as sodium, potassium, calcium, phosphorus, magnesium, iron, manganese, cobalt, copper, cadmium, nickel, lead and zinc in different parts of D. viscosa L. grown under normal irrigated, drought and salt stressed conditions have been recorded in Tables, 22, 23, 24 and 25 respectively and respectively in figures 21, 22, 23, 24, 25 and 26. It is evident that water stress and NaCl salinity markedly alter the composition of the plant with respect to various inorganic nutrients.

1. Sodium : Sodium is one of the trace elements, the essentiality of which has been recognised only recently, a monovalent cation, plays a significant role in halophytes. Its uptake and distribution in the plants have rarely been investigated in plants grown under water stressed conditions. However, there is tremendous literature available which discusses the uptake and translocation of this monovalent cation in number of plants under saline conditions.

Takeshi (1966) found very little difference in sodium contents of the leaves of Brasica rapa and Vigna sinesis due to water stress. A rise in plant sodium content at each stage of development in different grass species under moisture stress has been reported by Rahman et al. (1971) . According to these workers such an increase in sodium content may be attributed to the great reduction in dry matter at low moisture content. Lawlor and Milford (1973) reported that sodium causes to increase drought resistance of water stressed sugarbeet by altering leaf water balance. Ramati et al. (1979) and Ford (1981) have

Table:22 Effect of water stress on inorganic constituents* (Macronutrients) in root, stem and leaves of *D. viscosa* L.

Inorganic constituent	Plant part	Water stress (Days)				
		0(Control)	4	8	12	16
Sodium	Root	0.12	0.10	0.16	0.14	0.02
	Stem	0.11	0.12	0.10	0.11	0.11
	Leaf	0.14	0.22	0.14	0.13	0.14
Poassium	Root	0.40	0.50	0.60	0.50	0.80
	Stem	0.80	0.80	0.10	1.10	0.80
	Leaf	1.50	1.40	0.60	1.40	1.30
K:Na	Root	3.35	5.00	3.75	3.57	40.00
	Stem	7.25	6.66	1.00	10.00	7.25
	Leaf	10.5	6.36	4.26	10.76	9.26
Calcium	Root	0.85	0.75	1.65	0.80	1.45
	Stem	0.25	0.20	0.10	0.20	0.45
	Leaf	0.15	0.15	0.15	0.15	0.15
Phosphorus	Root	0.07	0.07	0.09	0.09	0.13
	Stem	0.08	0.13	0.11	0.13	0.15
	Leaf	0.12	0.15	0.17	0.18	0.12
Magnesium	Root	0.30	0.15	0.15	0.20	0.20
	Stem	0.20	0.10	0.20	0.25	0.15
	Leaf	0.30	0.25	0.30	0.25	0.20

* Values are expressed as g 100 g^{-1} dry issue.

Table :23 Effect of NaCl salinity on inorganic constituents* (Macronutrients) in root, stem and leaves of D. viscosa L.

Inorganic constituent	Plant part	NaCl Treatment (mM)				
		Control	25	50	100	200
Sodium	Root	0.10	0.14	0.16	0.28	-
	Stem	0.11	0.16	0.29	0.21	0.28
	Leaf	0.11	0.28	0.56	0.98	1.40
Potassium	Root	0.60	0.60	0.40	0.40	-
	Stem	1.10	0.80	0.80	0.24	0.22
	Leaf	1.30	1.30	0.40	1.10	0.60
K:Na	Root	6.00	4.29	2.5	1.43	-
	Stem	10.00	5.71	2.76	1.14	0.79
	Leaf	11.8	4.64	0.71	1.12	0.43
Calcium	Root	0.75	0.65	0.50	0.55	-
	Stem	0.35	0.35	0.65	0.55	0.50
	Leaf	0.70	0.70	1.05	1.05	1.40
Phosphorus	Root	0.05	0.03	0.03	0.01	-
	Stem	0.09	0.04	0.08	0.01	0.03
	Leaf	0.11	0.08	0.08	0.09	0.09
Magnesium	Root	0.20	0.30	0.10	0.15	-
	Stem	0.15	0.10	0.20	0.15	0.10
	Leaf	0.25	0.25	0.30	0.30	0.30

* Values are expressed as g 100 g^{-1} dry tissue.

observed an accumulation of sodium, potassium and chloride during water stress in Panicum ripens and P. maximum respectively. They considered that the grass leaves adjust osmotically to water stress apparently, through accumulation of solutes so that, there is a decrease in osmotic potential at full turgur.

Excessive salts in the nutrient medium cause disturbances in the normal uptake and distribution of inorganic ions and hence affect plant metabolism. Usually sodium and chloride get accumulated in the plants treated with sodium chloride. The ability of salt tolerant species to keep the uptake of sodium and chloride lower than that in their salt sensitive counterparts, under saline conditions, may be one of the causes of their relatively high salt tolerance capacity. Salt rejection mechanism has been observed by Waisel et al. (1986) in the mangrove, Avicennia marina. According to them, salt filtration by the root of this mangrove is the most important salt rejecting mechanism, preventing about 80 % of the salt which reaches to the root surface, from entering the shoot. Similar salt filtration mechanism which may not be as efficient as in Avicennia, appears to operate in Eleusine, Panicum and Pennisetum and that probably more efficient in their salt tolerant cultivars, enabling them to regulate the influx of sodium and chloride to the lower degree, under saline conditions (Gaikwad, 1989). Majority of glycophytic species are ion excluders and may accumulate high levels of sodium in their roots and stem (Flowers et al. 1977). Recently Downton (1978) has shown that less salt tolerant Avocado tress contained higher concentration of sodium and chloride in the leaves. Storey and Wyn Jones (1978) have correlated the grater salt sensitivity of Arimer cultivar of barley with poor ability of plants to regulate sodium and chloride accumulation in shoot. El-Shourbagi and Missak (1975) have studied the effect

of growing season and salinity on growth, mineral composition and seed lipid characteristics of some castor varieties . Their results have shown the reduced growth rate in each cultivar with progressive increases of NaCl concentration. Increased NaCl in the medium was associated with increased nitrogen, sodium and chloride in the plants. It is also reported that the roots of castor contain more sodium than leaves. Ashour et al. (1977) have reported a decrease in potassium concentration while an increase of sodium in wheat cultivars at early stages of growth under sodium chloride salinity. Nasr et al. (1977) have studied the effect of salinity and water table on the mineral content of plum and peach. It was found that the chloride content in the leaves and roots of plum and in the leaves of peach increased with salinity, whereas, chloride in peach root was not affected. The sodium content was found to be increased with salinity in plum but not in peach. Priebe and Jaeger (1978) report that Atriplex species take up NaCl only at low salt level and limit salt absorption at high salt levels. However, NaCl uptake of Vicia faba is proportionate to all soil salinity levels . Laszlo and Kuiper (1979) have shown that the Plantago species accumulated sodium in the shoot and maintained a relatively low level of sodium in the root under saline conditions. A pot culture experiment performed by Karadge and Chavan (1983) to evaluate salt tolerance potential of Sesbania aculeata revealed that the plant has a capacity to regulate sodium uptake under saline conditions, as a result, the chloride uptake always exceeded that of sodium. Flowers et al. (1986) have studied the effect of salinity on the growth and ion concentrations in number of tobacco cultivars. They found that under saline conditions increasing the external sodium : calcium ratio by decreasing the calcium concentration, increased the accumulation of

sodium and chloride into the leaf tissue. An accumulation of sodium in all plant parts of Dolichos biflorus, pronouncly more in roots and stems, has been reported by Nigwekar and Chavan (1987). Jeschke et al, (1986) found that dry matter gains of shoot and root of white lupine were almost linearly decreased with increasing external NaCl, relative growth rate of root being more affected than that of shoot. It was also observed that the concentrations of sodium and chloride in root bleading (xylem) sap and shoot tissues increased proportionately to applied NaCl indicating limited control over entry of sodium and chloride into root and xylem stream. K:Na ratio was higher in leaflets than in adjoining petioles and stem segments and in younger than older parts of shoot, suggesting capacities for sodium retention in stems and selectivity in potassium mobilization to young tissues. Torello and Rice (1986) found that salt tolerant 'Fults' alkali grass and 'Dawsons' red fescue restricted the accumulation of sodium ion to significantly low levels compared to salt sensitive Kentucky blue grass and 'Jamestown' red fescue, when grown under 170 mM NaCl in the medium. Sodium and chloride contents in the plant parts of Atriplex rhagodioides were found to be increased while potassium and calcium contents were decreased with increasing culture solution salinity (Khalid and Malik, 1987). It was further observed that all plant parts (root, stem and leaf) contain higher K : Na ratio than the culture solution, indicating selectivity for potassium or selectivity against sodium. Aslam et al. (1987) studied salt tolerance of Echinochloa crusgalli using gravel culture with root medium electrical conductivity between 3 to 25 dSm^{-1}. They also observed accumulation of sodium, chloride and calcium in the plant parts with increasing root zone salinity.

Effect of water stress and NaCl salinity on uptake and distribution of sodium in different parts of D. viscosa L. plants has been recorded in Tables 22 and 23 respectively and Fig. 21. It is evident that there is no significant effect on the uptake and the distribution of sodium in different plant parts when exposed to water stress. It can be seen that there is slight increase in the sodium content of the roots of the plants exposed to 8 to 12 days water stress. The stem sodium content remains unchanged throughout the duration of water stress. There is some measurable increase in the sodium content of the leaves when the plants were exposed to a mild water stress (4 days). However, this trend of accumulation of sodium in the leaf tissue is not maintained during further increase in drought intensity. It appears that sodium may not have a role to play in the osmotic adjustments through solute accumulation or salt accumulation in the cell sap exposed to dessication.

As against water stress conditions, NaCl salinity treatments in D. viscosa L. considerably cause to increase the level of sodium in all plant parts. However, the accumulation of sodium is more pronounced in the leaves. It can be seen that the sodium content of root increases slowly with increasing salinity level and reaches the maximum (0.28 g 100^{-1} g dry tissue). Accumulation of sodium in the stem tissue of the salt grown plant shows almost the same trend that observed in roots. It can also be seen that sodium is accumulated in the leaf tissue at fairly high rate when compared to that either in root or stem. Increase in the level of sodium in leaf tissue is quite linear and remarkable.

Sodium when accumulates in plant parts, is considered to be either toxic or beneficial. However, this depends on the location at which it

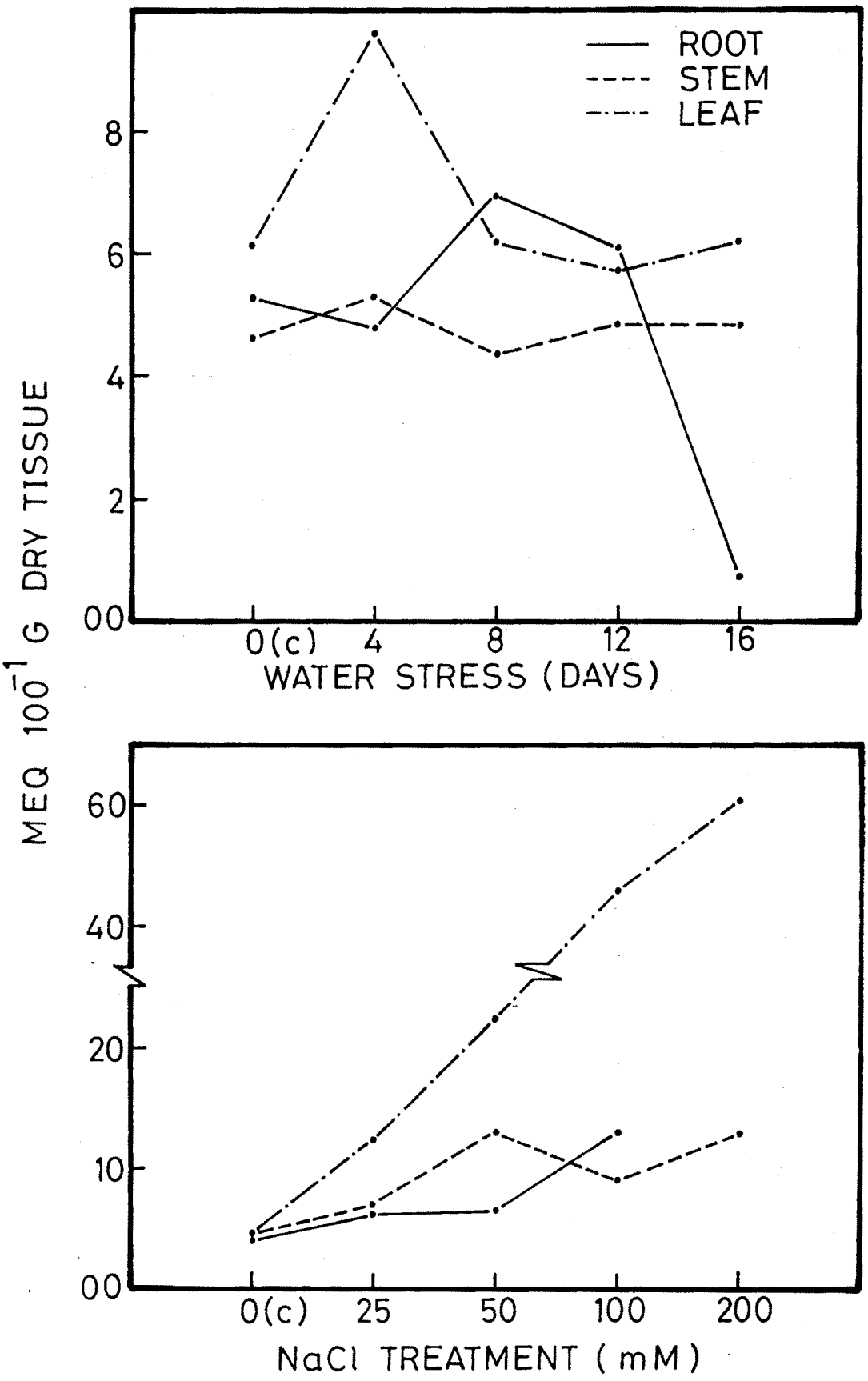

FIG.21. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF SODIUM IN VARIOUS PARTS OF D. viscosa L.

is accumulated. It has been reported in number of salt tolerant plants that when sodium is absorbed in large quantities along with water under saline conditions, get accumulated, particularly, in the leaf tissue where it is compartmentalized, probably in the huge vacuoles. Thus, eventhough there is tremendous accumulation of sodium in the plant parts, the metabolic activities of the cell are kept away from the toxic effects of sodium. However, if it is accumulated in the cytoplasm, may bring about changes in osmotic potential of cell sap which affect the metabolic activities. Thus sodium may become toxic. Ben-hayyiam (1985) found no difference among various NaCl tolerant cell lines of orange with respect to sodium and chloride uptake, and all these cell lines took up similar or even larger amount of sodium and chloride than that NaCl sensitive cell line and concluded that sour orange NaCl tolerant cell lines survive under elevated levels of external salts through its accumulation. It appears that accumulation of sodium in the leaves of D. viscosa L. may be beneficial helping moderate salt tolerance capacity of the plant.

2. Potassium : Potassium is one of the important macronutrients in plant, indispensable for the normal growth and development. Usually plant absorbs this monovalent cation in larger quantities and plant tissue is rich in this nutrient. It is a highly mobile element, frequently translocated, particularly, from the older tissues to the young growing parts, the meristems, where it is highly essential for protein synthesis, growth and accumulation of cytokinins as well as auxins. Potassium concentration in the plant tissue is correlated with the rate of growth and yield of a plant. It has been found that potassium shows a

wide range of its involvement in the metabolic activities of a plant. A number of enzyme systems require its presence for their maximal activation. Potassium influences various metabolic processes like photosynthesis, respiration and nitrogen metabolism through its tremendous role in water relations. Most of the turgour related activities are dependent on this monovalent cation. Role of potassium in stomatal movement is widely known.

The effect of water stress and NaCl salinity on the uptake and distribution of potassium in different parts of D. viscosa L. has been recorded in Tables 22 and 23 respectively and depicted in figure 22. It is evident that leaf of D. viscosa L. is the site of accumulation of potassium. The root contains lower amount of potassium as compared to that either in stem or leaf. The values recorded for potassium content of different parts of D. viscosa L. indicate that on an average the potassium content of the plant is quite sufficient as Epstein (1972) has suggested that the potassium level in plant tissue adequate for plant growth is 1 % dry weight.

It is evident from Table 22 and Figure 22 that uptake and translocation of potassium seems to be slightly affected by water stress. it can be seen that with increasing the intensity of drought, there is some measurable increase in the potassium content, only of the roots of D. viscosa L.. The potassium content of the roots of well irrigated plant (0.4 % dry weight) is doubled due to very long span of water stress (16 days). As far as stem potassium content is concerned there is almost no change due to water stress except that it is drastically affected due to 8 days water stress. in the leaf tissue, however, the potassium level is declined due to water stress. It can be seen that the leaves of control plants show the maximum amount of potassium (1.5 % dry weight). From the data

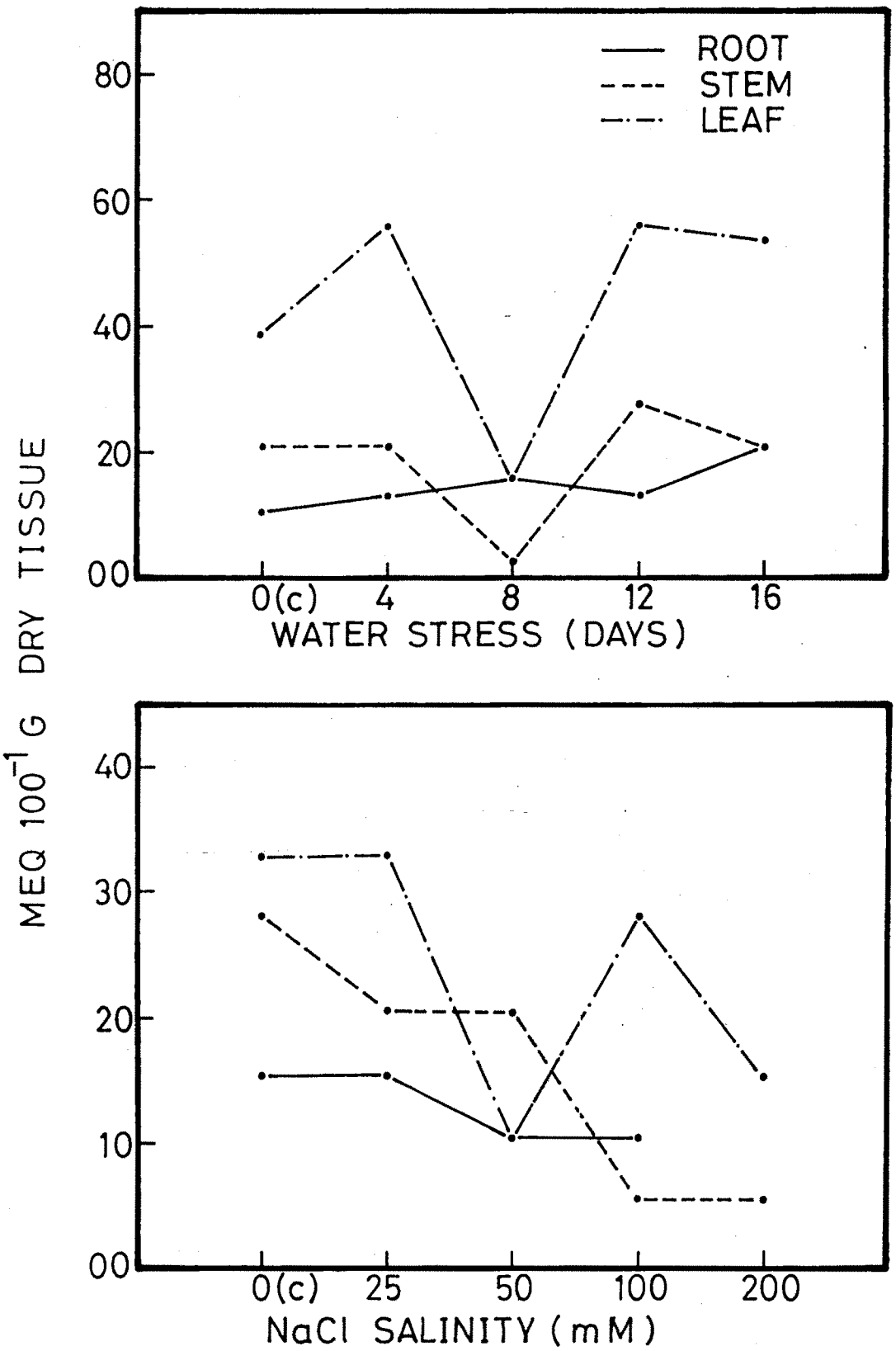

FIG.22. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF POTASSIUM IN VARIOUS PARTS OF D. viscosa L.

it appears that probably not the uptake but the translocation of potassium from the root to the stem and then from stem to the leaves is affected due to drought.

Quite a different trend of the uptake and distribution of this monovalent cation is observed in D. viscosa L. plants exposed to NaCl salinity. It can be seen from Table 23 and Figure 22 that with increasing NaCl concentration in the medium there is decrease in the potassium contents of the root. The stem also shows similar trend but its potassium content is markedly decreased at higher salinity levels (100 and 200 mM NaCl). The leaf tissue also follows the same trend where, there is decrease in potassium content with increasing salinity level. It appears that under saline conditions, probably both uptake as well as translocation of potassium are affected in D. viscosa L.

Present findings are in agreement with those of Richards and Wadeleigh (1952) who has summarized the existing data on nutrient availability in relation to soil moisture and concluded that water stress causes a definite decrease in potassium concentration in the plant parts. Similar observations have been made latter by several workers (Sakanau and Iguchi, 1968; Gilmore, 1971, Mengel and Broun Schweing, 1972; Verma et al., 1976; Martinez Carrasco et al., 1979; Singh et al., 1979). However, the experiments of Stewart and Hungate (1966) and Shimomura (1967) indicated that potassium uptake is only slightly reduced by water stress. Kongstrud (1969) has reported a varietal difference regarding potassium uptake during water deficit. He found that moisture stress causes to increase potassium in black currants but not in apples. There are also a few reports where increase in potassium uptake due to moisture stress has been observed. Water stressed leaves of Brassica rapa and

Vigna sinensis showed accumulation of potassium (Takeshi, 1966). Singh and Singh (1970) found an increase in potassium level in rice plants in the 1st period of their growth under depleted soil water condition but latter the trend was found to be reversed. Rahman et al. (1971) noticed that moisture deficit is associated with an increase in potassium content during all stages of growth of eight different plant species.

A high rate of potassium uptake by root cell depresses the osmotic potential in the cells and this induces water uptake. Similar situation probably prevails in D. viscosa L. under water deficit. The uptake of water by roots and the ability of the plant to exploit soil water, therefore, seems to be unaffected (Mengel and Kirkby, 1980) in D. viscosa L. under drought conditions. Potassium content of a plant controls transpiration which should be checked in arid environments (Brag, 1972). The effect of potassium in the regulation of transpiration can be attributed to the changes in stomatal aperture during drought. Ford et al. (1981) observed accumulation of potassium, sodium, and chloride in Panicum maximum, which was accounted for the osmotic adjustment. The accumulation of potassium in the roots and stem of water stressed D. viscosa L. may be considered as an adaptation for drought conditions.

Role of potassium in salinity tolerance in plants has been very well documented (Larsen, 1967; Rains and Epstein, 1967; Karmarkar and Joshi, 1969; Joshi et al., 1962 , Joshi, 1973, 1975; Rozema,1975, 1976; Hansen et al., 1976). Chhabra et al., (1979) observed that potassium content of sunflower leaves at maturity, increases with increase in exchangeable sodium percentage. According to Lynch et al. (1982), salt tolerance of a barley cultivar, Briggs was correlated with some measure of sodium tolerance as

well as sodium exclusion from actively growing tissue and sustained potassium acquisition. In the study of Curtis and Lauchli (1983), less inhibition of growth of relatively slow growing breeding line of Kenaf (Hibiscus cannabinus) by 75 mM NaCl was reflected by significantly lower sodium and higher potassium concentration in the mature leaf tissue. According to Norlyn and Epstein (1983) high internal potassium concentrations were associated with superior rates of emergence of triticale, a crop developed from an intergeneric cross between wheat and rye, under salt stress. The existence of sodium related growth stimulation in Spergularia marina and associated increase in the efficiency of potassium utilization for growth, was confirmed by Cheeseman and Wicken (1986) in which growth and accumulation of both the ions were well balanced, resulting in stable Na^+ and K^+ concentrations within the plants after adjustment to saline medium. Aslam et al. (1987) studied salt tolerance of Echinochloa crusgalli. They found that the plant was able to maintain its tissue water content and K^+ concentrations in the tissue water.

Though a role of potassium in salt tolerance is fairly well established, the K^+ uptake process is found to be significantly affected in glycophytes due to salt stress (Shourbaggy and Missak, 1975; Roland, 1975; Guggenheim and Waisel, 1977; Ashour et al. 1977; Nasr et al., 1977; Zid and Bourkhris, 1977; Guillen et al. , 1978; Priebge and Jaegar, 1978; Laszlo and Kuiper, 1979; Chen et al., 1980; Chavan and Karadge, 1980; Divate and Pandey, 1981; Soufi and Walace, 1982; Joshi, 1984; Jeschke et al., 1986, Martinez et al., 1987; Khalid and Malik, 1987). According to Khalid and Malik (1987) accumulation of ions against a concentration gradient, selective potassium uptake and partitioning of excess salts in

the leaf seem attributable to the high salt tolerance of Atriplex species.

From the present observations with uptake and distribution of potassium by D. viscosa L. under saline conditions and further, looking to K:Na ratio in different plant parts which is continuously decreased with increasing salinity level in the medium, it appears that D. viscosa L. has no ability to maintain the level of potassium in the tissue or has no mechanism of selective absorption of potassium from the medium. The salt tolerance seen in D. viscosa L. seems not to be due to the role of potassium but probably calcium has to play some decisive role in the mechanism.

3. Calcium : Effect of water stress and NaCl salinity on the uptake and distribution of calcium in different parts of D. viscosa L. has been recorded in Tables 22 and 23 respectively and figure 23. It is evident from table 22 and figure 23 that calcium is accumulated in the roots of water stressed D. viscosa L. The level of calcium in the roots increases from 0.85 % (dry wt) in well irrigated plants to 1.65 % (dry wt) in 8 days water stressed plants and it is 1.45 % (dry wt) in the plants grown in the medium from which water was withhold for 16 days. This divalent cation is accumulated in stem, only in case of 16 days water stressed plants. It is also clear that there is no change in the leaf calcium content due to water stress. It is also evident that calcium appears to remain accumulated in the root tissue followed by stem tissue and only a little amount of it is received by leaf. This is clear from the values recorded for calcium content of different parts of D. viscosa L. This indicates that calcium has relatively low mobility and therefore its translocation from root system to the shoot is rather slow. The present results, therefore,

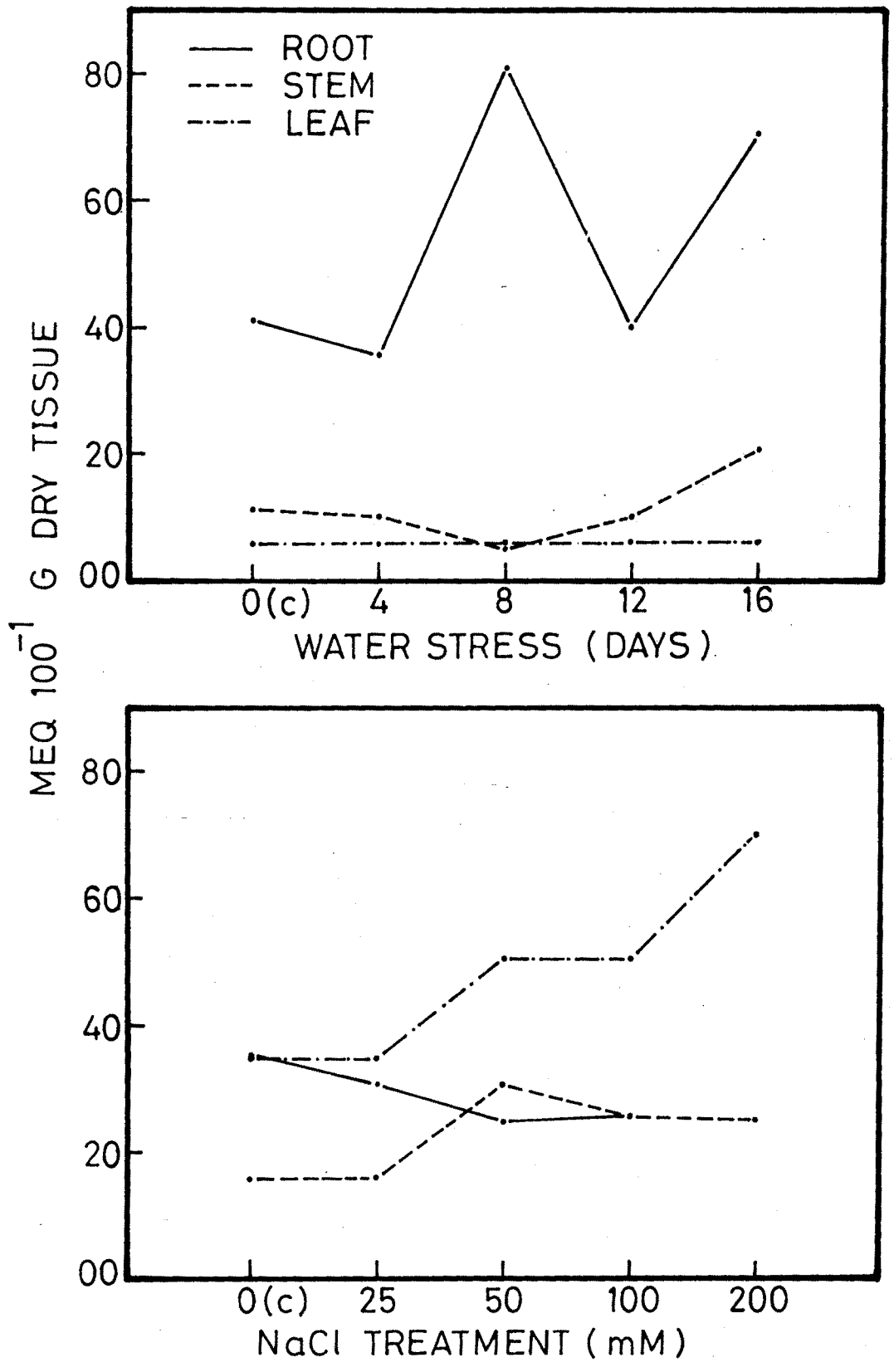

FIG.23. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF CALCIUM IN VARIOUS PARTS OF D. viscosa L.

further suggest that eventhough, the uptake of calcium is not affected by water stress, its translocation is inhibited by drought conditions.

D. viscosa L. however, responds quite differently with respect to uptake and translocation of calcium, to NaCl salinity. It is observed (Table 23 and Figure 23) that with increasing level of NaCl salinity in the medium there is only a slight decrease in calcium content of roots. On the other hand, stem calcium content is considerably increased due to salinity. This is quite significant at 50 and 100 mM NaCl concentrations. Interestingly, calcium is found to be accumulated in the leaf tissue due to salinity. It can be seen that the calcium content of leaf is doubled (1.40% dry wt) due to the highest salinity level (200 mM NaCl) to that (0.70 % dry wt) in the leaf tissue of the plant grown under non-salinized conditions. It appears that under saline conditions, D. viscosa L. has a good capacity to absorb and translocate calcium to the shoot parts.

Calcium plays an important role in a number of metabolic activities. It is an integral part of cell wall and hence plays a key role in growth and development of new cells. It is also found to be involved in synthesis and translocation of carbohydrates. It is also known to play a significant role in salinity tolerance in rather salt sensitive plants. It is found to be involved in mechanism of heat resistance in thermophilic bacteria (Ljunger, 1973). In arid regions, high temperatures and dryness are generally associated with each other. Therefore, calcium may have some important role in plants adapted in these arid conditions. However, the exact role of calcium in heat tolerance or drought resistance in higher plants has not been worked out.

Water stress causes variable changes in calcium concentration in the plants (Richards and

Wadleigh, 1952). Takeshi (1966) found an increase in calcium content of the leaves of Brassica rapa and Vigna sinensis due to water stress. Kongsturd (1969) has observed that moisture stress led to increase the calcium content in black currants but not in apples. Soil moisture deficit during different stages of development of some Panicum species caused to accumulate calcium in the plant parts (Rahman et al., 1971). Similar observations have been made in case of Lablolly pine by Gilmore (1971). Samuels (1972) also observed accumulation of calcium in different parts of sugarcane grown under moisture depleted conditions. In contrast to these reports, an adverse effect of water stress on calcium uptake has been recorded. According to Kunno et al. (1964) the inhibition of calcium and magnesium absorption may be one of the reasons for increased flower and pod shedding caused by water deficit in soybeans. Symptoms of calcium deficiency in groundnut crop subjected to drought have been recorded by Giller (1969). Singh and Singh (1970) have observed that calcium was greatly reduced in wilting rice leaves. Vander Boon (1973) demonstrated that drought lowered the calcium content and raised K : Ca ratio in tomato fruits. Stewart and Hungate (1966) have found no effect of soil moisture on calcum uptake in Phaseolus vulgaris. The leaf calcium content was found to be unaltered in Sorghum bicolor grown under moisture stressed conditions (Eck et al., 1979). The present observations with D. viscosa L. are in line with the above reports and it can be suggested that the calcium uptake in D. viscosa L. is stimulated under drought conditions which can be considered as an adaptive feature. It can also be true that potassium and calcium which together accumulate in the root system of D. viscosa L. under drought conditions may maintain the root activities thereby tolerating the drought conditions.

A great importance has been attributed to calcium in salt tolerance (La-Haye and Epstein, 1969). Recovery from the damage due to salt stress by the application of calcium sulfate in the medium was reported by Chimiklis and Karlander (1973). Epstein (1972) has suggested an antagonism between sodium and calcium. A reduction in calcium uptake under saline conditions in several plants is observed by number of workers (Matar et al., 1975; El-Shourbagy and Missak, 1975; Guggenheim and Waisel, 1977; Priebge and Jaeger, 1978; Laszlo and Kuiper, 1979; Chavan and Karadge, 1980; Starck and Kozinska, 1980; Divate and Pandey, 1981; Flowers et al., 1986; khalid and Malik, 1987). Contrary to these observations an increase in calcium content in some plant species under saline conditions has also been reported (Joolka et al. , 1977; Ayoub, 1977; Karadge and Chavan, 1983). Aslam et al. (1987) have studied salt tolerance of Echnichloa crusgalli using gravel culture. They found that salinity depressed germination and shoot yield, however, the plant was found to withstand the saline conditions upto 15.9 dSm^{-1} at which a 50 % reduction in shoot yield was observed. Further, they have noted that the plant was able to maintain its tissue water content and potassium concentration in the tissue while sodium, calcium and chloride were increased with increasing root zone salinity. recently Nigwekar and Chavan (1987) have reported that salt stress caused an increase in the calcium content of the leaves and roots of moderately salt tolerant plant, Dolichos biflorus. A degree of physiological balance between Na^+ and Ca^{2+} must be present if toxicity due to high concentration of Na^+ alone is to be avoided (Bernstein and Hayward, 1958). The inability of sugarcane cultivar CO-740 to develop salt tolerance has been suggested to be due to less calcium uptake by the plants in the saline environment (Nimbalkar and Joshi, 1975). Calcium has been shown to

regulate membrane properties and it is proposed that calcium and sodium probably compete for common uptake sight (Lessani and Marschner, 1978).

From the present results, it is quite clear that inspite of less mobility, calcium is observed more under saline conditions. Even its translocation from the root to the shoot seems to be improved under saline conditions. This is quite significant from an increase in the level of calcium in leaf tissue with increasing salinity level. Thus, it appears that D. viscosa L. is able to maintain balance between Na^{+} and Ca^{2+} to avoid the probable toxicity due to high concentrations of sodium as suggested by Bernstein and Hayward (1958).

Phosphorus : The role of phosphorus in energy transfer reactions and in the composition of cell wall lipid and nucleotides is well known. The influence of water stress and NaCl salinity on phosphorous content of various parts of D viscosa L. plants, such as root, stem and leaf has been recorded in Tables 22 and 23 respectively and depicted in figure 24. It is evident from Table 22 and Figure 24, that the phosphorus content of all plant parts is increased remarkably under drought conditions. Among the various plant parts, however, the increase in phosphorous is quite significant in stem followed by root. Thus phosphorus uptake in D. viscosa L. is stimulated by drought conditions. The response shown by phosphorus metabolism in the plant to salinity stress, however, seems to follow an opposite trend. From the observations recorded in Table 23 and figure 24 it is quite clear that the phosphorus content of roots of D. viscosa L. decreased linearly with increasing salt concentration in the medium. It can be seen that there is about 80 % reduction in the phosphorus level of the roots due to salinity at 100 mM salt concentration. In the stem tissue the phosphorus level falls down from

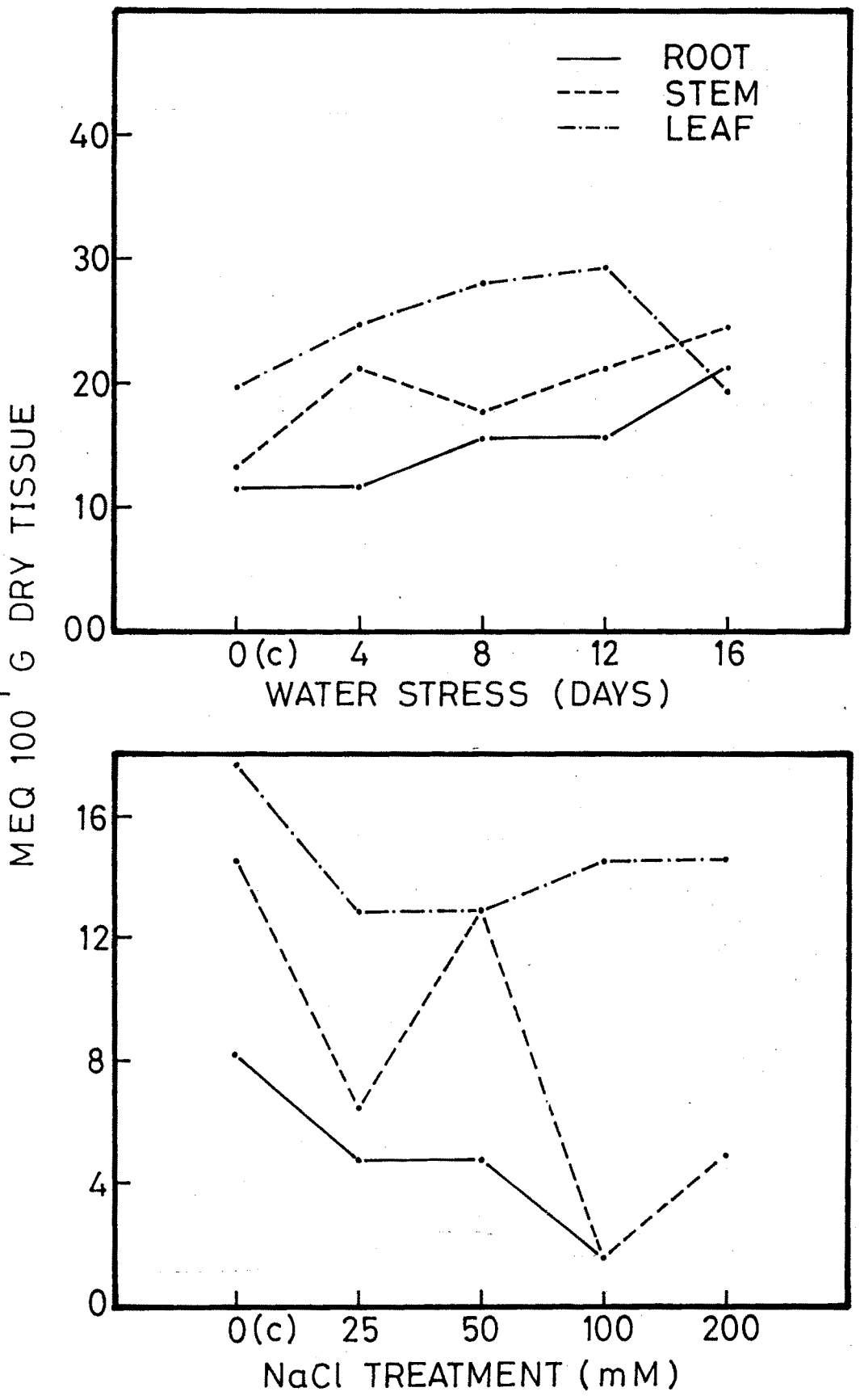

FIG.24. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF PHOSPHORUS IN VARIOUS PARTS OF D. viscosa L.

0.09 % in control to 0.01 % in 100 mM NaCl treated plants. Leaf phosphorus, however, shows a slight decrease due to salinity. It appears that NaCl salinity not only affects the uptake of phosphorus from the medium but also the translocation of it from the root to the foliage is affected.

Most of the workers have noticed that water stress greatly hampers phosphorus uptake process. Wilson et al. (1968) observed that reduction in phosphorus content due to drought was a common feature in many annual forage legumes and it was of the order of 4 to 68%. Sakanoue and Iguchi(1968) have shown that the uptake of phosphorus was the most sensitive to drought of all the nutrients. Pandey and Singh (1969) have observed a decrease in phosphorus uptake due to drought in rice. Kongstrud (1969), Rahman et al. (1971), Forde (1972), Dunham and Nye (1976) and Eck et al. (1979) have recorded a decrease in phosphorus uptake in apple, grasses and legumes, oil palm, onion and sorghum respectively. Greenway et al. (1969) have reported that the potential above -10.4 atm in tomato plants affects the uptake and distribution of phosphorus in both root and shoot.

The reduction in phosphorus uptake due to drought leads to further metabolic disturbances as phosphorus is essential for many processes. Phosphorus becomes a limiting factor for glycolysis in water stressed plants (Gorden and Bichurina, 1970). Samuilov and Lebedeva (1973) observed a sharp reduction of nucleotide phosphate and phoric esters of sugars due to severe drought affecting the enzymatic metabolism of the plant.

The present results with D. viscosa L. are different from those discussed above. Increase in the uptake of phosphorus and its distribution in various parts of D. viscosa L. indicate less disturbances in the phosphate metabolism leading to the least deviation

of a normal metabolic activities in the plant under drought conditions.

Importance of phosphorus accumulation in the resistance to secondary salt induced stress has been reported by Wilson et al. (1970) . Accumulation of this ion in different parts of salt tolerant as well as salt sensitive plants, grown under saline conditions, has been reported by many workers (Gates et al., 1966; Ravikovitch and Yoles, 1971; Ansari, 1972; Rahman et al., 1972; Syed and Dumbroff, 1973; Austenfeld, 1974; Chavan and Karadge, 1980; Lal and Bharaddwaj, 1984; Nigwekar and Chavan, 1987). Ccntrary to these reports there are several observations where phosphorus uptake by the plant has been reported to be affected by salinity stress (Paliwal and Maliwal, 1972; Kleinkopf et al., 1975; Dahiya and Singh, 1976; Nasr et al., 1977; Starck and Kozinska, 1980). The present results with D. viscosa L. are also on the similar lines. However, as this plant is successful in maintaining rather high phosphorus level in the leaf tissue, under saline conditions, it has a sturdy nature against NaCl salinity. However, this cannot be considered as a strong point adding to the salt tolerance in D. viscosa L.

5. Magnesium : Magnesium is essential in plant for a number of reasons. It is involved in the structure of photosynthetic pigment, chlorophyll. Magnesium also acts as a cofactor for a large number of important enzyme systems in plants. There is only a little work done on the fate of this divalent cation in plants under stress conditions. Sakanaue and Iguchi (1968) found that magnesium uptake was greatly reduced in rice plants under water stress. On the other hand Kongstrud (1969) observed an increase in magnesium content in black currant but not in apple. Gilmore (1971) found decreased amount of this nutrient in the leaves of

loblolly pine due to water stress. The effect of water stress on magnesium content of root, stem and leaves of D. viscosa L. has been recorded in Table 22 and Figure 25. it can be seen that the magnesium content of the roots of D. viscosa L. is decreased considerably due to water stress. However, sten magnesium seems to be slightly affected due to water stress. Same trend has been shown by leaf magnesium It appears that water stress has almost no influence on uptake and translocation of magnesium in D. viscosa L. Retention of chlorophylls in the leaves under drought, in this plant supports this statement.

The influence of NaC1 salinity on uptake of magnesium by D. viscosa L. has been recorded in Table 23 and depicted in figure 25. It is evident that with increasing level of salinity in the medium there is some increase in the magnesium contents of the root and that only at the lower salinity level (25 mM NaC1). However, it is markedly decreased due to salinity stress at higher salt concentrations. The pattern shown by magnesium content of the stem is indefinite. However, there is only a slight effect of salinity on the magnesium content of stem. It is interesting to see that the magnesium of leaf is not only maintained but also increased slightly under saline conditions, particularly, at higher salt concentrations. Thus, magnesium metabolism in D. viscosa L. seems to be less sensitive to salinity stress. Retention of chlorophylls in the leaves of this plant under saline conditions strongly supports this.

Contradictory reports are available regarding the fate of this divalent cation in the plant under saline conditions. A decrease in magnesium content in the plant parts due to salinity stress has been observed in beans (Meiri et al., 1971; Helal and Mengel, 1981), Panicum turgidum, Oryzopsis miliacea, Crotalaria aegyptiaca, Medicago sativa, Panicum

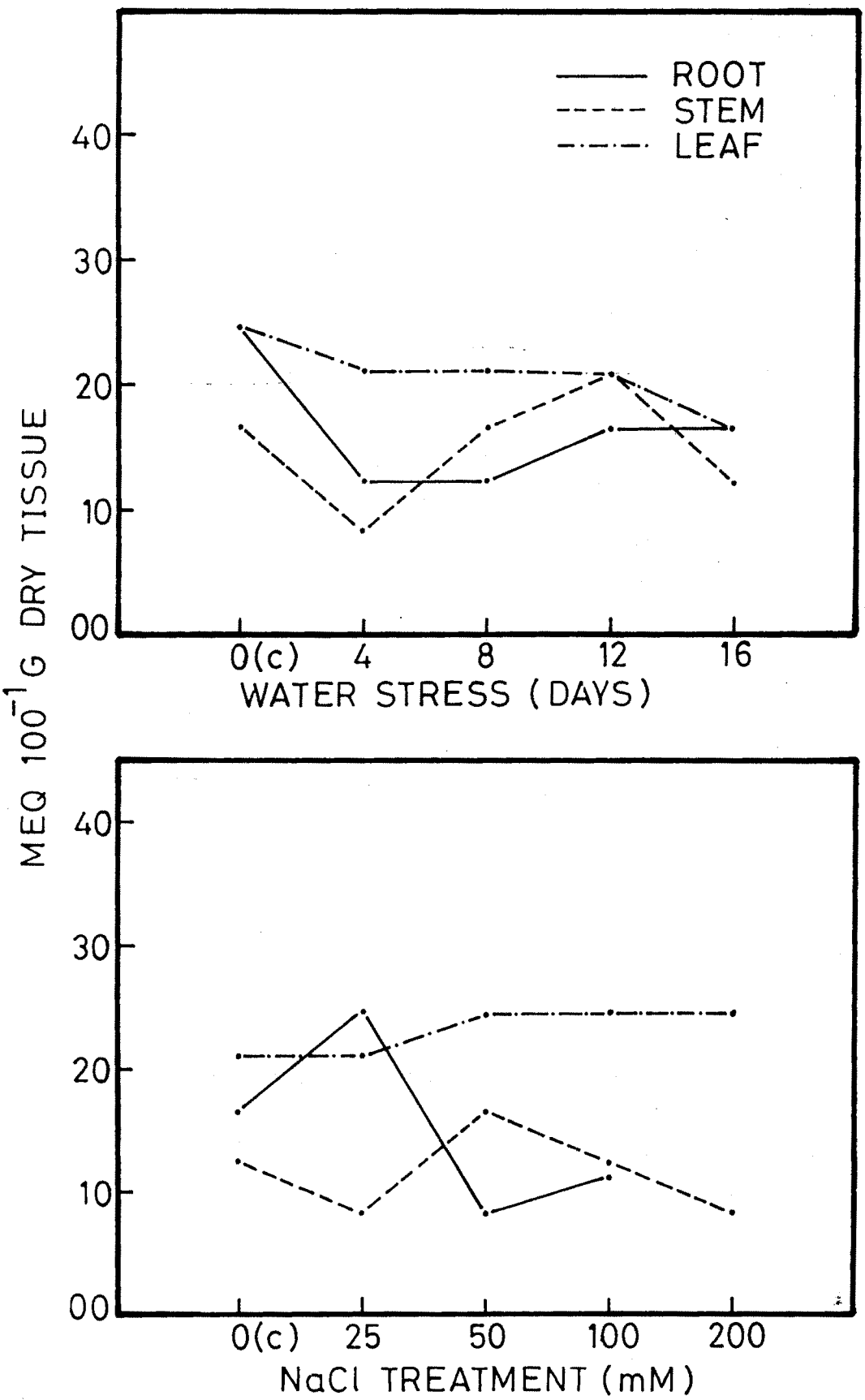

FIG.25. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF MAGNESIUM IN VARIOUS PARTS OF D. viscosa L.

antidotale, P. coloratum, P. maximum and Chloris gayana (Rahman et al., 1972), Castor cultivars (El-Shourbagy, 1975), chloroplasts of peanut (Reddy and Das, 1978), salt tolerant and salt sensitive Plantago species (Laszlo and Kuiper, 1979), Desertholly (Soufi and Wallace, 1982), peas (Lal and Bharadwaj, 1984) and aquatic plant, Cyperus involucratus (Hocking, 1985). Contrary to these reports Wignarajah et al. (1975) and Hajrasuliha (1980) in beans, Joshi (1984) in pigeon pea, Sinha et al. (1986) in Sorghum and Martinez et al. (1987) in tomato have reported an increase in Mg uptake under salt stress. On the other hand Nasr et al. (1977), Priebe and Jaegar (1978) and Chhabra (1979) have observed no significant effect of salinity on magnesium content in plum and peaches, Vicia faba, Atriplex nitens, A. calotheca and A. halimus and sunflower respectively. Atkinson et al. (1967) regarded the maintenance of magnesium in the leaves of a mangrove Aegialitis annula, as the reason for its salt tolerance. Bernstein (1975) has suggested that the salt tolerance capacity of the species is reflected by its ability to absorb nutritionally adequate level of calcium and magnesium from the soil. The present observations with D. viscosa L. are well consistent with the observations made by Atkinson et al. (1967) and agree with the suggestion made by Bernstein (1975).

6. Micronutrients :

There are very few attempts which describe the effect of drought or salinity stress on micronutrient metabolism in plants. Iron and manganese are studied relatively more by a few workers while the work on other micronutrients is very scanty.

a. Iron : Iron is one of the most important plant micronutrients. It acts as a prosthetic group for several enzymes, notably the cytochromes which function

Table:24 Effect of water stress on inorganic constituents* (Micronutrients) in root, stem and leaves of D. viscosa

Inorganic constituent	Plant part	Water stress (Days)				
		0(Control)	4	8	12	16
Iron	Root	860	1160	620	440	470
	Stem	290	200	200	200	200
	Leaf	670	370	480	370	350
Manganese	Root	40	40	30	20	20
	Stem	20	20	20	20	20
	Leaf	50	40	50	40	40
Cobalt	Root	2	10	Trace	Trace	Trace
	Stem	2	30	20	Trace	Trace
	Leaf	4	20	40	30	20
Copper	Root	1720	540	3260	620	2920
	Stem	460	420	240	420	860
	Leaf	280	300	280	280	260
Cadmimum	Root	2	2	2	Trace	2
	Stem	5	6	4	Trace	2
	Leaf	6	4	8	4	4
Nickel	Root	2	60	30	30	70
	Stem	3	50	40	40	90
	Leaf	50	30	80	40	40
Lead	Root	20	20	80	8	20
	Stem	50	70	50	20	10
	Leaf	90	40	110	90	50
Zinc	Root	84	30	38	38	120
	Stem	20	26	14	30	62
	Leaf	16	18	16	18	20

* Values are expressed as ppm.

Trace : The amount which cannot measured.

Table:25 Effect of NaCl salinity on inorganic constituents* (Micronutrients) in root, stem and leaves of D. viscosa L.

Inorganic constituent	Plant part	NaCl treatment (mM)				
		00 (Control)	25	50	100	200
Iron	Root	270	270	270	270	260
	Stem	90	70	80	90	90
	Leaf	340	370	430	450	470
Manganese	Root	40	16	18	16	10
	Stem	22	12	22	8	6
	Leaf	52	54	74	84	82
Cobalt	Root	2	2	2	80	2
	Stem	2	Trace	60	Trace	2
	Leaf	10	4	4	8	8
Copper	Root	1100	2720	500	1020	1100
	Stem	1060	1900	540	1320	1220
	Leaf	420	540	1380	420	1460
Cadmimum	Root	2	Trace	2	Trace	2
	Stem	3	Trace	Trace	2	2
	Leaf	2	2	Trace	Trace	2
Nickel	Root	2	92	58	28	34
	Stem	4	18	20	88	26
	Leaf	12	36	40	12	50
Lead	Root	4	8	22	18	18
	Stem	20	16	8	12	8
	Leaf	12	14	12	12	4
Zinc	Root	58	140	88	58	43
	Stem	64	22	24	82	84
	Leaf	18	34	78	22	80

* Values are expressed as ppm.
Trace : The amount which cannot be measured.

in respiratory electron transport and in enzymes like peroxidase and some dehydrogenases. It has a specific role in chlorophyll synthesis, because iron-porphyrin compound is formed as an intermediate of chlorophyll synthesis. Ferridoxin is an electron carrier in photosynthetic phosphorylation . Iron is also reported to be directly implicated in nucleic acid metabolism and it also plays a regulatory role in nitrogen fixation and in nitrate reduction in plants (Price, 1968; Price et al., 1972). The effect of water stress and salinity stress on uptake and distribution of this micronutrient has been recorded in Tables 24 and 25 respectively and in figure 26. It is evident from Table 24 that there is accumulation of iron in the roots of D. viscosa L. water stressed for 4 days. However, further increase in the intensity of drought causes a decrease in the level of iron in the roots. In the stem tissue also there is a decrease in iron concentration in water stressed plants. Water stress causes a reduction in the iron content of leaves. Thus it appears that due to water stress iron uptake in D. viscosa L. is affected.

Present observations well agree with the observations made by Basiouny ard Biggs (1971) and Rahman et al. (1971) in citrus and Astragalus tennensis respectively. However, Ivanov and Karakash (1985) have reported that soil moisture stress caused to increase the soluble iron content of the roots. Similar observations have been made by Jadhav (1984) in prosomillet. Gaikwad (1987) has found that the iron content in the stem of moth bean was increased after 3 days water stress and thereafter there was a linear decrease, whereas in the leaves, it was increased after 7 as well as 15 days water stress. A decrease in iron content in D. viscosa L. plant due to water stress may have a bearing on various metabolic activities. However, the changes observed in the iron content of

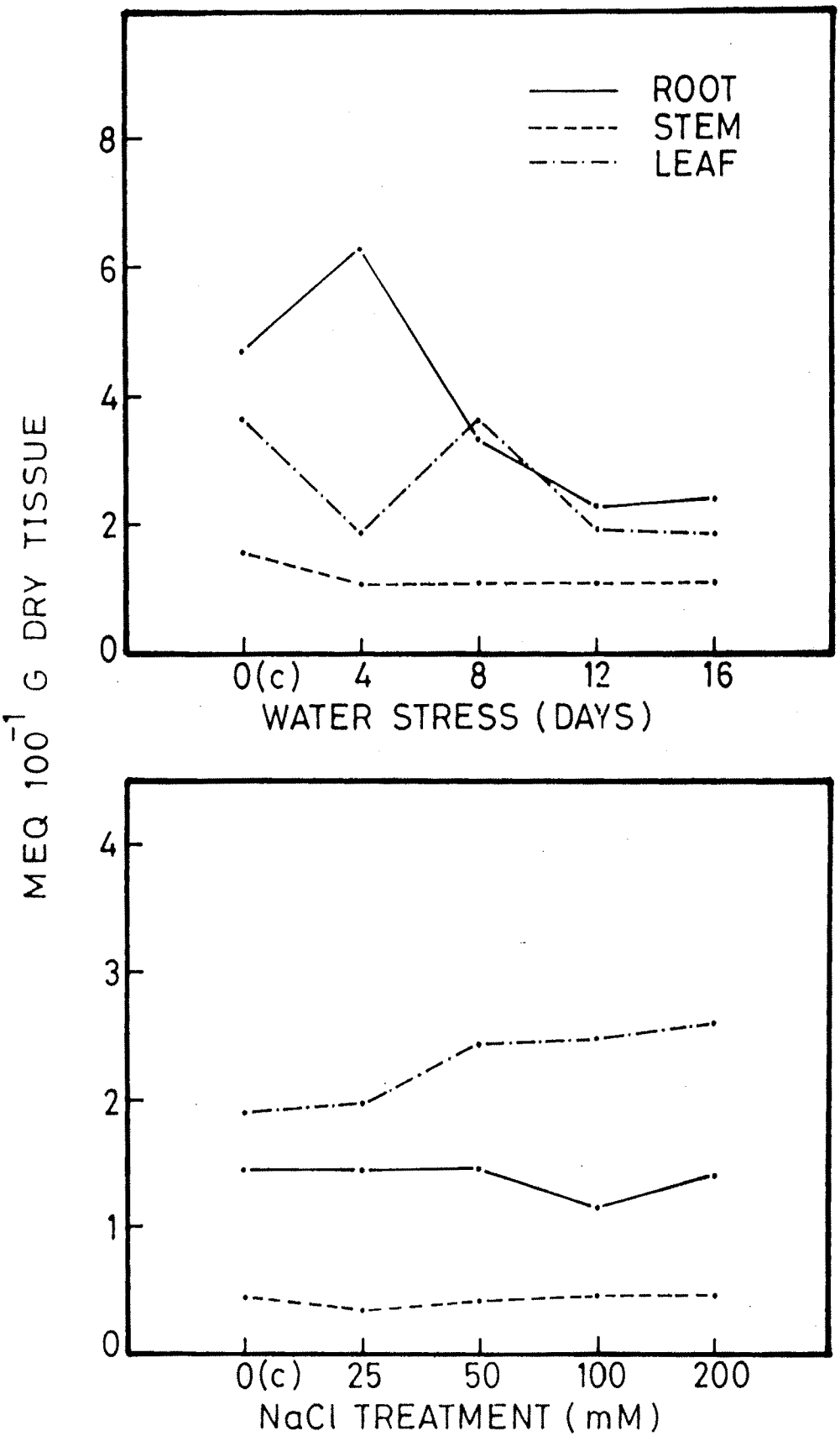

FIG.26. EFFECT OF WATER STRESS AND NaCl SALINITY ON THE UPTAKE AND DISTRIBUTION OF IRON IN VARIOUS PARTS OF D. viscosa L.

the tissue are not pronouncing so as to strongly affect the metabolic activities, particularly, respiration and nitrogen metabolism in D. viscosa L.

It is observed that there is accumulation of this metallic ion in the leaf tissue of D. viscosa L. under saline conditions (Table 25 and figure 26). It can be seen that the iron content of leaf in well irrigated plants is 340 ppm which increases linearly to 470 ppm in plants treated with 200 mM NaCl salinity. It can also be seen that the iron content of stem only slightly changes due to salinity while, in case of root, there is a slight decline in the iron level, particularly at the higher salinity levels. Accumulation of iron has been observed by Nimbalkar and Joshi (1975) in sugarcane, Dahiya and Singh (1976) in pea, Chavan and Karadge (1980 a) in peanut, and by Pandey and Kannan (1979), D. Arrigo et al. (1983) and Bhivare (1984) in different cultivars of bean, grown under saline conditions. Roots and tops of tomato, squash and soybean were found to be richer in iron content when treated with NaCl, which may be, according to Mass et al. (1972), due to abrupt changes in membrane permeability or reduced growth of the top. Recently, Karadge and Chavan (1983) have observed stimulation of iron absorption due to salinity in Sesbania species. Further, they found that iron remains to be accumulated in roots thus leaflets are kept away from the accumulation of this ion. From the results obtained with D. viscosa L., it appears that both uptake and translocation of iron are stimulated by salinity and therefore, there is accumulation of iron in the leaves. However, this increased level of iron may not be so toxic to the leaf metabolism in the species. At higher salinity level the accumulated iron in the leaf however, may exert some toxic effects.

b. Manganese : Manganese, like magnesium activates a number of phosphate transferring enzymes and plays an important role in photolysis of water in photosynthesis. Decarboxylases and dehydrogenases of TCA cycle are also activated by Mn^{2+}. Manganese brings about the oxidation of IAA by activating IAA oxidase. Manganese is also in some way involved in the oxidation -reduction processes in the photosynthetic electron transport system and indirect relationship between the influence of manganese on photosynthesis and on nitrite reduction has been shown by Hewitt (1970). The critical deficiency level for most plant species is in the range of 15 to 25 ppm Mn^{2+} in the dry matter of upper plant parts. High levels of Mn^{2+} can be toxic to plants. In case of soybean this occurs when the manganese concentration is in excess of about 160 ppm in the mature foliage(Ohki, 1977).

The manganese content of different parts of D. viscosa L. grown under water stressed and salinity stressed conditions has been recorded in Tables 24 and 25 respectively. It is clear that among the various plant parts, leaf has the highest amount of manganese in the tissue followed by root and then stem. It is evident that there is no significant effect of water stress on manganese content. It can be seen that there is almost no change in the manganese content of stem and leaf. However, the level of this micronutrient in the roots declines by 50% in the plant water stressed for 12 and 16 days.

On the other hand, as shown in Table 25, the manganese level of leaf tissue increases remarkabely under saline conditions. However, the manganese content of both roots as well as stem of D. viscosa L. sharply declines due to salinity stress. It may be due to a dual effect of salinity on Mn^{2+} uptake. Probably, absorption of manganese might have been affected by

salinity but not the translocation of this nutrient to the leaves under saline conditions.

The decrease in manganese content of the root and stem tissues is more intense than the increase in its content in the leaf tissue, particularly, at the higher salinity level.

Sakanoue and Iguchi (1968 b) carried out extensive work to study the effect of low soil moisture on growth and nutrient absorption of rice at various stages of growth. They reportec that drought increased the absorption of manganese. Working with the same plant, Pandey and Singh (1969), however, found reduction in manganese content due to moisture stress. As there is no remarkable effect on manganese uptake in D. viscosa L. under drought conditions, the species appears to be drought insensitive in this regard.

Contradictory reports are available describing the effect of salt stress on manganese nutrition of plants. A stimulatory effect of salt stress on manganese content has been reported by Hassan et al., (1970) in barley, Nimbalkar and Joshi (1975) in sugarcane, Pandey and Kannan (1979), D` Arigo et al. (1983), in beans, Chavan and Karadge (1980 a)in peanut, Wallace et al. (1982) in Atriplex species and by Fageria (1985) in rice. Adverse effect of salt stress on manganese accumulation has been observed in Italian rye grass, barley, cucumber, lucerne and spinach (Shimose, 1973), peas (Dahiya and Singh 1976), pigeon pea, (Deshpande, 1981), Atriplex hymenelytra (Soufi and Wallace, 1982) and Sesbania species (Karadge and Chavan, 1983). Martinez et al. (1987), however, did not find any effect on manganese content of tomato hybrids under salinity treatment. Present results with D. viscosa L. are also on similar lines.

c. Cobalt : Cobalt behaves in plants like other heavy metals. In similar way to iron, manganese, zinc and

copper it tends to form chelate compounds. It can also displace other ions from physiologically important binding sites and can thus decrease the uptake and mode of action of other heavy metals. Excess cobalt nutrition induces iron and manganese deficiency in plants. It is now well established that cobalt is essential for microorganisms fixing molecular nitrogen. Cobalt is thus required in the nodules of legumes, alder as well as in nitrogen fixing algae. Cobalt influences the synthesis of haem (Lafrate and Thomas, 1956) which is prosthetic group of the iron-porphyrin enzymes like catalase, peroxidase and some cytochromes (Shkovlnik, 1984).

The influence of water stress and salinity stress on cobalt nutrition of D. viscosa L. has been recorded in Tables 24 and 25 respectively. It is evident from Table 24 that the cobalt content of root and stem in water stressed plants follows an indeterminate pattern. It can be seen that due to water stress, particularly after 4 and 8 days water stress, there is accumulation of cobalt 5 times that of control in the roots and about 10 to 15 times in the stem respectively. However, it was impossible to measure the quantity of cobalt in both the plant parts after 12 and 16 days water stress. The values recorded for leaf cobalt content clearly indicate that the uptake of cobalt is remarkably stimulated due to water stress. It can be seen that cobalt is accumulated in the leaves of D. viscosa L. exposed to all duration of water stress, 10 times to the control in 8 days water stressed plants. From the results it can be said that water stress stimulates uptake of cobalt and it is mostly accumulated in the leaf tissue. The root and stem tissues show almost similar property in salt stressed plants as there is no definite pattern shown by these plant parts with respect to cobalt content. It can be seen from Table 25 that the root cobalt content

remains unaltered under saline conditions except that at 100 mM NaCl level where it is sharply, rather abnormally, increased (60 ppm). The cobalt content of stem is decreased under saline conditions except that at 50 mM NaCl level where it is abnormally accumulated. The cobalt content of leaf tissue, however, shows some notable pattern. Leaf cobalt content is decreased at all salinity levels. In conclusion it can be said that probably NaCl salinity checks the uptake and translocation of cobalt in D. viscosa L.

The present results with D. viscosa L. indicate a differential response of the species to water stress and salinity stress with respect to cobalt nutrition indicating some difference in the mechanism of stress tolerance towards physical and physiological drought.

d. Copper : Copper is taken up by the plants in only a very small quantities. The copper content of most plants is generally between 2 to 20 ppm in the dry plant material. There is evidence that copper strongly inhibits the uptake of zinc and vice-versa (Schmid et al. 1965; Bowen, 1969). Copper is not readily mobile in the plant although, it can be translocated from older to the younger leaves. Copper is a constituent of the chloroplast protein, " plastocyanin" which forms a part of the electron transport chain linking the two photochemical systems of photosynthesis. Cytochrome oxidase, ascorbic acid oxidase, polyphenol oxidase and laccase are copper containing enzymes. Recent experimental data suggest that the desaturation and the hydroxylation of fatty acid is also catalysed by copper containing enzymes (Wable and Davies,1977). Copper appears to participate both in protein and carbohydrate metabolisms. Observations of Hallsworth et al. (1960) suggest that there is a specific requirement for copper in symbiotic nitrogen fixation.

There is almost no work on fate of this divalent cation, a metallic iron in plants under stress conditions. A decrease in copper content as a result of salt stress has been reported in barley (Hassan et al. (1970), corn (Bhatti and Sarwar, 1977), Atriplex hymenilytra (Soufi and Wallace, 1982) and beans (D` Arrigo et al., 1983; Bhiware, 1984). The observations made by Fageria (1985) in rice and Gaikwad (1988) in millet species under saline conditions are contradictory to these reports.

Table 24 records the copper content of root, stem and leaf of D. viscosa L. grown under well irrigated and water stressed conditions, while, the effect of NaCl salinity on copper content of various parts of the species has been recorded in Table 25. It is evident that water stress has no consistent effect on the copper content of root. It can be seen that after 4 days of water stress there is a sharp decrease in the copper content but in the root exposed to 8 days water stress, it is tremendously increased, where it is almost doubled. The same pattern of decrease and again increase in the copper content of root is observed. The values of copper recorded for stem indicate that with increasing intensity of drought there is decrease in copper content except, that in the plant, water stressed for 16 days, where it is sharply increased by about 100% over control. On the other hand, leaf copper content appears to be least affected by water stress. In conclusion it can be said that water stress does not lead to induce any copper deficiency in D. viscosa L. Maintenance of copper level in leaf tissue under drought conditions can be considered as an adaptive feature of D. viscosa L.

The response shown by D. viscosa L. with respect to copper uptake to salinity stress slightly differs from that shown to water stress. It can be seen from the values in Table 25 that with few exceptions

the copper content of all the plant parts is increased due to NaCl salinity. This is quite significant in the leaves, followed by stem and to some extent in the roots. Thus, under saline conditions plant has shown an ability to absorb copper more and retain it in the leaf tissue. It is also apparent from the results that the patterns shown by copper under drought are more or less similar to those shown by iron and manganese. Same situation also prevails when the plant is grown under saline conditions.

Thus copper accumulated in different parts of D. viscosa L. does not affect the uptake and translocation of iron and manganese. Thus the changes observed in these micronutrients in D. viscosa L. plants under stress conditions are not unfavorable.

e. Cadmium, Nickel and Lead : There is considerable current interest in cadmium in plant nutrition. Cadmium and zinc are chemically very similar. Cadmium is thus able to mimik the behaviour of essential element zinc in its uptake and metabolic function. Unlike zinc, however, Cd is toxic both to plants and animals. In plants, excess Cd may also disturb Fe metabolism and cause chlorosis. Cd differs markedly from lead in that it can be transported readily from the soil via the plant root to the upper plant parts. Its availability depends much on soil pH and the presence of other cation species. The uptake of Cd is probably a passive process and the movement in the plant resembles that of Ca^{2+}. Cd is considered to be a highly dangerous pollutant which brings about hazards in animals.

Nickel is closely related to Cobalt both in its chemical and physiological properties. High nickel concentrations have toxic effects on plants. Normally the Ni content of plant material is about 0.1 to 5 ppm of the dry matter. Toxic symptoms in oats, a Ni

sensitive crop, were observed in plants with Ni contents in excess of 100 ppm (Crooke, 1956). Ni appears to be mobile, particularly in the phloem. The biological significance of Ni as possible micro-nutrients has been reviewed recently by Welch (1982). Ni probably plays a role in nitrogen fixing legumes.

Lead is a major chemical pollutant of the environment and is highly toxic to man. Lead taken up by plants is accumulated in cell wall and this may well protect the cell from the toxic effects. Foy et al. (1978) have suggested 0.5 ppm as the normal level of lead in plants.

The influence of water stress and salinity stress on uptake and distribution of Cd, Ni and Pb in D. viscosa L. has been recorded in Tables 24 and 25 respectively. It can be seen from Table 24 that there is no much influence on the uptake of cadmium by water stress. The cadmium content of root, stem and leaf remains almost unaltered during drought conditions except that there is some decrease in the cadmium content of root and stem after 12 days water stress. Leaf cadmium content also shows a depression at intense drought conditions. Almost similar trend is shown by cadmium in D. viscosa L. under saline conditions (Table 25).

It is interesting to note that the uptake of Ni is stimulated remarkably by both stresses. It is clear from Table 24 that there is tremendous increase in the level of Ni in the root and stem of D.viscosa L due to water stress. However, leaf Ni content remains almost steady under drought conditions. From the values recorded in Table 25, it is clear that Ni is heavily accumulated both in root as well as in stem under saline conditions. Eventhough there is increase in the level of Ni in the leaf tissue, it is not so vigorous to that seen in roots and stem. Eventhough, there is such tremendous accumulation of Ni in all plant parts

of D. viscosa L. under stress conditions, nowhere it is crossing the level of 100 ppm, the concentration suggested to be a critical concentration to produce toxic symptoms in plants (Crooke, 1956).

The lead content of root, stem and leaves of D. viscosa L. grown under drought and salinized conditions has been recordec in Tables 24 and 25 respectively. It is evident that there is nowhere accumulation of this heavy metal in plants exposed to drought conditions. However, leaf appears to be the site of accumulation of this pollutant under both normal irrigated and water stressed conditions. Under saline conditions there seems to be accumulation of Pb in the roots but, since there is a decrease in the level of Pb in stem as well as leaf tissue, there is retardation of uptake of Pb under saline conditions.

f. Zinc : The levels of zinc in plant material are low and generally in the order of upto 100 ppm in the dry matter. Zn uptake is an active process. Copper in the nutrient medium strongly inhibits Zn uptake. Similar competitive effect of Fe and Mn on Zn uptake have been reported. High levels of phosphorus supply induces Zn dificiency.In its function, in some enzyme systems Zn resembles Mn and Mg in that it brings about the binding and conformation between enzyme and substrate. A number of enzymes including enolase are thus activated in more or less the same way by Mn , Mg or Zn. Number of Zn-metalo-enzymes have been recognised. These include number of dehydrogenases, in particular, glutamic acid dehydrogenase, lactic acid dehydrogenase, alcohol dehydrogenase as well as proteinases and peptidases (Valleo and Wacker, 1970). Zinc is closely involved in the nitrogen metabolism of the plant. Formation of indolacetic acid is indirectly influenced by Zn through tryptophan synthesis (Tsui, 1948). According to Jyung et al. (1975), Zn has a possible

role in plant metabolism involved in starch formation. Zn along with Cu has been shown to be a constituent of the enzyme superoxide dismutase. This enzyme brings about the decomposition of oxygen radicals which can be produced from molecular oxygen. It thus protects aerobic organisms from attack by oxygen radicals.

The effect of water stress and NaCl salinity on Zn nutrition of D. viscosa L. has been recorded in Tables 24 and 25 respectively. It is evident from Table 24 that the Zn content of roots sharply decreases due to water stress for 4 to 12 days. However, it is sharply increased in the plants water stressed for 16 days. The amount of Zn in the stem tissue is more or less increased due to water stress even upto 16 days water stress. Leaf Zn content also follows similar trend. It appears that the total amount of zinc absorbed by the plant is decreased due to water stress for 12 days. However, there is increase in the total amount of Zn in the plants severely water stressed (16 days). Heavy uptake of this micronutrient due to prolonged water stress upto 16 days may be due to disruption of root cellular membrane leading to passive uptake of various ions.

From table 25 it is clear that with increasing level of NaCl salinity in the medium there is accumulation of Zn in the roots of D. viscosa L. However, at the highest salinity level it is considerably decreased. On the other hand Zn content of the stem tissue is decreased in plants stressed at 25 and 50 mM NaCl concentrations. Higher concentrations have stimulated the uptake of Zn and its accumulation in the stem. It is interesting to note that Zinc is heavily accumulated in the leaf tissue due to salinity at all concentrations. It appears that on an average, the uptake and translocation of this divalent metallic cation in D. viscosa L. is stimulated by NaCl salinity.

Bradshaw et al. (1965) have reported that Zn content of bean tops and rye grown on Sassfras loam were 112 and 93 ppm, respectively, while that of the same plants grown on collangton loam were five times higher, 551 and 456 ppm respectively. Accumulation of zinc as a result of salt stress has also been reported by D` Arrigo et al. (1983) in beans and by Martinez (1987) in tomato hybrids.