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Salt affected soils of various types in irrigated areas cover about 20 million hectares (49,42 million acres). This is equivalent to all irrigated land in the USA and USSR combined.

These figures of salt affected soils, with their progressive increase under irrigation practices, will definitely lead to a tremendous reduction in food and fiber production unless proper soil management and soil reclamation programs are immediately undertaken.

The other side of the problem is to meet, given the limited water resources available, the necessary food demands which are increasing at a very high rate. Superficially, it might appear that increasing the amount of cultivated land would offer the best solution to the problem. However, the scarcity of fresh water resources needed for putting the new areas under cultivation makes the problem even more complicated.

In this respect, the utilization of water resources other than fresh ones is a must. In the meantime, if such water is used for irrigation without the proper management, it could have negative effects on crop production as well as contributing to the deterioration of soil productivity due to the side-effects on the physico-chemical characteristics of soils.

Thus, if it is planned to use low quality water on a large scale in irrigation, the complex interaction of soil management, water quality and its management and the agronomics of various irrigation methods, as well as the capacity to manage the salinity problems, must be well developed and fully understood beforehand.

The success of such plans requires the development of new strategies for using low quality water in irrigation, assessed on scientific, practical and economic bases. Such strategies should include climatic, soil and crop factors to eliminate as far as possible the drawbacks on crop production and soil characteristics.

In 1984, the Bari Institute started a research programme on the use of saline water in irrigation including the following main topics:

– the influence of irrigation with saline water of different salt concentration levels on the growth and yield of some main crops in the Mediterranean area;

– the mode of saline water application;

– salt accumulation and its distribution in the different soil layers under saline water irrigation using different irrigation methods;

– leaching the accumulated excess salts using fresh water as well as water of low quality.

This paper will summarize the experimental work included in the programme and the results obtained by giving some outlines which could be utilized as far as we are concerned for establishing a new strategy for the use of low water quality in irrigation.

I - Salinity and plant growth

Salinity exerts a variety of effects on plant development and output quality, depending on factors such as the nature and amount of soluble salts, the crop variety and its different tolerance to salinity and the various development stages, the atmospheric conditions because of their effect on the evapotranspiration rate, and the irrigation management (Koikor *et al*, 1976; Bower, 1976; Ingvalson *et al*, 1976).

Salinity effects can be considered under three general categories:

i) general growth suppression,

ii) growth suppression caused by nutritional imbalance of essential ions, and

iii) growth suppression caused by ions of toxic nature.

There is no infallible way to rigidly separate these categories. Each category could be a major cause of growth suppression individually and all could contribute collectively to various degrees.

1. Seed germination and seedling establishment

The germination or seedling stage is the most sensitive stage to saline water irrigation. It is usual that with increasing salinity or SAR, or both, of irrigation water, germination is delayed as well as reduced. The reduction in germination under saline conditions could be due to increased osmotic pressure of the soil solution, which consequently reduces the absorption rate thus causing moisture stress in the seed. It could also be due to the influx of ions in quantities large enough to make them toxic to the seed embryo.

There are different responses for germination between varieties of the same plant. Some varieties are more tolerant at germination compared to others and varietal differences are so wide that some varieties may fail to give good germination even at an EC of 4 mmhos/cm, whereas the others may do well up to 20 mmhos/cm. It is not necessarily true that varieties which are tolerant at the germination stage will do equally well in final yields.

In view of this discussion it is important to know the critical limits of the degree of salinity of irrigation which may not adversely affect the germination of a particular crop or variety. Equally, the identification of the varieties that give high yields under saline conditions rather than those which show a high germination percentage should receive prior consideration.

In this respect, part of the programme was devoted to providing more information concerning the aforementioned aspect. A pot experiment was conducted on a fine textured soil using ten different field crops with variable salt tolerance degrees, irrigated with water of various salt concentration levels of EC values 4, 8, 12 and 16 mmhos/cm plus a control treatment irrigated with fresh water of EC value 0.9 mmhos. The crops were selected covering the range of salinity tolerance from the highly tolerant barley to the highly sensitive carrot (Mass, 1984).

After germination, the seedlings were assessed for growth after one month. This was measured in terms of leaf area and dry matter, vegetative and root production. The seed germination percentages for the crops as a function of salinity level in irrigation water are illustrated in **Figure 1**. The results obtained from this study could be summed up as follows :

– irrespective of variety, tolerance to salinity in general is in the order: barley, wheat, corn, broad beans, sugarbeet, tomato, onion, peas, carrot, lettuce.

– saline water up to 4 mmhos could be used safely for the majority of tolerant and moderately tolerant field crops without deterioration in terms of reduction in germination. However, this does not necessarily mean that crops which are tolerant at the germination stage up to this level of water salinity, will do equally well in final yields. On the other hand, with sensitive field crops a greater amount of seed application is needed to maintain a higher plant population as a safeguard against some failure, poor tillering and losses in germinated seeds.

– three grain plants, barley, wheat and maize, showed modest reduction in germination with increasing salinity, and even at the highest salinity level (16 mmhos/cm) more than half of the seeds germinated. With the other crops, germination tended to decline drastically at salinity levels above 8 and 12 mmhos, depending on the plant in question. The most sensitive plants did not germinate at all over 8 mmhos.

The influence of salinity on seedling development was assessed by measuring the leaf area (**Table 1**) and the dry matter production divided into the vegetative and radical parts (**Table 2**). Comparing the behaviour of those parameters under different saline irrigation treatments, we came to the following conclusion:

– leaf area and dry vegetative production were found to decline with increasing salinity, particularly in the case of more sensitive plants, whereas there were notable variations in leaf areas and vegetation depending on the plant. Root production showed an even greater reduction for all plants in relation to irrigation water salinity.

Examining the ratio between vegetation and root production, it was found that:

i) barley showed little decrease in vegetative production with respect to root production, indicating a specific salt tolerance mechanism;

ii) sugarbeet, wheat, tomato, corn and broad beans maintained a fairly constant ratio in their vegetative and root production with increasing salinity. This is evidence of their attempt to maintain equilibrium in the face of increasing salinity which gives them relative tolerance to moderate salinity levels;

iii) lettuce, pea, onion and carrot showed relatively greater reduction in root development than in vegetation even at modest levels of salinity. This indicates a state of disequilibrium under saline conditions whereby the root system is unable to support effective plant growth.

In principle, the data obtained in this experiment are in agreement with those of Maas (1984). However, such data could not, in general, be applicable under different field conditions. The plant response to an EC increase is not only affected by the soil physical properties but also by other factors such as climate (Magister *et al.*, 1943), relative humidity (Hoffman *et al.*, 1978), nutrient solution composition (Kafkak *et al.*, 1971), and water stress.

Another point which should be considered with great care is that salt tolerance data were obtained under certain specific conditions of salt uniformity distribution in the soil profile and surface irrigation. Will such data have the same validity by changing from surface to drip or sprinkling irrigation, and if there is lack of uniformity in salt distribution within the soil profile? The fact that classification of plants into groups according to their tolerance degrees was based on planting seeds in a non-saline seedbed and imposing salinity after the seedlings have emerged does not satisfy the arid and semi-arid regions where brackish or saline waters are to be used even at the seedling stage.

The stage of germination and emergence of the seedlings is of vital importance because a failure at this stage generally leads to a poor stand and a considerable yield decrease. We need more field experiments for more available data, including the possible interaction effects of all the factors influencing the results under the complex conditions in the field.

Passing from the germination and seedling stage to the other advanced growth stages, the programme included several experiments on some of the predominant crops in Mediterranean countries.

The experiments included elucidation of the influence of irrigation with waters of different salt concentration levels applied in variable modes on the growth of several crops (broad bean, wheat and cotton).

The influence of irrigation with waters of EC values 0.9, 4, 8 and 12 mmhos/cm applied with different application modes, either by its alternation with fresh water at different proportions or directly without any fresh water alternation, on leaf area and dry matter production for beans and wheat are shown in **Tables 3** and **4** respectively.

The development of roots under the different irrigation treatments for wheat (**Table 5** and **Figure 2**) and for beans (**Table 6** and **Figure 3**) was also studied.

From this series of experiments we came to the following conclusions:

– in general, in both wheat and beans, the relative leaf area is influenced not only by the salt concentration in irrigation but also by the mode of water application. Alternating fresh and saline water in proportions of 60%/40% provoked minimal reduction in leaf area of both beans and wheat with respect to the fresh water treatment. Moreover, if such alternation is not practicable, a single fresh water irrigation at seedling is sufficient to neutralize a large proportion of the salinity damage.

– not all the plants are equally influenced by salinity: the results regarding the dry matter production of both vegetative and radical parts indicated that wheat is resistant up to 8 mmhos/cm, while beans only tolerate 4 mmhos/cm.

– if we are to use saline water in irrigation, it is important not only to determine the salinity of the water with respect to the crop we wish to grow, but also how to manage effectively such water. Obviously, the best results are to be obtained by alternating as much fresh water as possible with saline water, but even if the saline percentage is as high as 60%, good crop yields can nevertheless be maintained. If frequent alternate irrigations with fresh water are not feasible, it is important to irrigate at least once at the seedling stage to allow the young plants to develop a sufficient root system to resist salinity at later stages of development and to gain access to deeper soil layers where salinity is generally lower than at the surface.

Another experiment was conducted on wheat as it is one of the major field crops in the Mediterranean area. Besides, it is considered as a moderately tolerant crop which could resist a relatively high salt concentration level in irrigation water.

In this experiment wheat was subjected to continous irrigation with saline water of variable EC values between 1 and 12 mmhos/cm. Two modes of water application were tested, i.e. surface and sub-irrigation from the bottom of the pots using mixtures of saline water and fresh water in different proportions, and alternate application of fresh water and saline water from the surface only.

Straw dry weight, root dry weight and wheat grain yield, g/pot, are given in **Tables 7, 8** and **9** for the three aforementioned parameters respectively.

This experiment gave further indications to one of the points which was tackled by several investigators (Allison, 1964; Ayers and Wescot, 1985; Rhoades, 1977, 1984; Van Schilfgaard and Rhoades, 1979) and which is strictly related to improving irrigation water quality. The point which is still under question is: in order to improve water quality, is it better to alternate water application of low and good water quality or to blend high salt waters with relatively low salt waters?

The data obtained favour alternate water application.

Let us consider the situation in Egypt where two major water resources for irrigation are available: one of good quality (River Nile water) and the other one of low quality (drainage water) amounting to nearly half the quantity of the available fresh Nile water. In regard to this, to utilize both water resources successfully, we have two possibilities. The first is to blend the two water resources at a certain ratio to get an allowable salt concentration level in the final mixture. The second is to use both water sources separately by alternating them. We are in the cycle of the latter approach for the following reasons:

A. If we have water of good quality it is not reasonable to deteriorate its quality by mixing. Such water could be used at the time it should most be needed, for instance, at the germination and seedling stages which are very sensitive to the salinity level of irrigation water. The failure to establish a well developed seedling will definitely lead to reduced yield. The continuous irrigation with water of differents salt concentration levels will result in salt accumulation in soils in quantities proportional to the degree of salinity in irrigation water. To bring the soil to the permissible salt concentration level, the excess salts must be leached out and this requires waters of relatively good quality.

B. Blending water needs the construction of big reservoirs for mixing, besides frequent measurements for checking the salinity level. This is economically costly and practically tedious.

C. With the plants which are sensitive to the salinity level in irrigation waters, satisfactory production could only be achieved with water of good quality through alternative application modes. The disadvantages appearing under mixing could be completely eliminated and offer a free-hand possibility in using the different water resources according to the prevailing conditions.

The cyclic use of water of low and high salinity prevents the soil from becoming too saline while permitting, over a long period, the substitution of brackish water for a better quality water for a substantial fraction of the irrigation needs.

Blending will not reduce the total salt load, but may allow more cropping area to be planted because of the increase in water volume caused by dilution.

However, the matter is not simply the alternation of water resources. A suitable cropping pattern is also required that allows the substitution of saline water by normal water to irrigate certain crops in a suitable tolerant growth stage. Indeed, the timing and amount of possible substitution will, of course, vary with the quality of the two waters, the cropping pattern, the climate, certain soil properties and the irrigation system.

Returning again to our experiment in a trial to evaluate the two irrigation systems, surface and sub-surface irrigation data declared that when irrigating with waters of EC values exceeding 8 mmhos, the studied parameters were highly and/or significantly influenced under both surface and sub-irrigation treatments, but these influences are always greater under the surface irrigation treatments than under the sub-irrigation ones. The roots as well as the shoots were much more developed under sub-irrigation rather than under surface irrigation and this was not only evident under saline water treatments but also where irrigation was practised with fresh water.

Under sub-irrigation, by virtue of the water movement from the bottom to the surface by capillary action, all the salts are carried to the surface layer freeing the active rootzone from salt burden so as to allow better plant development. Moreover, under this system, the soil is kept under a constant moisture level, hence the losses in water due to evapotranspiration will be compensated for by the upward movement due to the difference in the moisture gradient between soil layers.

In cases where low quality water has to be used, sub-irrigation can be a better choice, but at the end of the season the soil must be flushed with enough water to wash down the salts already accumulated in the surface layer.

This could be the case when we have a water table near the root zone and it is the main source of supplying the growing plants with their water requirements without carrying out any supplementary irrigation. But the situation will be complicated if such conditions are prevailing and irrigation is practised. However, it should always be borne in mind that the tolerance degree of plants, the salinity degree of the water table, as well as the soil physical characteristics (including the effective root zone depth) are the main factors governing the success or failure of the sub-irrigation technique.

II - Salinity and salt accumulation and distribution in soils

A knowledge of the effect of irrigation water on soil properties is of utmost importance in order to maintain good soil productivity. Another part of the programme was devoted to the analysis of the soil after continuous irrigation with water of various salt concentration levels during the growing period of the different investigated crops. This was designed to elucidate the variation in salt accumulation and distribution through different soil depths as a function of the mode of water application and the irrigation methods.

Salt distribution and the SAR values in different soil depths under different irrigation treatments are given in **Figure 4** and **5**.

Soil analysis indicated that the mode of application of the irrigation water was found to be influential, since the alternation of fresh and saline water not only gives rise to a lower general accumulation of salts, but also to a more even distribution of salts throughout the different layers of the soil. The alternate application reduced salt concentation about 1.6 to 2.8 times relative to that in the saline irrigation alone. This stresses the importance of effective irrigation management in reducing the danger of excessive saline build up in soil.

Salt accumulation, like its distribution through the different soils depths, was gradually increased with the excessive increments in the salt content of irrigation waters. The average SAR was always less than 15 indicating the onset of dangerous salinity and/or alkalinity. However, it should be stressed that relatively high, though essentially safe, SAR values were reached after only three months of irrigation, indicating once again that good irrigation management is required in the long term to prevent further SAR increase.

1. Salinity and irrigation methods

The irrigation practices which are important in the management of saline water could be outlined as: scheduling (amounts and intervals), irrigation methods, and management of multi-source irrigation water of different qualities.

Among the different irrigation methods, trickle irrigation has received the attention of several workers under saline water practices as it provides the best possible conditions of total soil water potential for a given quality of irrigation. It also has the advantage of avoiding leaf injury which is the principal problem encountered with sprinkler irrigation.

A detailed study was therefore included in our programme to evaluate the changes that could take place in the growing parameters of maize (Ze. Mais L.) and its yield under saline irrigation practices using drip irrigation and traditional surface irrigation methods in different soil textures. Moreover, salt accumulation and its distribution pattern in the different soil depths under the two irrigation systems were studied besides following the build up of salinity after each water application. This was done by sucking the soils solution at different soil depths at different distances from the dripper under trickle irrigation and at different soil depths under the surface irrigation.

The influence of soil type, water salinity and irrigation methods on the maize growing parameters and its yield are illustrated in **Figures 6**, **7**, **8**, **9** and **10** for LAI, plant height, plant dry matter, root dry matter and grain yield.

Comparing those figures as a reflection of plant development we get an overall idea of the way salinity and the method of irrigation affect plant growth and yield.

Under surface irrigation with fresh or slightly saline water, root development is moderate and general growth is good. Indeed, there is some evidence that slight salinity stimulates more roots and foliage, though the benefit in terms of grain yield is only evident in clay soils. If the salinity of the irrigation water reaches 6 mmhos/cm, root development is a little inhibited, but general plant growth, as measured in total dry matter and leaf areas, remains good, particularly in clay or sandy clay soils. Foliar growth under this treatment is noticeably poorer in sandy clay loam, but grain production is unaffected and remains fairly high in all soils with irrigated salt concentration up to 6 mmhos/cm.

Above this level of salinity, at 9 mmhos/cm, root growth under surface irrigation remains quite good, but it supports short leaf plants that do not develop good grain heads.

The same qualities of water applied with the drip technique produce distinctly different results. At low salt concentrations the overall dry matter produced is comparable to surface irrigation, but root growth is much more pronounced as roots grow to seek out soil of relatively lower salinity, particularly in sandy clay loam. Leaf area is proportionately lower, but grain production is comparable, and may even be a little better if there is a little salinity and the soil is sandy clay. At the highest water salinity levels, grain production also remains higher than under surface irrigation, even though root and general dry production are greatly reduced.

All in all, comparing the two irrigation methods, both surface and drip application proved effective when using water of low salinity.

At relatively high salinity levels, such as 9 mmhos/cm, drip irrigation provided substantially better grain yield than surface irrigation. The better response of grain yield at relatively high salt concentration levels under drip rather than surface irrigation could be attributed to the variation in salt accumulation and its distribution pattern in different soil depths under the two investigated irrigation systems (see **Table 10**).

The general distribution of salts reflected in the EC values obtained after the harvesting of maize, indicates that surface irrigation was found to lead to accumulation of salt principally in the deepest soil layer, followed by the surface layer and finally by the intermediate layer. This is an effect of the wetting-drying cycle which produces a gravitational movement of salts downward when the soil is saturated, and a capillary upward movement as the soil dries out. Under drip irrigation, on the other hand, much higher concentrations were found in the surface layer, followed by the bottom layer, and then the intermediate layer. Although the accumulated salts showed a similar distribution pattern under the two irrigation systems, there is a notable difference in the degree of salt accumulation within the different soil layers. With drip irrigation the intermediate layer as well as the one at the botton had an EC value nearly 50% lower than those under surface irrigation, especially in the lighter textured soils.

Another point which results in such variations of plant growth parameters and yield production is how the salts are built up and their distribution vertically and horizontally by successive saline water irrigations under surface irrigation (**Figure 11**) and drip irrigation (**Figures 12** and **13**).

In view of the results obtained, we came to the following conclusions:

– salt distribution and its accumulation in soils is not only dependent on the system of irrigation but also on the soil texture as well as the salt content of the irrigation water. The final salt distribution pattern is a result of the complex interaction between the three variables combined together.

– in surface irrigation at 15 cm depth, the EC increased sharply but this was not noted at some depths, indicating that most of salts remain in the upper layer.

– with drip irrigation, the EC value 5 cm from the dripper showed greater accumulation of salts than at 17 cm from the dripper. This was the case with the two different soil depths of 15 cm and 30 cm respectively, although the majority of salts remained in the former layer.

The data concerning salt accumulation and its distribution under cropping or in the uncropped soils clearly indicate that with drip irrigation we can keep the soil moisture continuously high, at least in part of the root zone. This maintains a low salt concentration level and this results in leaching the zone below the tricklers. The roots of the growing plants tend to cluster in this leached zone of high moisture near the tricklers and so they avoid the salt that accumulates at the wetting front, resulting in relatively good crop production. However, by using saline water in irrigation regardless of the irrigation system, we are faced with salt accumulation which must be moved away from the active root zone. The last part of this programme was therefore devoted to salt leaching.

2. Salinity and leaching practices

Generally, continuous and intermittent practices are the two methods used for leaching accumulated salts. Nowadays, as drip irrigation is widely spread, it is intended to examine the validity of this system in removing the excess accumulated salts in saline soils beside elucidating its utility in this respect as compared with the traditional leaching methods.

In this respect, soil columns of different Ec values 5.8 and 25 mmhos/cm were subjected to successive leachings with distilled water, using the classic constant head submersion technique and the drip irrigation technique to judge the relative efficiency of the two methods.

In spite of the simplicity of this experiment, it provided additional information that could be summarized as follows:

– of the two leaching techniques, the drip application system was found to be more efficient than the traditional submersion method in leaching the total salt content of the columns up to a salinity level of around 25 mmhos/cm, beyond which submersion gave better results (**Figure 14**). Moreover, the results show that the first two leachings are responsible for the removal of the great majority of the salts initially present in the soil, irrespective of the soil salinity level. This indicates that a wise soil management policy can maintain soil salinity within acceptable levels without using large quantities of valuable non-saline water.

– leached soils, even those of very high salinity (25 mmhos/cm) arrived at EC values well below the marginal saline value of 4 mmhos/cm, whatever the technique used, with a uniform EC distribution in the different layers in the case of submersion and a gradual increase towards the bottom with the drip irrigation technique (**Figure 15**).

Another trial was carried out in soil columns where the soils were packed in a way identical to that existing before the leaching in order to represent, to some extent, the actual field conditions (**Figure 1**). Leaching was then carried out with constant head and drip technique using saline water of EC 3, 6 and 9 mmhos/cm.

The comparison of EC values before and after leaching is of particular interest and is shown for the two application methods in **Figures 3** and **4**.

Data indicated that whatever the original salinity in the soil was at different depths, the salt quantities after leaching were unifrom, on average, for all soil depths and soil types similar to those of the leaching water. This means that saline water can indeed prove useful for leaching salinity from soils, irrespective of soil type, but residual salinity will always remain at a level comparable to that of the water utilized.

However, there are two main principles that should be carefully considered when leaching with water of low quality: first, the leaching water must be of EC value lower than that of the soil EC, and second, frequent tests should be performed on soils under leaching bearing in mind that the target to aim at is a soil salinity equivalent to that of the water to avoid the potential danger of reintroducing salts by excessive leaching.

III - Conclusions and outlook for the future

Data and results from this series of studies provide evidence of the potential of using low quality water for irrigation. Taking the prevailing condition in Egypt as an example, if the huge bulk of drainage water were used in irrigation, it would permit a notable expansion in the cultivated irrigated area and would satisfy a great part of the demand for food and fibres in Egypt.

Greater attention has recently been paid to this subject, especially in arid and semi-arid regions. The use of alternative water resources is thus now a must in these areas due to the scarcity of available fresh water resources. However, in spite of the vast information now available on how to manage such waters successfully to minimize the drawbacks on crop production and soil characteristics, several points still need to be cleared up.

Information on the consumptive use of many crops is available for irrigation with non-saline waters. The question arises whether such information could be applied or not to brackish waters. If not, what adjustment needs to be made?

Under brackish water practices, it is not clearcut and it is still controversial whether the reduction in osmotic potential causes the same reduction in yield as an equivalent reduction in matric potential and whether the reduction in growth yield due to salinity is the cause of reduced water consumption or *vice versa*.

Plant growth is a function of the salinity and matric potential of the soil water; while salinity could be controlled by leaching, the matric potential is controlled by an adequate and timely water application. In this regard, the question arises whether it is necessary to narrow the interval between waterings in order to keep the concentration of soil solution at a lower level so as to diminish the harmful effect of the salt, or, on the contrary, if it is possible to make the interval longer and to apply large amounts of water.

Concerning leaching of excess accumulated salts in soils, the question arises if we should leach accumulated salts periodically when salt accumulation in soils becomes excessive, or if leaching should be done at every irrigation.

The last point, which has a vital role in salinity control, is to identify clearly the irrigation method to be used taking into consideration the prevailing irrigation conditions.

In our opinion, in order to get the maximum benefit from such water, strong cooperation is urgently needed between scientists of soil science, plant breeding, plant physiology, hydrology and socio-economics in order to assess, in scientific and practical terms, the technology and potential of using low quality water in irrigation for sustained production on a permanent economic basis.

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Figure 1: Germination percentage of different field crops under different salt concentration levels in irrigation water

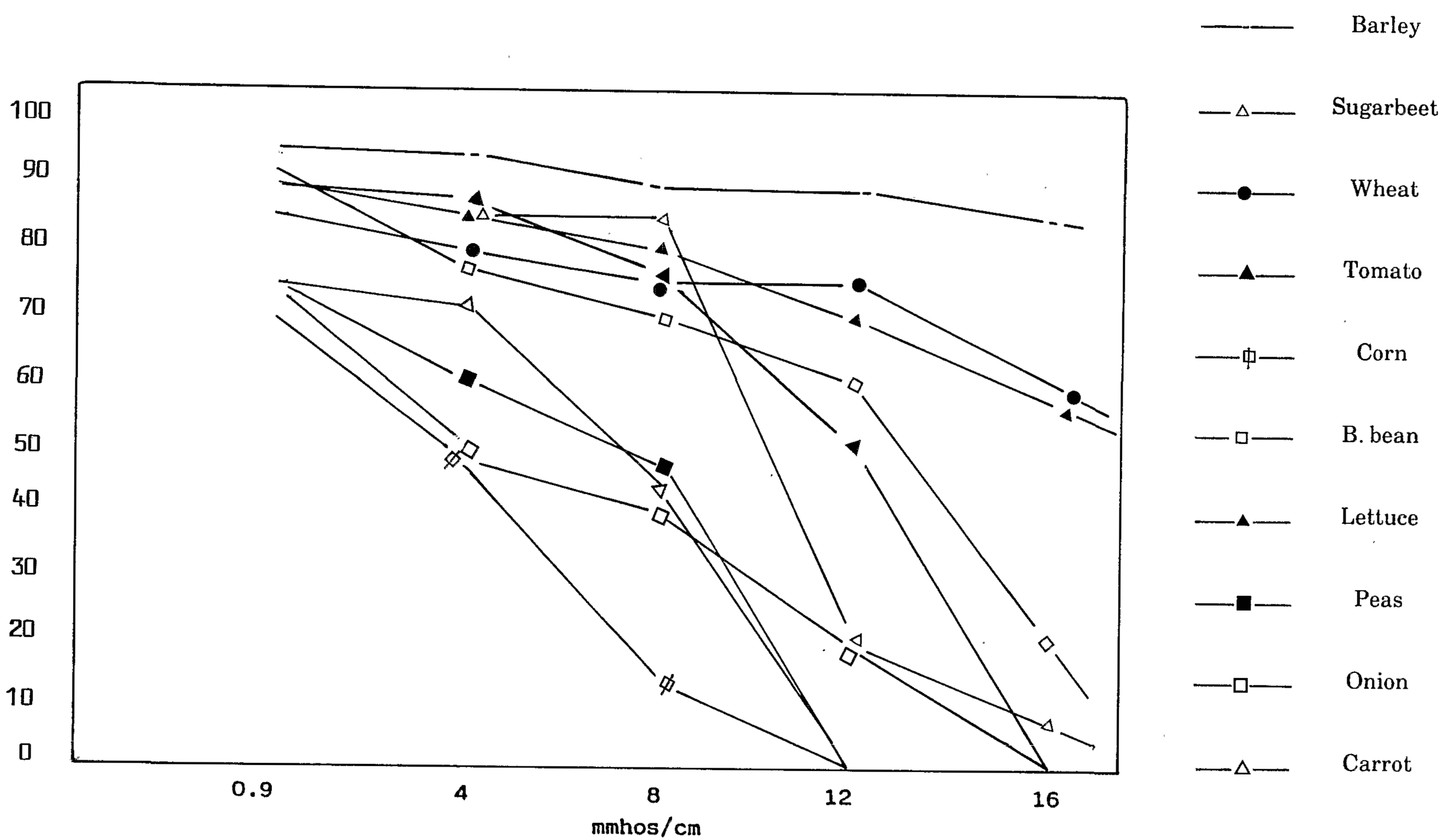


Table 1: Leaf area (cm2/plant) under different salt concentration levels

Crop	Salinity level in mmhos/cm (25° C)				
	S_0 0.9	S_1 4.0	S_2 8.0	S_3 12.0	S_4 16.0
Barley	25.70	27.46	25.67	22.48	18.29
Sugarbeet	19.51	20.16	19.12	26.76	13.60
Wheat	26.49	19.89	20.61	15.10	13.09
Corn	37.84	36.60	32.83	20.70	4.96
Tomato	15.71	11.17	7.24	5.10	- -
Lettuce	45.58	45.71	22.29	- -	- -
Broad bean	66.65	61.39	42.74	23.48	17.40
Pea	79.79	72.77	39.21	- -	- -
Onion	6.31	4.36	1.36	- -	- -
Carrot	11.34	8.03	3.96	- -	- -

Table 2: Dry weight of vegetative and radical part of the seedlings under different irrigation treatments

Crop	Salt concentration levels									
	S_0		S_1		S_2		S_3		S_4	
	Veget.	Root	Veget.	Root	Veget.	Root	Veget.	Root	Veget.	Root
Barley	1.60	1.48	1.67	1.13	1.72	0.92	1.38	0.87	1.18	0.53
Sugarbeet	2.77	1.20	2.73	1.22	1.74	0.75	0.99	0.22	0.31	0.27
Wheat	0.88	1.12	0.87	1.07	0.75	0.85	0.43	0.71	0.22	0.31
Tomato	2.69	0.85	1.87	0.41	1.13	0.28	0.38	0.08	- -	- -
Corn	2.84	1.92	2.67	2.11	2.14	1.54	1.15	0.73	0.20	0.14
Broad bean	4.68	2.25	3.19	1.75	2.79	1.38	1.12	0.64	0.42	0.32
Lettuce	2.76	0.92	0.89	0.66	0.53	0.09	- -	- -	- -	- -
Pea	2.06	1.23	2.24	0.72	0.60	0.23	- -	- -	- -	- -
Onion	0.91	0.34	0.84	0.11	0.11	0.04	- -	- -	- -	- -
Carrot	0.95	0.46	0.77	0.37	0.27	0.09	- -	- -	- -	- -

Table 3: Influence of different salinity levels in irrigation water, and their modes of application on relative leaf area of wheat and bean plant

Modes of application	Relative leaf area (cm2/50 leaves)					Leaf area (cm2/plant)				
	LEVELS OF SALINITY									
	S_0	S_1	S_2	S_3	$\bar{X}$	S_0	S_1	S_2	S_3	$\bar{X}$
B	4,930	4,755	4,294	3,554	4,383	1,050	1,072	834	534	872.5
C	4,730	4,772	4,584	4,136	4,555	1,095	1,091	1,071	974	1,057
D	5,068	4,790	4,463	3,989	4,577	1,059	1,071	1,071	951	1,038
E	5,165	3,924	3,690	2,686	3,866	1,086	985	748	370	797.2
X	4,973	4,560	4,257	3,591	4,345	1,072	1,054	931	707	941

Table 4: Influence of different salinity levels in irrigation water, and their modes of application on dry matter production of wheat and bean plants

Modes of application	Dry weight (g/pot)					Dry weight (g/pot)				
	LEVELS OF SALINITY									
	S_0	S_1	S_2	S_3	$\bar{X}$	S_0	S_1	S_2	S_3	$\bar{X}$
B	80.1	79.6	68.4	55.9	71.0	51.6	51.9	42.8	29.3	43.9
C	80.4	80.1	70.3	69.7	75.1	54.2	53.8	50.8	44.2	50.8
D	80.3	79.6	71.8	68.9	75.1	58.9	52.9	49.0	43.4	51.1
E	81.4	73.0	62.4	38.7	63.8	54.5	45.4	33.9	22.0	39.0
X	80.5	78.0	68.2	58.3	71.2	54.8	51.0	44.1	34.7	46.2

Table 5: Influence of salinity level of the irrigation water and their modes of application on the dry weight of the root system of wheat

Mode of application	Dry weight, gr. Salinity level				
	S_0	S_1	S_2	S_3	Mean
B	52.4	49.4	22.2	16.3	35.1
C	52.4	56.6	53.5	45.4	52.0
D	52.4	53.4	40.7	39.1	46.4
E	52.4	49.0	21.8	11.1	33.6
$\bar{X}$	52.4	52.1	34.6	28.0	41.8

Figure 2: Development of roots under different irrigation treatments for wheat

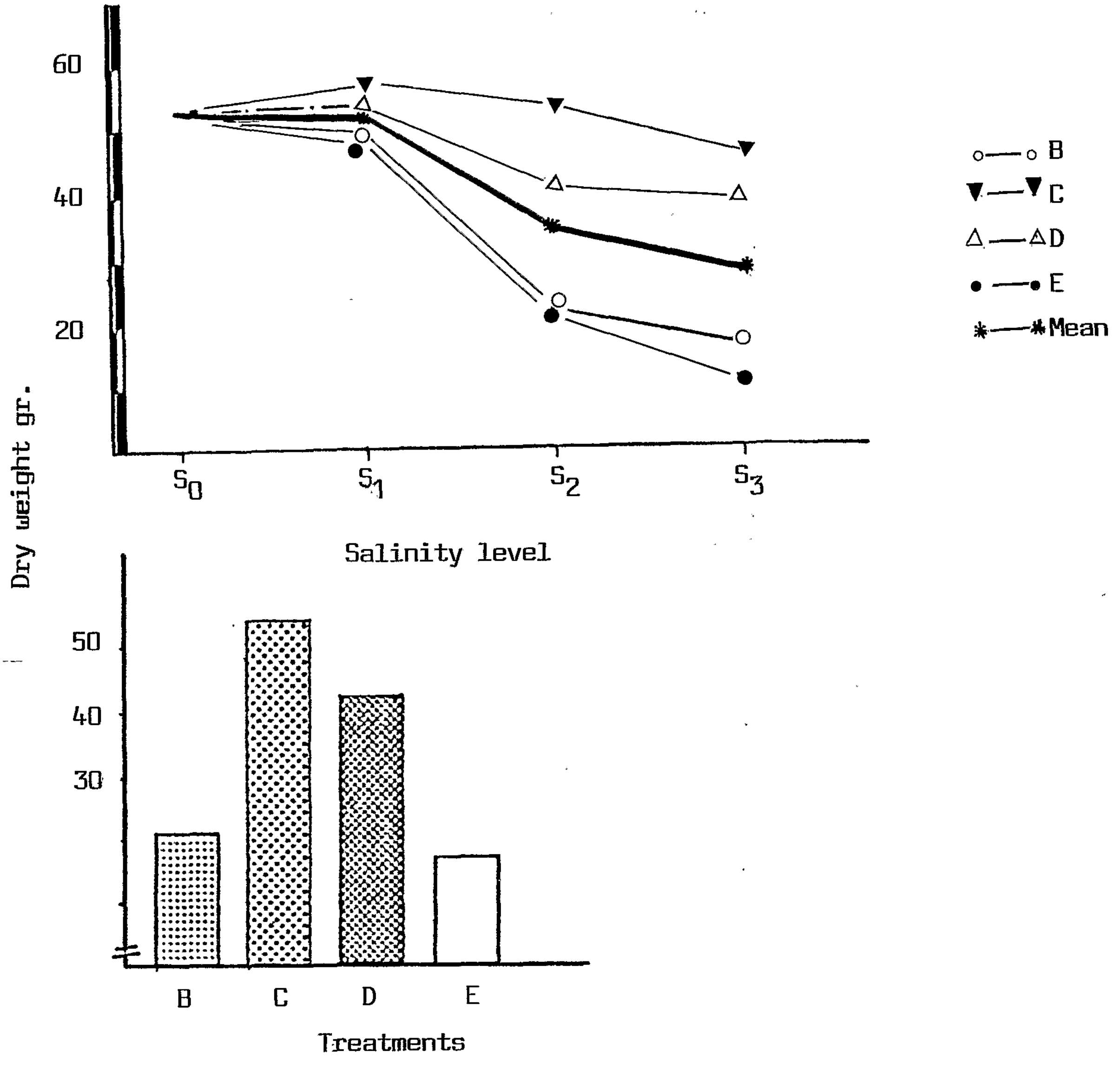


Table 6: Influence of salinity level of the irrigation water and their modes of application on the dry weight of the root system of beans

Mode of application	Dry weight, gr.				
	Salinity level				
	S_0	S_1	S_2	S_3	Mean
B	28.6	24.3	21.1	13.6	21.9
C	28.6	26.8	22.3	20.1	24.5
D	28.6	28.5	20.8	21.0	24.7
E	28.6	16.6	18.5	10.2	18.5
$\bar{X}$	28.6	24.1	20.7	16.2	22.4

Figure 3: Development of roots under different irrigation treatments for beans

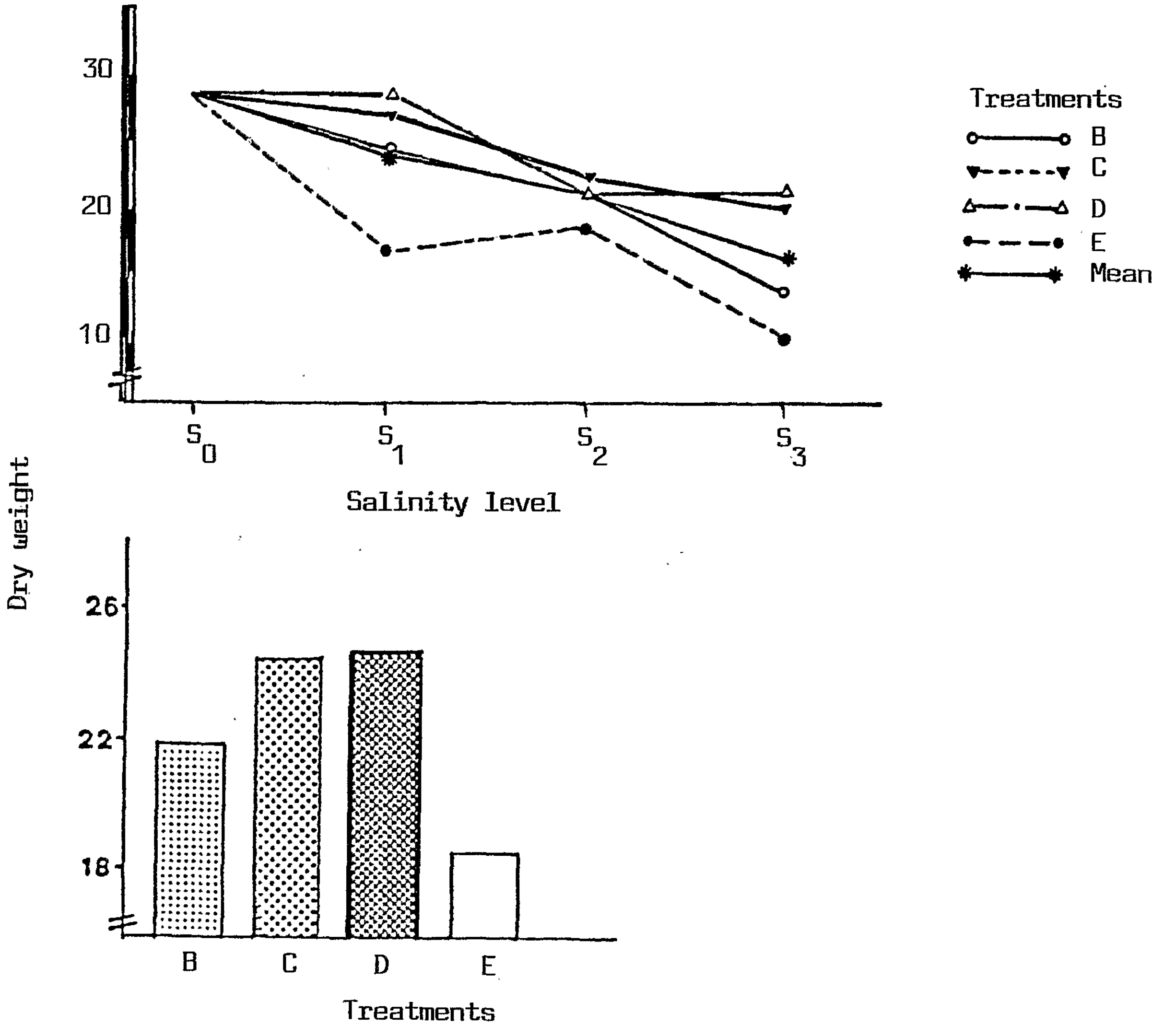


Table 7: Straw dry weight (g/pot) under different irrigation treatments with different salinity levels and modes of application

Water salinity level (mmhos/cm)	Mode of water application							
	Constant mixtures					Alternative		
	Fresh water (FW) **A**	70% FW + 30% SW **B**	50% FW + 50% SW **C**	30% FW + 70% SW **D**	Saline water (SW) **E**	70% SW + 30% FW **F**	30% SW + 70% FW **G**	FW at seedling **H**
	Surface irrigation							
0	72.5	--	--	--	--	--	--	--
4	--	57.0	52.1	50.6	51.3	64.8	65.8	59.3
8	--	53.2	50.1	43.2	38.2	55.9	62.8	50.3
12	--	53.8	47.3	39.7	31.7	47.2	54.0	41.7
Mean	72.5	54.7	49.8	44.5	40.4	55.9	60.9	50.4
	Subirrigation							
	$\bar{A}$	$\bar{B}$	$\bar{C}$	$\bar{D}$				
0	92.4	--	--	--	--	--	--	--
4	--	80.8	77.3	64.7	59.0	--	--	--
8	--	67.3	62.2	55.3	51.3	--	--	--
12	--	55.6	54.3	49.5	43.2	--	--	--
Mean	92.4	67.8	64.6	56.5	51.2	--	--	--

Table 8: Root dry weight (g/pot) under different irrigation treatments with different salinity levels and modes of application

Water salinity level (mmhos/cm)	Mode of water application: Constant mixtures					Alternative		
	Fresh water (FW) A	70% FW + 30% SW B	50% FW + 50% SW C	30% FW + 70% SW D	Saline water (SW) E	70% SW + 30% FW F	30% SW + 70% FW G	FW at seedling H
	Surface irrigation							
0	9.0	--	--	--	--	--	--	--
4	--	8.9	8.1	7.2	7.0	7.2	8.0	8.4
8	--	7.0	7.0	5.2	5.0	6.3	7.0	5.0
12	--	5.3	5.8	4.2	3.5	5.0	6.5	4.0
Mean	9.0	7.2	6.9	5.5	5.2	6.2	7.2	5.8
	Subirrigation Ā	B̄	C̄	D̄				
0	14.5	--	--	--	--	--	--	--
4	--	12.8	11.3	10.5	9.0	--	--	--
8	--	11.5	9.4	7.5	5.0	--	--	--
12	--	9.8	7.9	6.4	3.0	--	--	--
Mean	14.5	11.4	9.5	8.1	5.7	--	--	--

Table 9: Wheat grain yield (g/pot) under different irrigation treatments with different salinity levels and modes of application

Water salinity level (mmhos/cm)	Mode of water application: Constant mixtures: Fresh water (FW) A	70% FW + 30% SW B	50% FW + 50% SW C	30% FW + 70% SW D	Saline water (SW) E	Alternative: 70% SW + 30% FW F	30% SW + 70% FW G	FW at seedling H
	Surface irrigation							
0	51.6	--	--	--	--	--	--	--
4	--	37.5	36.9	36.5	37.0	40.3	43.3	38.3
8	--	36.2	33.1	25.4	22.2	34.4	38.2	27.0
12	--	32.2	29.5	23.4	17.8	24.8	33.5	17.8
Mean	51.6	35.3	33.2	28.4	25.7	33.2	38.3	27.7
	Subirrigation							
	Ā	B̄	C̄	D̄				
0	56.8	--	--	--	--	--	--	--
4	--	48.1	32.3	31.5	30.4	--	--	--
8	--	36.5	32.3	29.0	27.4	--	--	--
12	--	34.1	27.2	24.8	15.8	--	--	--
Mean	56.8	39.6	30.6	28.4	24.5			

Figure 4: EC values under different application modes of saline water and through different soil depths

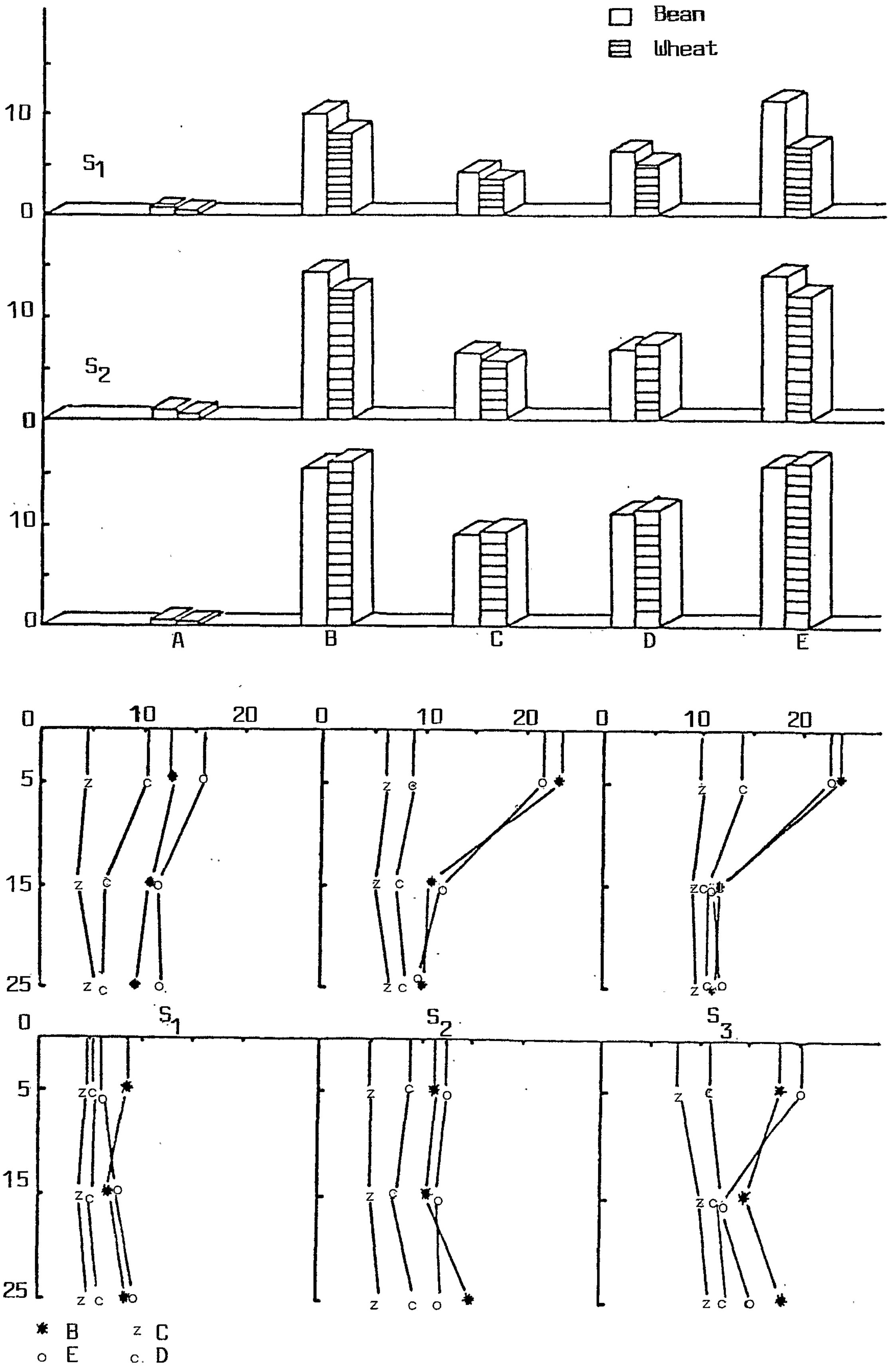


Figure 5: SAR values under different application modes of saline water and through different soil depths

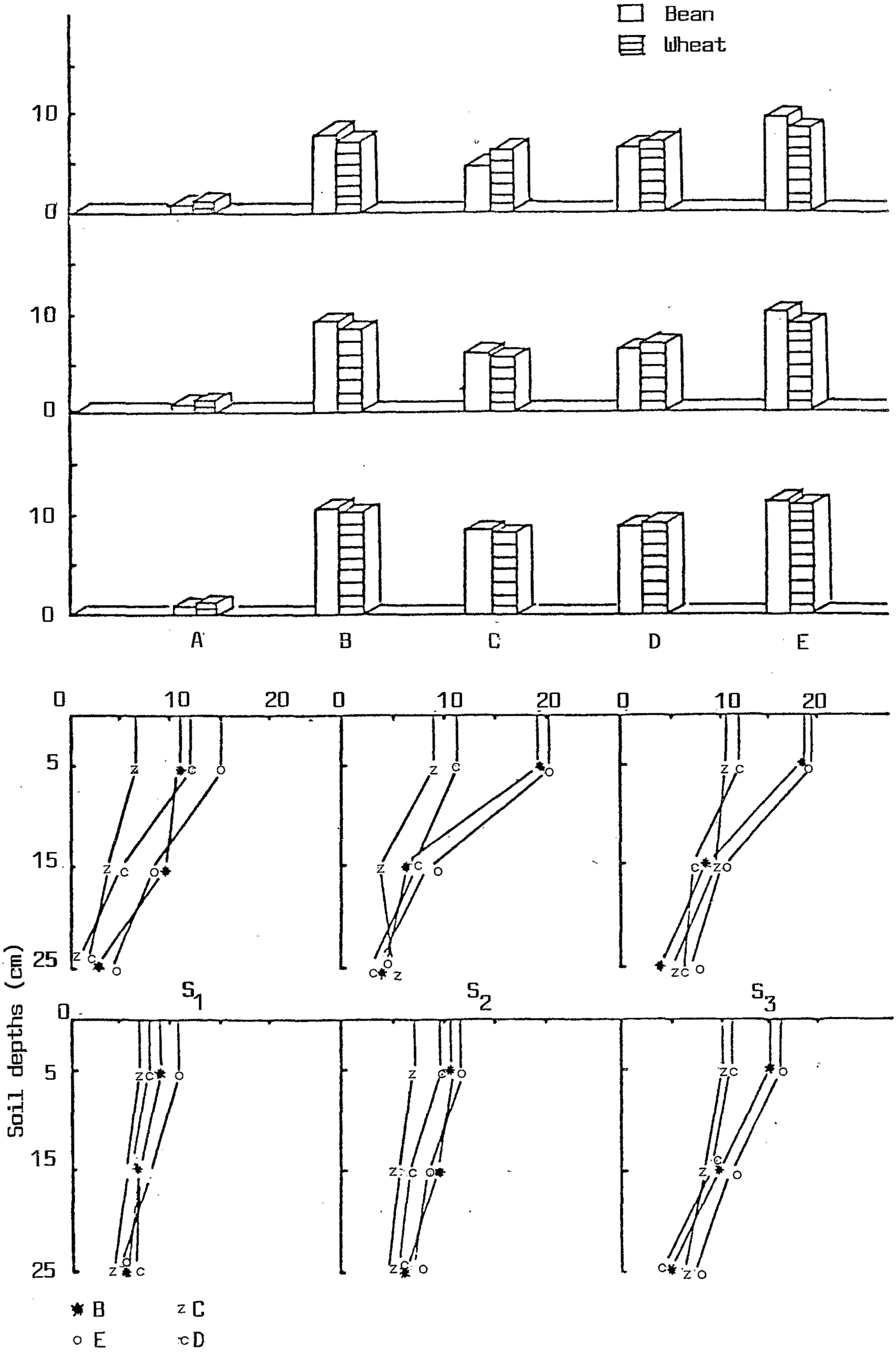


Figure 6: Influence of modes of irrigation, soil type and water salinity on Leaf Area Index (LAI)

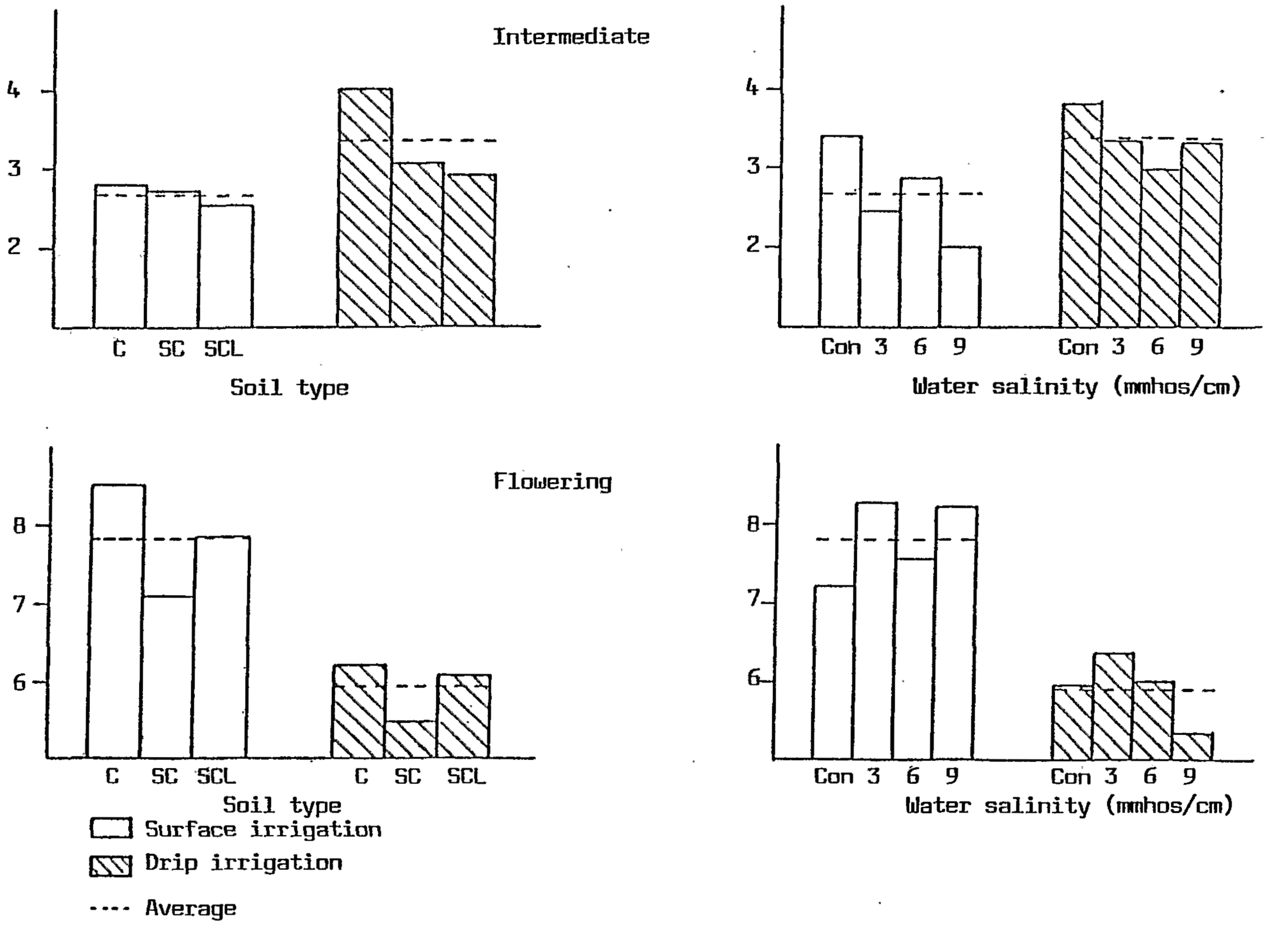


Figure 7: Influence of modes of irrigation, soil type and water salinity on Plant Height (cm) Flowering

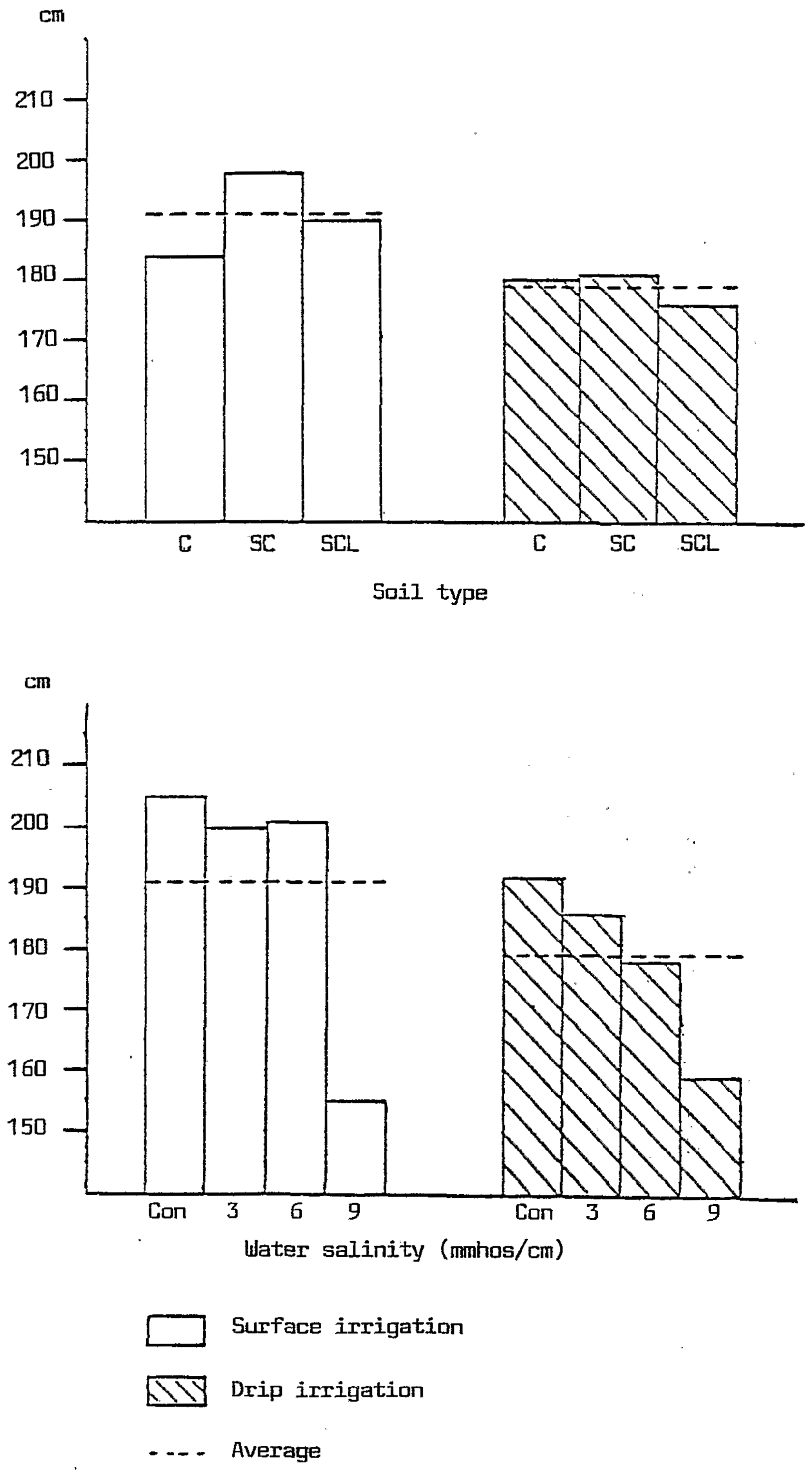


Figure 8: Influence of modes of irrigation, soil type and water salinity on Plant Dry Matter (g/pot)

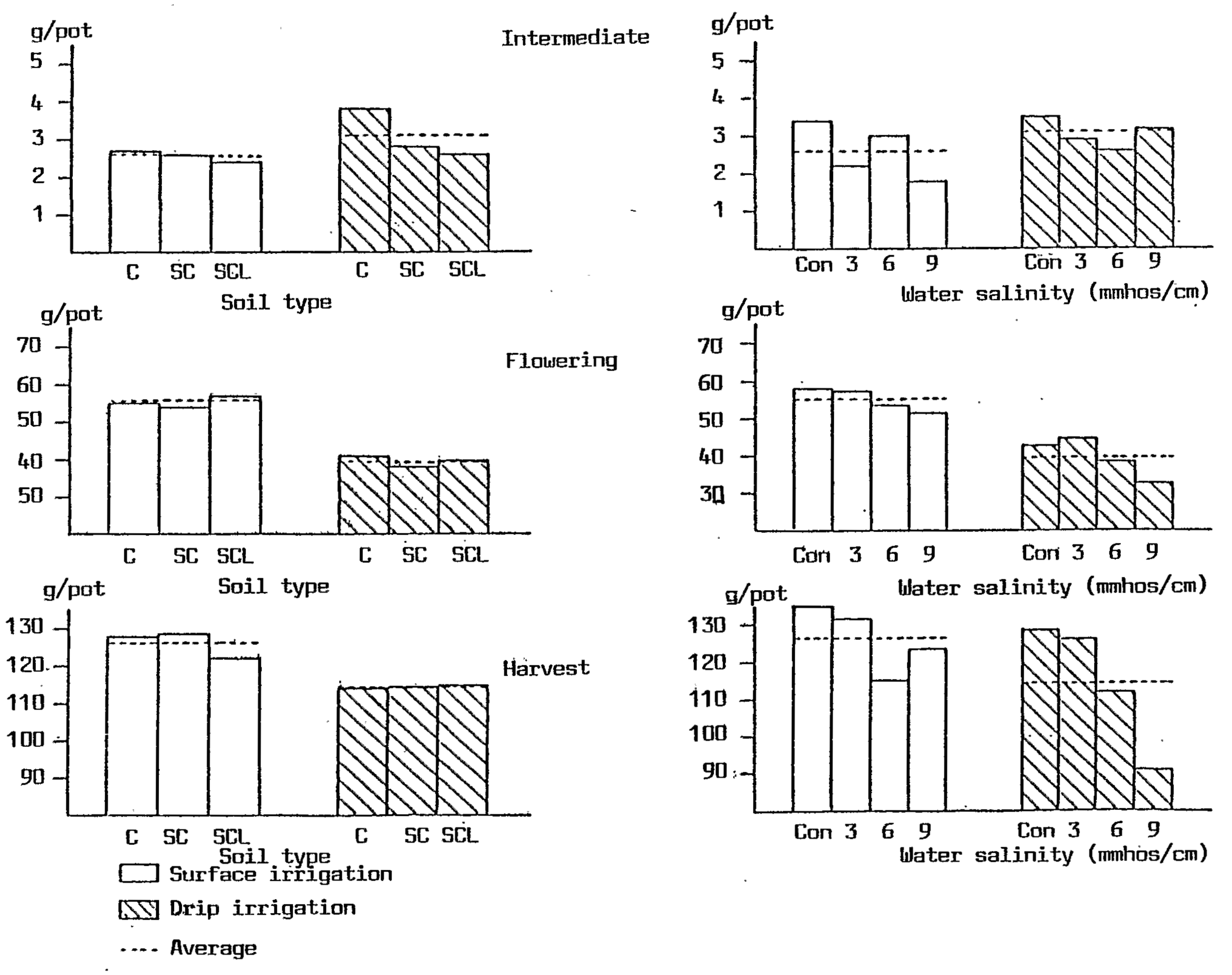


Figure 9: Influence of modes of irrigation, soil type and water salinity on Root Dry Matter (g/pot) Harvest

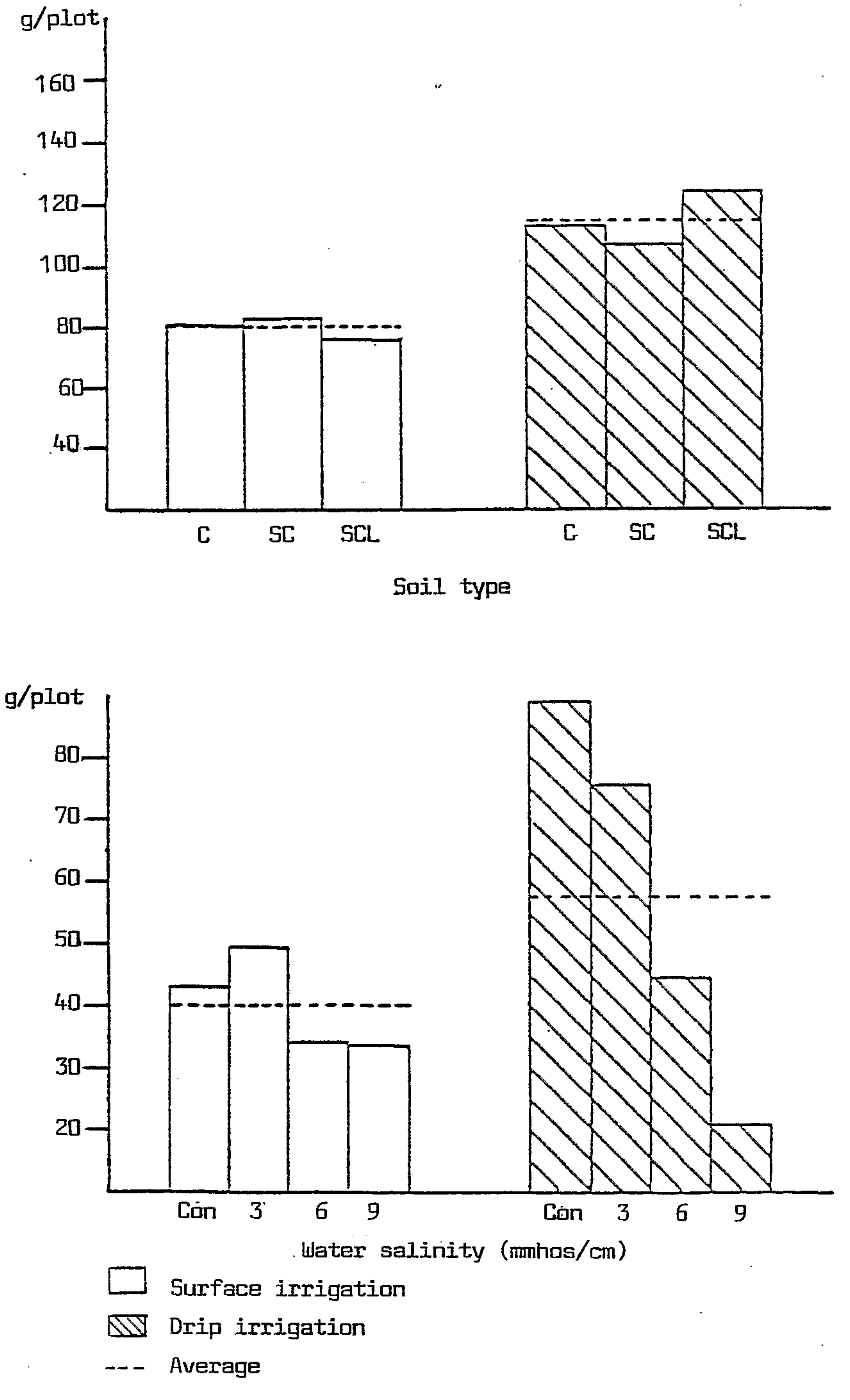


Figure 10: Influence of modes of irrigation, soil type and water salinity on Dry Grain Production (g/pot) - Harvest

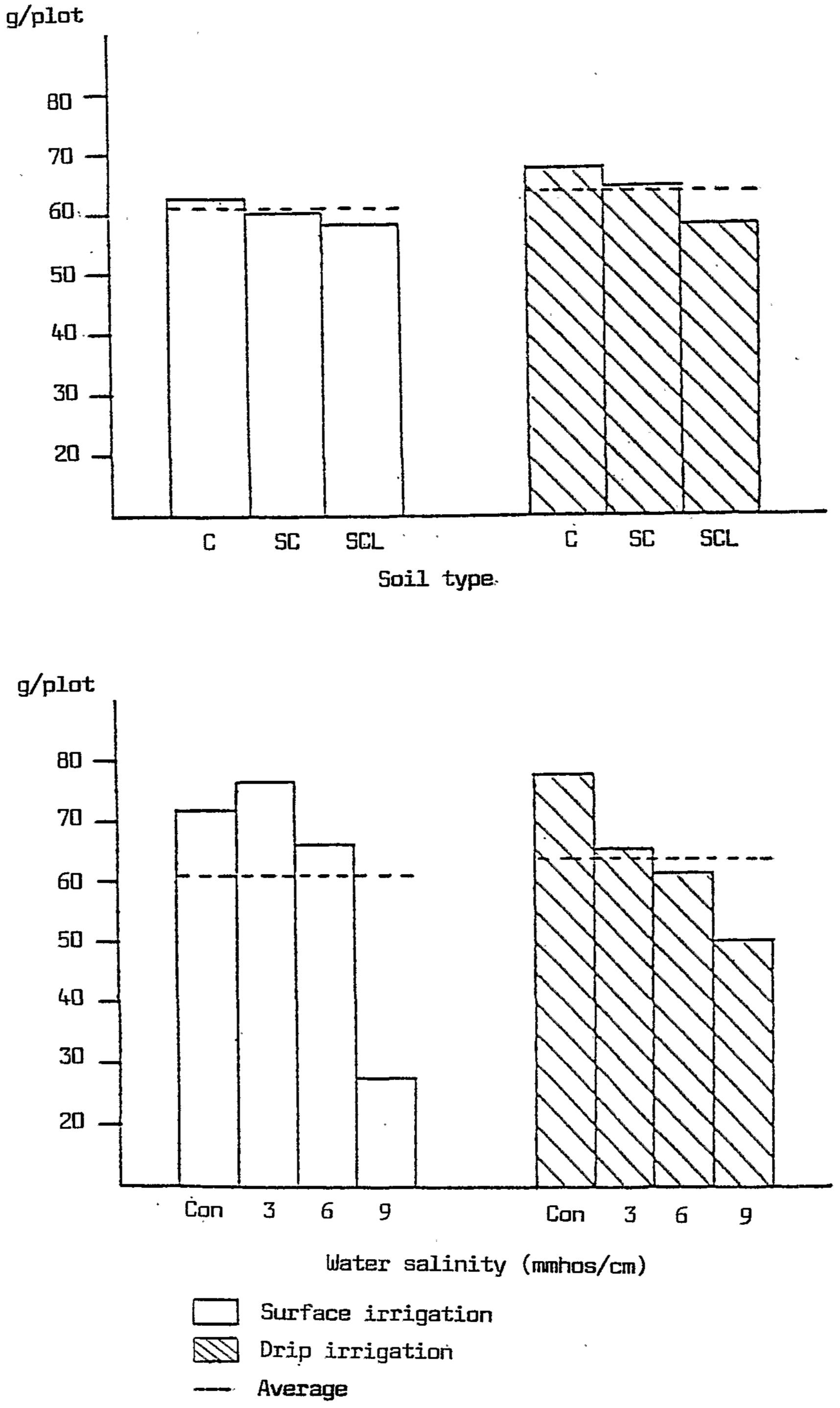


Table 10: Influence of modes of irrigation, soil type and water salinity on EC value in mmhos/cm

Water salinity	Modes of irrigation							
	Surface				Drip			
	Soil type							
	Clay	Sand clay	Sand clay loam	Mean	Clay	Sand clay	Sand clay loam	Mean
0 - 10 cm								
Control	1.1	1.4	1.1	1.2	1.7	2.1	2.4	2.1
3	5.3	9.9	5.9	7.0	7.9	12.3	12.5	10.9
6	14.3	17.8	22.7	18.3	17.7	20.2	25.0	21.0
9	26.8	26.3	26.7	26.6	37.0	25.8	27.5	30.1
Mean	11.9	13.9	14.1	13.3	16.1	15.1	16.9	16.0
10 - 25 cm								
Control	1.3	1.2	1.0	1.2	1.0	0.9	0.9	0.9
3	8.2	7.5	7.5	7.7	5.5	3.4	4.3	4.4
6	15.7	10.0	13.4	13.0	11.0	6.3	6.2	7.8
9	20.0	16.5	13.9	16.8	15.2	8.1	7.7	10.3
Mean	11.3	8.8	9.0	9.7	8.2	4.7	4.8	5.9
25 - 40 cm								
Control	1.1	2.8	2.6	1.8	1.6	1.7	2.0	1.8
3	9.5	14.3	15.7	13.2	8.9	5.5	9.9	8.1
6	21.3	16.5	18.3	18.7	17.8	9.1	9.1	12.0
9	27.2	23.5	20.7	23.8	23.3	11.7	11.9	15.6
Mean	14.8	14.2	14.3	14.4	12.9	7.0	8.2	9.4

Figure 11: EC value in mmhos/cm under surface irrigation for the three soil types

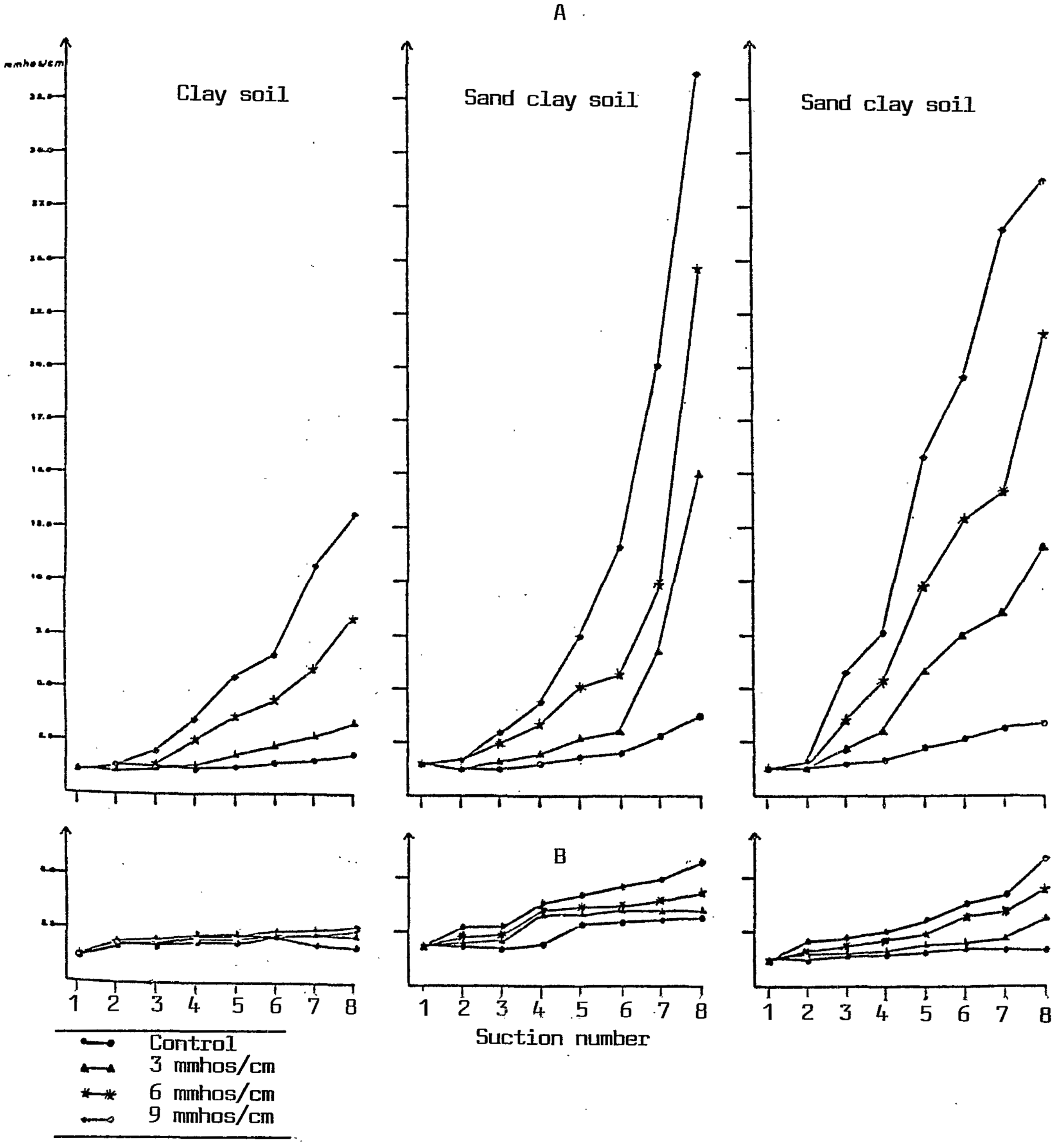


Figure 12: Distribution of the EC value in mmhos/cm under surface irrigation at 5 cm from the dripper

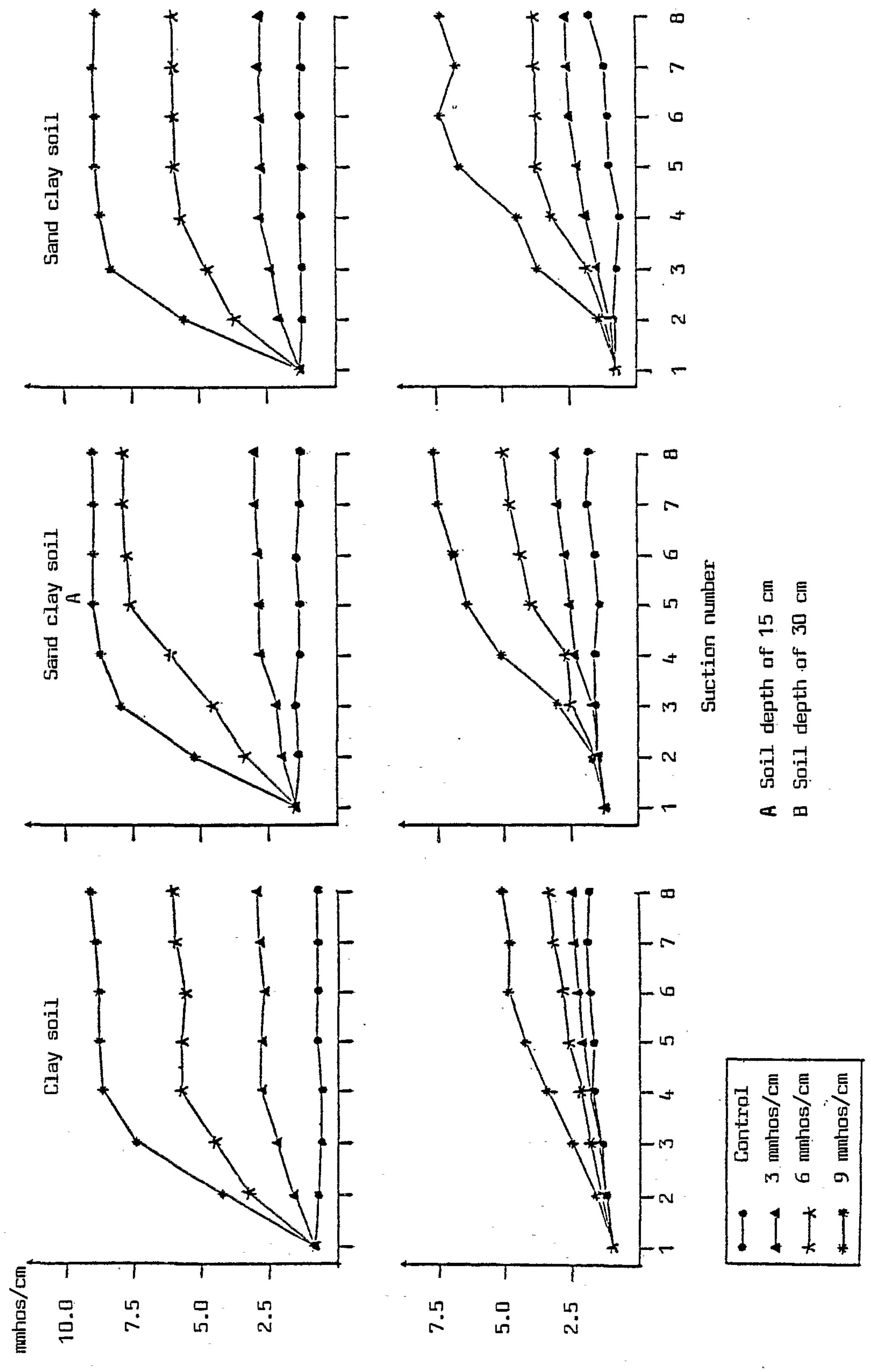


Figure 13: Distribution of EC value in mmhos/cm under drip irrigation at 17 cm from the dripper

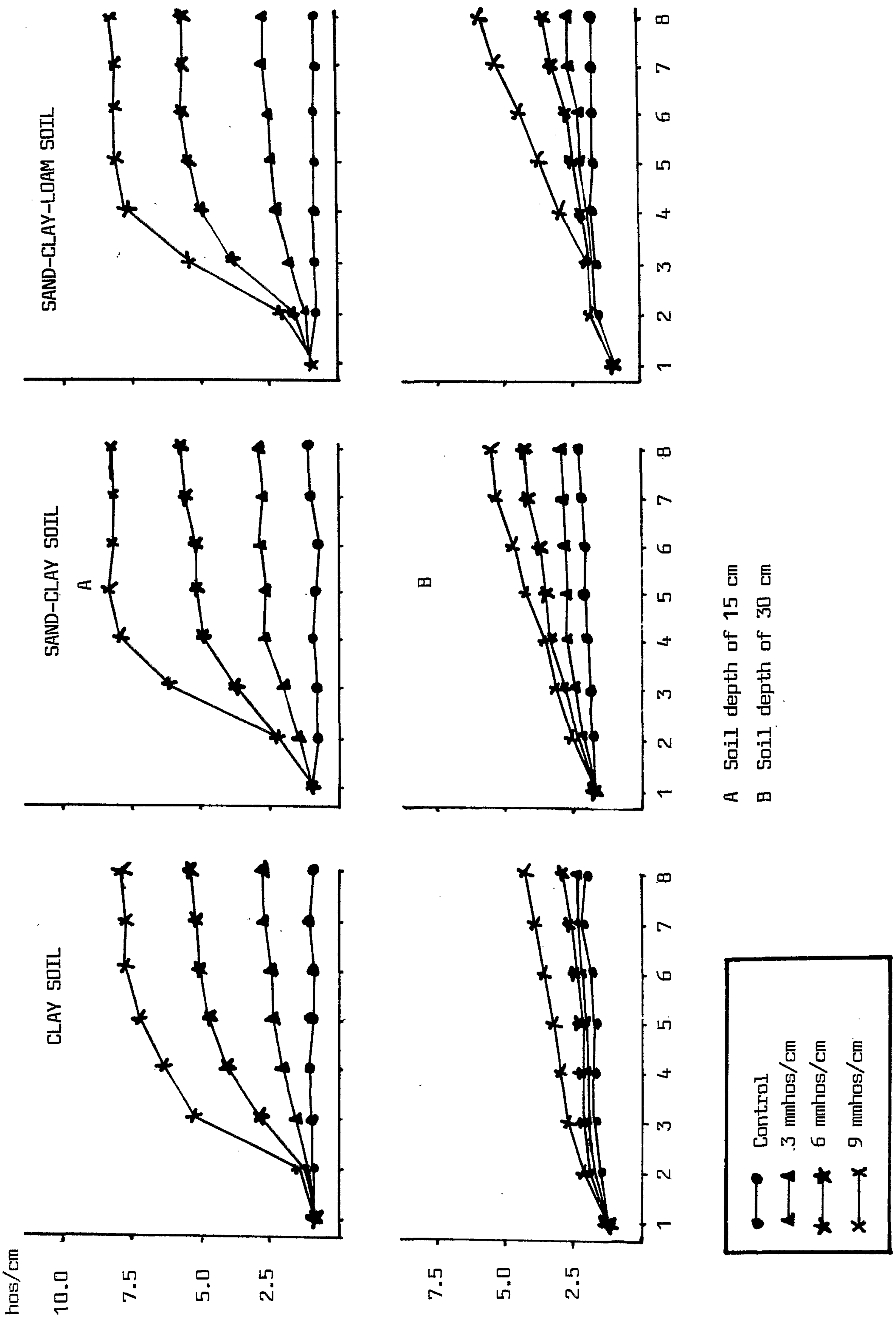


Figure 14: Salts removed under successive leachings using submersion and drip techniques leaching

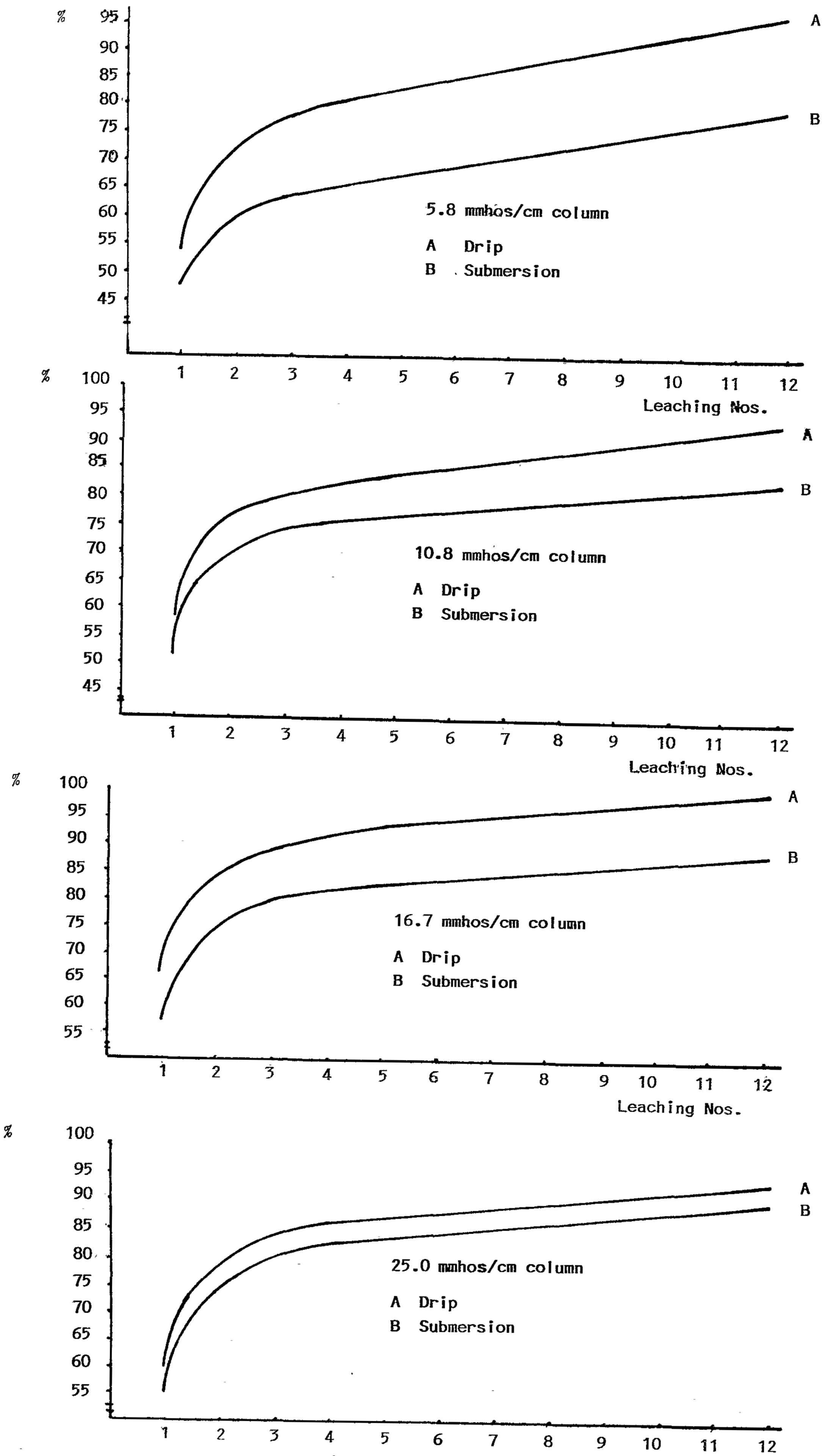
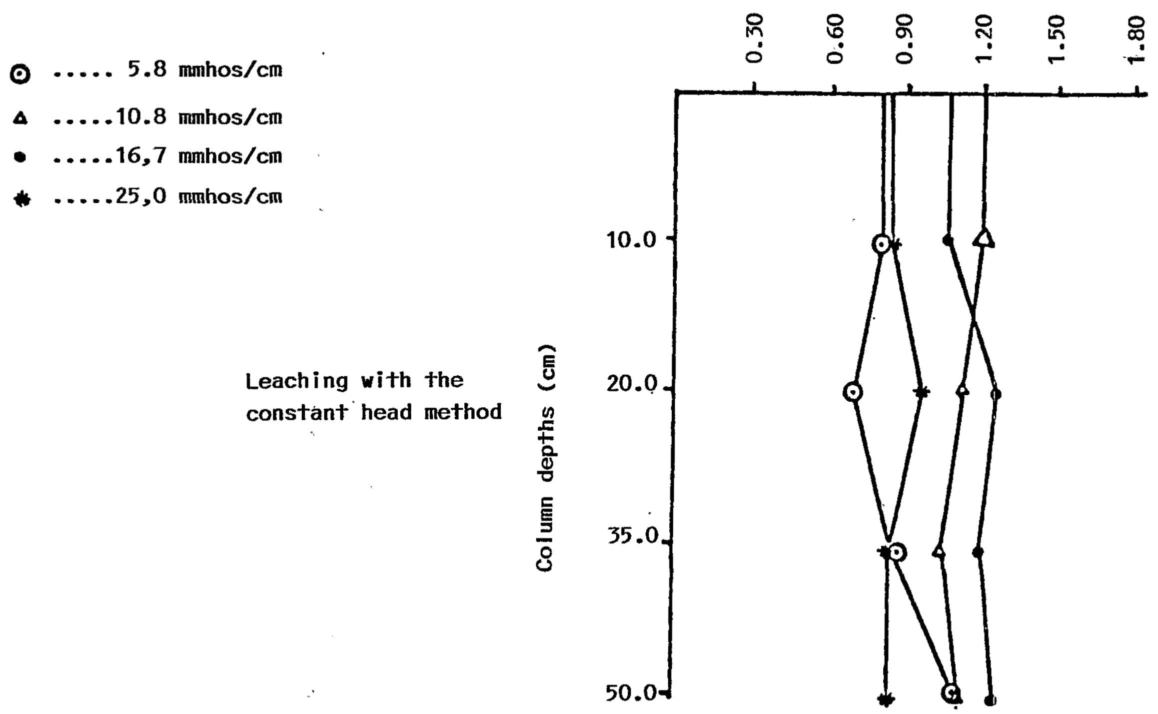
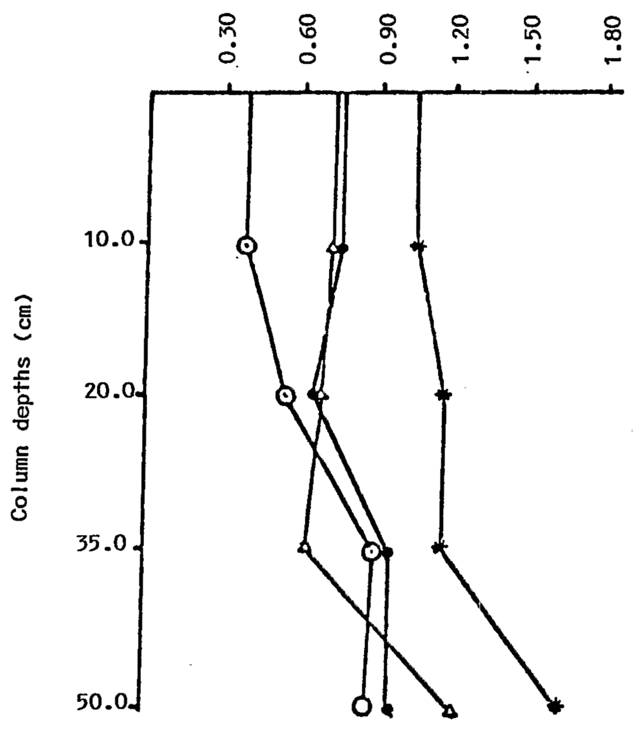


Figure 15: Variation of the EC value in the columns after 12 leachings with distilled water (mmhos/cm)

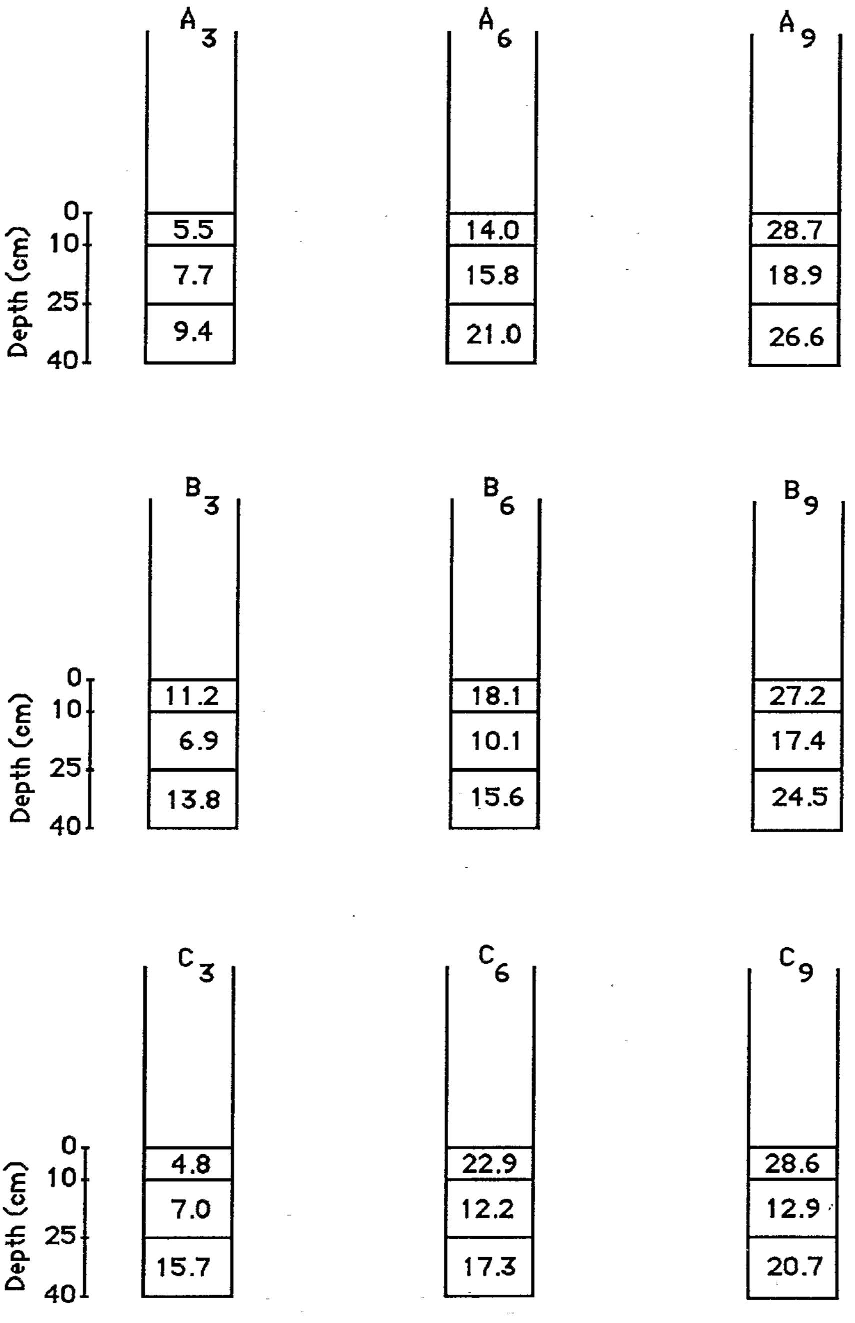


Leaching with the constant head method



Leaching with the drip system

Diagram 1: design plan of the leaching on columns



- The symbols A, B, C, refer to soil clay, sand clay and sand clay loam respectively.
- The numbers refer to salt concentration level in leaching water.
- The values on the columns refer to EC values, in mmhos/cm, for each soil depth.

Diagram 2: EC values (in mmhos/cm) before and after the leaching on columns and their respective variation as a percentage for each soil layer, with surface technique

Depth (cm)	A_3 bef.	A_3 aft.	A_6 bef.	A_6 aft.	A_9 bef.	A_9 aft.
0–10	5.5	2.4	14.0	5.2	28.7	7.0
10–25	7.7	2.5	15.8	5.5	18.9	7.1
25–40	9.4	2.5	21.0	5.1	26.6	7.3

Depth (cm)	B_3 bef.	B_3 aft.	B_6 bef.	B_6 aft.	B_9 bef.	B_9 aft.
0–10	11.2	3.0	18.1	5.7	27.2	7.4
10–25	6.9	2.5	10.1	5.1	17.4	7.7
25–40	13.8	2.7	15.6	5.4	24.5	7.6

Depth (cm)	C_3 bef.	C_3 aft.	C_6 bef.	C_6 aft.	C_9 bef.	C_9 aft.
0–10	4.8	2.7	22.9	5.2	28.6	6.7
10–25	7.0	2.9	12.2	5.5	12.9	7.3
25–40	15.7	3.1	17.3	5.8	20.7	7.3

- The symbols A, B, C, refer to soil clay, sand clay and sand clay loam respectively.
- The numbers refer to salt concentration level in leaching water.
- The values on the columns refer to EC values, in mmhos/cm, for each soil layer.

Diagram 3: EC values (in mmhos/cm) before and after the leaching on columns and their respective variation as a percentage for each soil layer, with drip technique

Depth (cm)	A_3 bef.	A_3 aft.	A_6 bef.	A_6 aft.	A_9 bef.	A_9 aft.
0–10	5.5	2.7	14.0	5.3	28.7	7.8
10–25	7.7	2.5	15.8	5.1	18.9	7.9
25–40	9.4	2.9	21.0	5.2	26.6	8.4

Depth (cm)	B_3 bef.	B_3 aft.	B_6 bef.	B_6 aft.	B_9 bef.	B_9 aft.
0–10	11.2	2.8	18.1	6.3	27.2	8.1
10–25	6.9	2.8	10.1	5.6	17.4	8.3
25–40	13.8	2.8	15.6	6.2	24.5	8.2

Depth (cm)	C_3 bef.	C_3 aft.	C_6 bef.	C_6 aft.	C_9 bef.	C_9 aft.
0–10	4.8	3.0	22.9	5.6	28.6	8.2
10–25	7.0	2.9	12.2	5.4	12.9	7.9
25–40	15.7	3.0	17.3	5.6	20.7	7.9

- The symbols A, B, C, refer to soil clay, sand clay and sand clay loam respectively.
- The numbers refer to salt concentration level in leaching water.
- The values on the columns refer to EC values, in mmhos/cm, for each soil layer.