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Effect of a change in water source on the chemical and physical properties of an irrigated black earth in the Lockyer Valley

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Summary

A salinity analysis was undertaken on a Lockyer Valley farm with a steadily worsening salinity problem. On this farm, bore water of very high salinity (up to 8.15 mS cm^{-1}) has been used for the supplementary irrigation of cotton on a black earth soil and, during the 2 years before this study, visible surface salt had begun appearing on some areas of the farm. The study confirmed that a high salinity (but low sodium) hazard existed, and that this was increasing primarily as a result of long term rises in bore water salinity.

One section of the farm which had been salinised by bore water irrigation was subsequently irrigated for 5 years with low salinity water from a water harvesting scheme. The change in water source produced a marked reduction in soil salinity, accompanied by a visible change in surface soil structure which was documented by aggregate size analysis. The structural change in the dam-irrigated soil may be related to an unfavourable exchangeable magnesium to exchangeable calcium ratio. There is no evidence that either the reduction in salinity or the structural change in the dam-irrigated soil has affected cotton growth.

1. INTRODUCTION

The salinity problem in the Forest Hill area of the Lockyer Valley is widespread. Bore and creek water of poor quality is used for supplementary irrigation on alluvial black earth soils, and cropping has been restricted mainly to cotton, barley and beetroot, all of which have a high tolerance of soil salinity (Richards 1954). On the cotton farm of Mr A. Brimblecombe (Moira Farm), where bore irrigation has been used since 1939, soil and water analyses were conducted in 1964 (Talbot, Dickson and Bruce 1971) and 1975-76 (IPMU 1977). It was found that the water salinity had increased over time, with 8.15 mS cm^{-1} being the highest conductivity so far recorded (IPMU 1977). Talbot *et al.* (1971) reported a maximum value of 6.33 mS cm^{-1} for bore water in 1964.

The highest mean soil salinity level found on the farm by Talbot *et al.* (1971) was equivalent to an electrical conductivity on the saturation extract (EC_{sat}) of 4.95 mS cm^{-1}. This value, which was for the 30 to 60 cm depth, is within the tolerance limit for cotton of 10 mS cm^{-1} (Richards 1954). During the summer of 1975-76 an EC_{sat} of 14.25 mS cm^{-1} was recorded for the top 15 cm of the profile (IPMU 1977), and surface salt was visible. The high salt level resulted from the heavy usage of irrigation water during the hot dry growing season. Cotton yields were little affected because the salinity levels recorded at depth were much lower, and the surface salt occurred fairly late in the growing season.

A water harvesting scheme with a shallow earth storage dam was constructed on the farm, and since 1972 one area has been irrigated with this water only. Previously, the same area had become salinised as a result of bore water irrigation (Talbot *et al.* 1971). Although the scheme was an attempt by the farmer to alleviate the salinity problem, he has observed that this area has since formed a poorer seedbed compared to the rest of the farm.

The objectives of this study were (1) to assess the salinity hazard of the bore water and salinity status of the bore-irrigated soil so that future recommendations could be made regarding their usage, (2) to determine the change in soil salinity resulting from the change from bore water to dam water and (3) to quantify visible differences in surface soil structure between the dam-irrigated and bore-irrigated soils.

2. CHANGES IN SOIL AND WATER SALINITY

Materials and methods

The soil type on this farm and the surrounding area is a black earth (Northcote: Ug 5.15) of alluvial origin. Soil samples were taken in December 1977 when the cotton crop was 6 weeks old and had received one pre-planting and one post-planting irrigation (total of 250 mm ha^{-1}) using furrow irrigation. The rainfall for the year 1977 was 560 mm, compared to the average of 750 mm.

Three treatment areas were sampled:

1. Irrigated with bore water for 18 years (1959-1977).
2. Irrigated with bore water for 23 years (1949-1972) and subsequently irrigated with dam water for 5 years (1972-1977).
3. Non-irrigated, cultivated land from an adjacent farm.

The sampling sites for the irrigated treatments corresponded positionally to two sampling sites used by Talbot *et al.* (1971) in 1964 (5 and 15 year irrigations, respectively). Ten cores were randomly sampled from each of the irrigated treatments using 175 × 110 m grids; in each case sampling was stratified into five ridge and five furrow cores. From the non-irrigated treatment which was under fallow, five cores were randomly selected from a 170 × 55 m grid. In all treatments, samples were divided into the following depth intervals: 0 to 10 cm, 10 to 20 cm, 20 to 30 cm, 30 to 60 cm and 60 to 90 cm.

Measurements of soil pH were made on 1:2.5 soil:water suspensions using a glass electrode. The EC of the samples was measured using the 1:5 soil:water extract method described by Bower and Wilcox (1965). Sodium (flame photometry), chloride (chloride electrode), calcium and magnesium (atomic absorption spectrophotometry) were also measured on the furrow sample extracts from the irrigated treatments and on the non-irrigated treatment extracts.

The 1:5 extract was chosen for these analyses because of convenience. Saturation extract data, however, enable proper interpretation in relation to crop response on salt and sodium-affected soils, and thus the relationships between the values of these properties measured on 1:5 and saturation extracts were determined (Table 1). To obtain these relationships, saturation extracts were taken (Bower and Wilcox 1965) from 11 samples consisting of seven selected randomly from the bore-irrigated treatment and four from the dam-irrigated treatment. The regressions were used to construct comparison scales in corresponding figures, with the exception of the sodium adsorption ratio (SAR), where the regression was fitted with a confidence interval and used to transform the data to give the true SAR values. All statistical analyses were performed on the 1:5 extract data, and the level of significance used was 5%.

Table 1. Relationships between parameters measured in saturation (Y) and 1:5 (X) soil extracts

Measurement	Regression	Correlation coefficient
EC ($mS\ cm^{-1}$)	$Y = 6.33X - 0.14$	0.96
Na^{+} ($meq\ L^{-1}$)	$Y = -0.08X^2 + 8.45X - 5.31$	0.99
$Ca^{++} + Mg^{++}$ ($meq\ L^{-1}$)	$Y = 8.32X^2 - 20.01X + 23.04$	0.96
Cl^{-} ($meq\ L^{-1}$)	$Y = 13.59X - 7.14$	0.98
SAR	$Y = 1.23X + 0.11$	0.98

The dam water and the three bores used together on the bore-irrigated treatment were also sampled. The bores were numbered 1, 2 and 3, to correspond positionally with the three bores measured by Talbot *et al.* (1971). In addition to the measurements made on the soil extracts, bicarbonate was determined by titration with sulphuric acid (Bower and Wilcox 1965).

A composite surface furrow sample (0 to 10 cm) was taken from each treatment during April 1979 for the determination of exchangeable cations. Two solvents for removing soluble salts were used, namely (1) glycol-ethanol (Tucker and Beatty 1974) and (2) 60% ethanol. There was no significant difference between the exchangeable cations determined using the two washes. Sodium, potassium and magnesium were determined on a neutral 1.0 M ammonium acetate extract. Because the soil contained free calcium carbonate, calcium was measured on a 1.0 M sodium acetate extract at pH 8.2 (Chapman 1965). As the pH values of the bore-irrigated and dam-irrigated soils exceeded 7.5, the sum of the basic cations was considered to be a reasonable estimate of the cation exchange capacity. The pH of the surface of the non-irrigated soil was close to 7, and the exchange capacity would be expected to be more than the sum of the basic cations because of the presence of a small amount of exchange acidity.

Results and discussion

The results of the irrigation water analyses are presented in Table 2, along with the data from Talbot *et al.* (1971). A comparison shows that bore water salinities have increased since October 1964. At that time, the highest conductivity was 6.33 $mS\ cm^{-1}$ (Talbot *et al.* 1971), compared to 8.15 $mS\ cm^{-1}$ measured in this study in December 1977 (Table 2). Two of the bores (unidentified) were also measured earlier in February 1976 when visible surface salt appeared, and gave values of 8.15 and 7.25 $mS\ cm^{-1}$ (IPMU 1977). Therefore, there was no marked change from February 1976 to December 1977, although the results are not fully comparable because of the different months of sampling. Between 1964 and 1977, sodium and calcium plus magnesium all increased, but with little change in the SAR except for an increase in bore 1 (Table 2). These increased bore-water salt levels may have resulted from the increased local demand on the aquifers and the clearing of forested slopes in the area.

Table 2. Chemical analysis of the irrigation waters

Source	Electrical conductivity (mS cm^{-1})	Ionic composition (meq L^{-1})					SAR
		Ca^{++}	Mg^{++}	Na^{+}	Cl^{-}	HCO_3^{-}	
Bore 1	8.15	13.5	44.3	31.3	76.2	15.5	5.8
Bore 2	7.15	15.4	45.3	17.8	67.7	10.6	3.2
Bore 3	7.15	12.4	41.3	22.4	66.0	10.4	4.3
Dam	0.67	0.9	2.6	2.5	3.9	1.7	1.9
Results of the October, 1964, analysis (Talbot *et al.* 1971)							
Bore 1	5.18	10.9	27.7	14.8	44.8	8.2	3.4
Bore 2	5.52	11.1	29.1	18.8	50.1	8.7	4.2
Bore 3	6.33	10.9	30.6	. .	57.4	9.5	. .

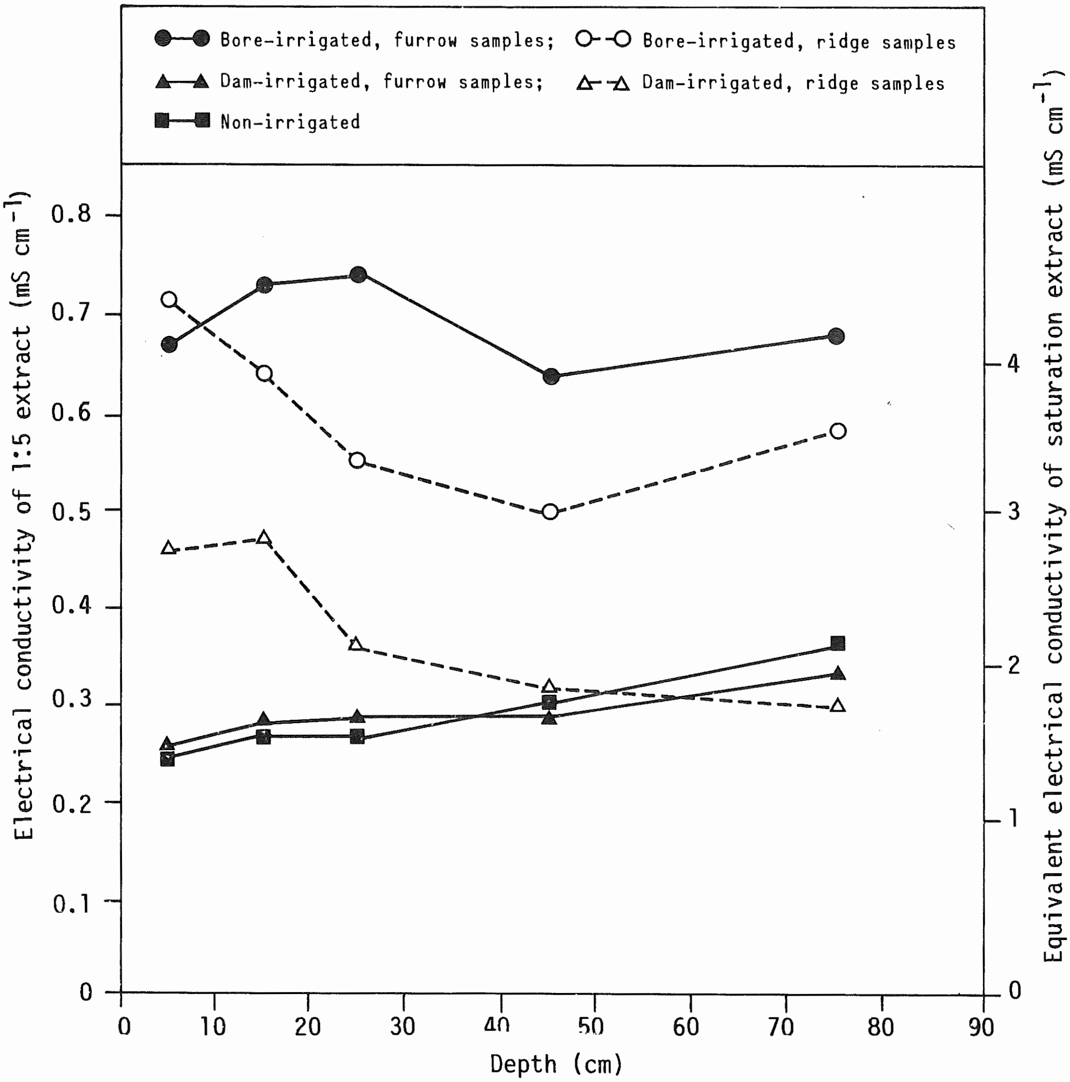

Figure 1. Variation in electrical conductivity with depth for the three irrigation treatments.

The values of the soil 1:5 extract conductivities ($EC_{1:5}$) for the bore-irrigated treatment were significantly higher than those values for the non-irrigated treatment at the same depths (Figure 1). Significant increases in sodium, calcium plus magnesium and chloride have occurred at all depths (Figures 2, 3 and 4, respectively). The highest mean $EC_{1:5}$ value from the bore-irrigated treatment was found at the 20 to 30 cm furrow depth, and was estimated to be 5.4 mS cm^{-1} on a saturation extract basis, using the regression in Table 1. This value was not significantly different from the EC values at the other depths or at the same ridge depth in this treatment. It appears unlikely that cotton growth was being affected by salinity at the time of sampling, since 5.4 mS cm^{-1} is well within the tolerance limits for cotton of 10 mS cm^{-1} for a 50% yield reduction (Richards 1954) and 6.7 mS cm^{-1} for no yield reduction (Hart 1974).

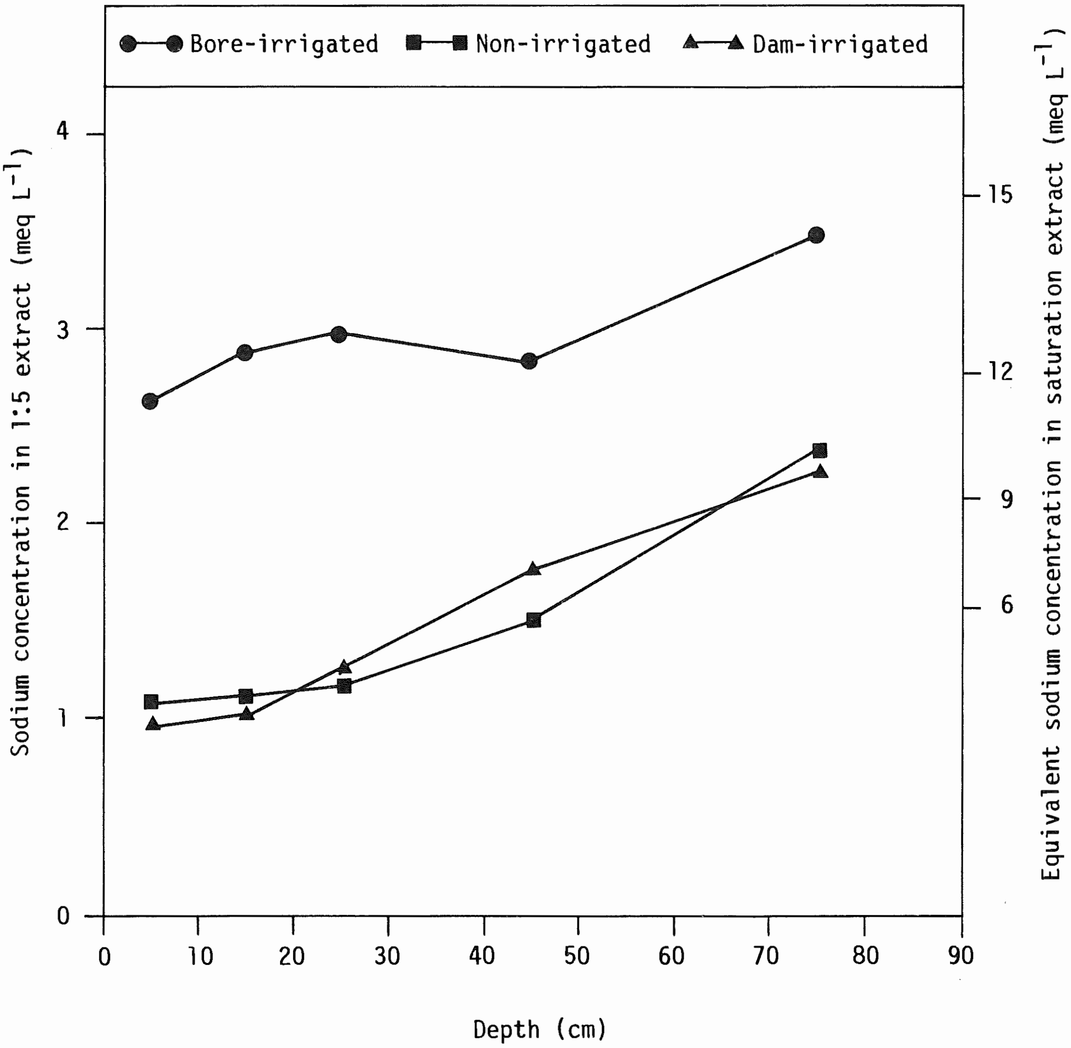

Figure 2. Variation in sodium with depth for the three irrigation treatments.

Since the 1975-76 summer, visible surface salt has been appearing on some areas of the farm receiving bore water, and during February 1976, an EC_{sat} value of 14.2 mS cm^{-1} was recorded for the 0-15 cm depth (IPMU 1977). As yet there have been no real indications that yields have been reduced by salinity, although yield comparisons have been made difficult by the use of different cultivars on some sections of the farm. The surface salt accumulations have so far been confined to the later months of the growing season when the mature cotton plants would be more tolerant of osmotic stress.

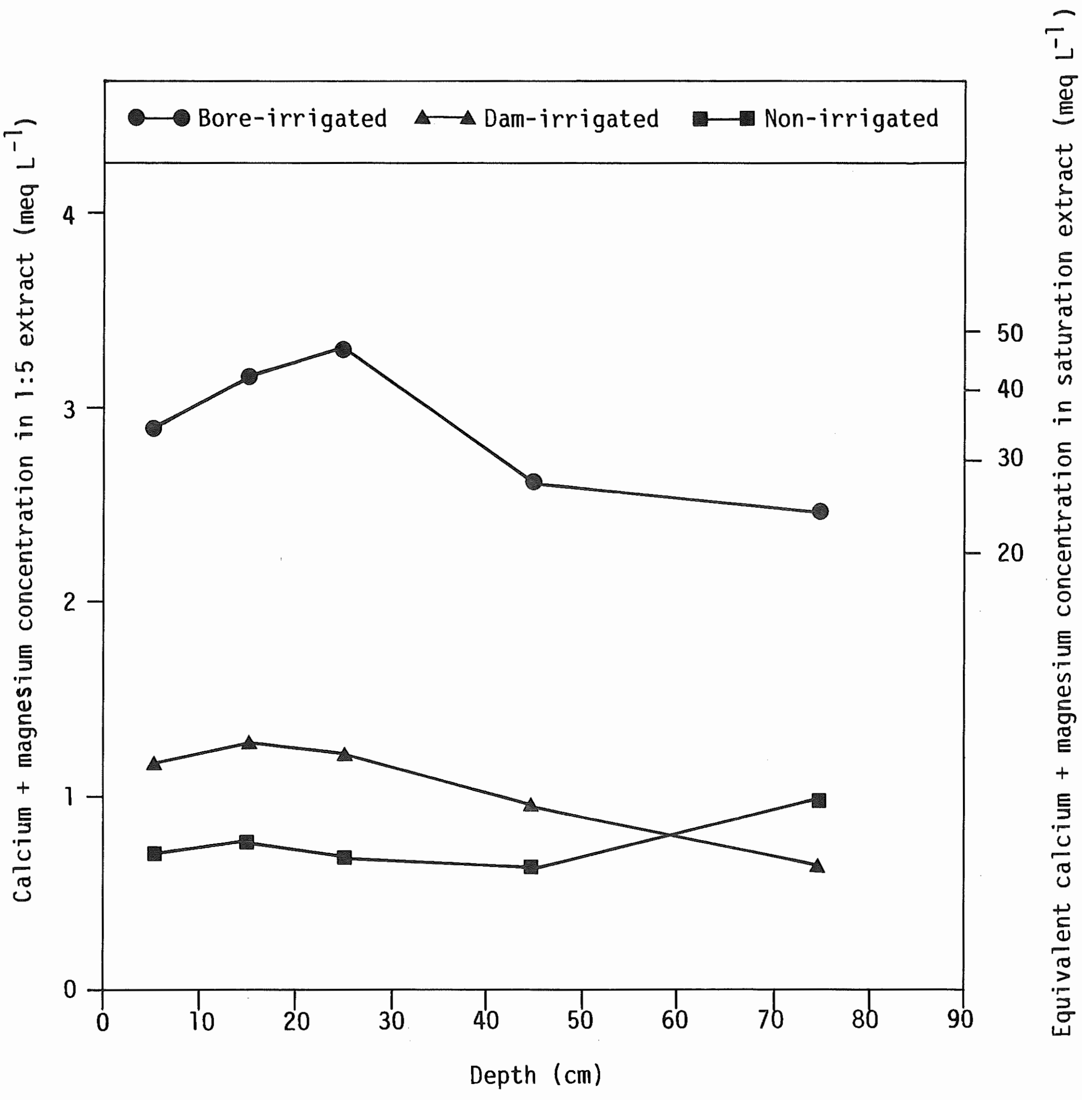

Figure 3. Variation in calcium plus magnesium with depth for the three irrigation treatments.

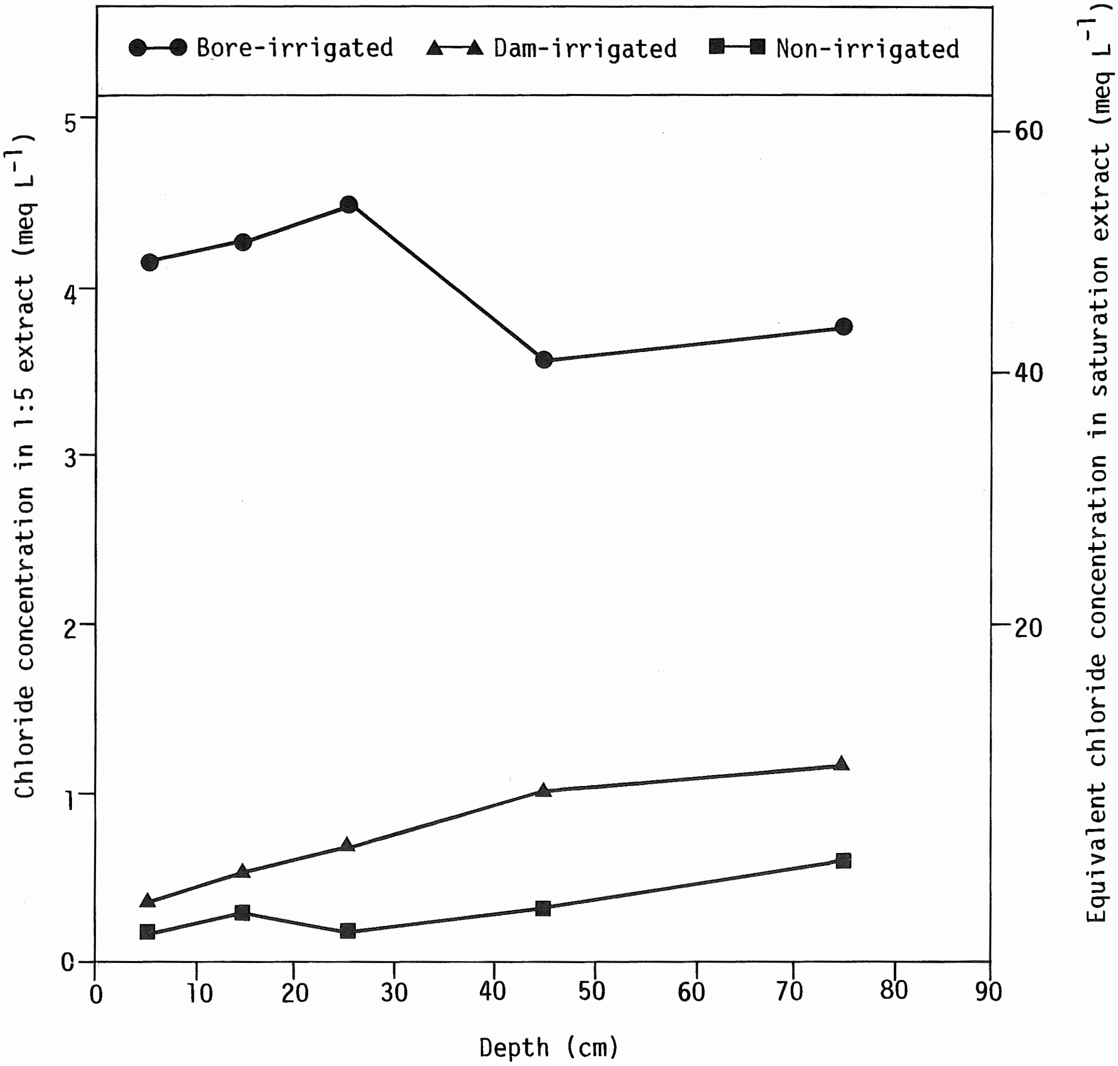

Figure 4. Variation in chloride with depth for the three irrigation treatments.

The available evidence indicates tht these recent occurrences of surface salt have resulted from large short term increases within a single growing season and not from an overall long term increase. In the 1964 study, there was little difference in EC between areas which had been irrigated for 5, 15 and 25 years with bore water (Talbot *et al.* 1971). Generally, the EC values from these two studies, which were both sampled during December, are quite similar and are mainly within the range of 3 to 5 mS cm^{-1} on a saturation extract basis.

Since there appears to be no appreciable long term increase in soil salinity, leaching must account for the movement of salt through the profile. These black earths characteristically have a low permeability when wet, but leaching of salt could occur via the movement of water down vertical cracks when high intensity rain falls on dry soil.

Unseasonably low rainfall could, therefore, increase the short term build-up of salt. During late 1977, rainfall was generally well below average and may have contributed to the latest occurrence of surface salt. However, the major cause of the short term increases in soil salinity which have occurred recently is the increased bore water salinity, and the possibility exists that the water quality will continue to deteriorate and further accentuate the problem.

The SAR for the bore-irrigated treatment was significantly higher than that for the non-irrigated treatment at the 10 to 20 cm depth, but the differences over the other four depth ranges were not significant (Figure 5). Therefore, soil sodicity was little affected by the bore water. Using the SAR/ESP relationship given by Richards (1954), it is evident that the ESP levels in all treatments are generally well below 6, indicating that no structural problems due to sodium should occur (Northcote and Skene 1972). Also, the surface ESP values which were obtained 2 years later were very low (Table 3).

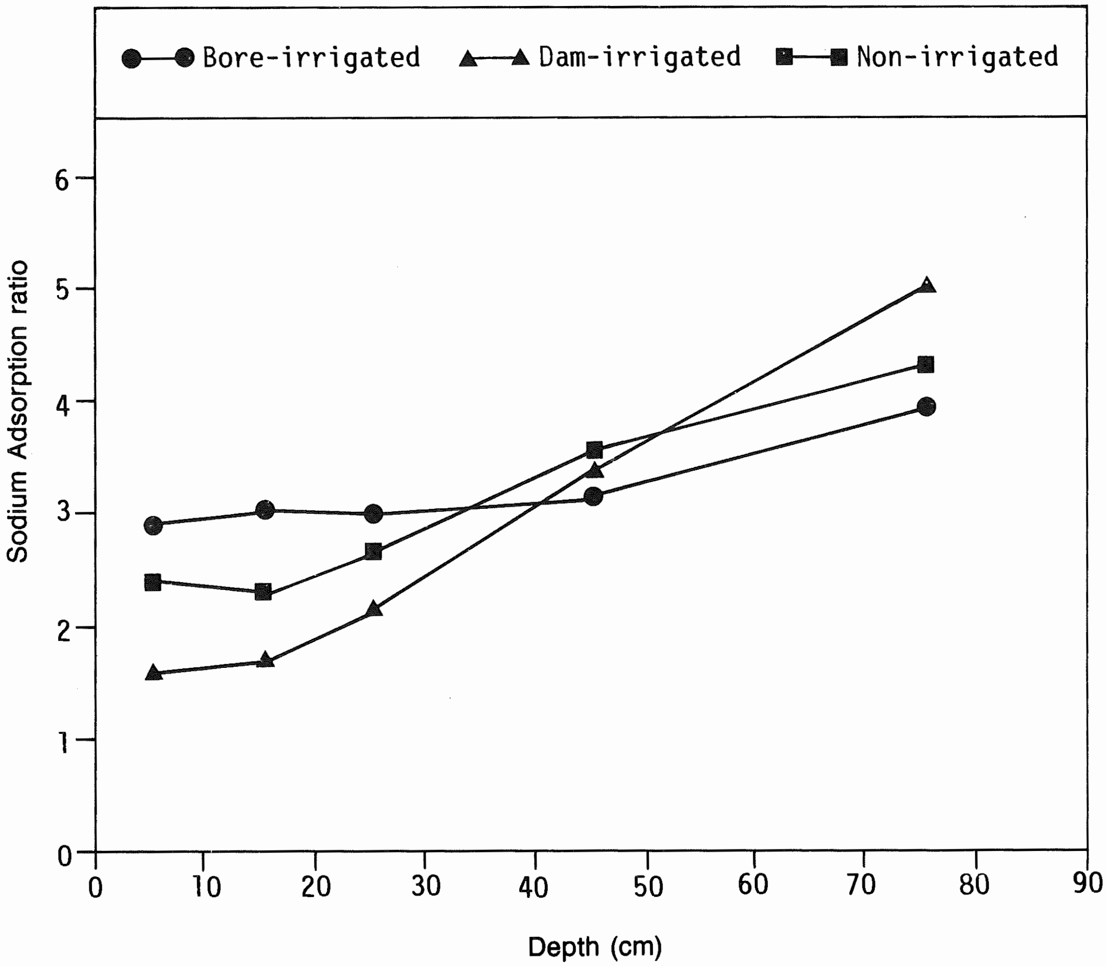

Figure 5. Variation in sodium adsorption ratio with depth for the three irrigation treatments.

Table 3. Exchangeable bases in the surface soil (0 to 10 cm)

Treatment	Basic cations (meq per 100 g soil)					ESP	Ca^{++}/Mg^{++}
	K^+	Na^+	Ca^{++}	Mg^{++}	Total		
Bore-irrigated	0.95	2.2	22.3	32.1	57.6	3.8	0.7
Dam-irrigated	1.2	1.7	27.5	25.5	55.9	3.0	1.1
Non-irrigated	1.8	0.41	19.5	13.6	35.3	1.2*	1.4

* Value overestimated because cation exchange capacity exceeded the sum of basic cations in this soil.

The pH means in the bore-irrigated treatment were significantly higher than those in the non-irrigated treatment, except at the 60 to 90 cm furrow depth and 30 to 60 cm and 60 to 90 cm ridge depths, where the differences were not significant (Figure 6). Bore water irrigation has caused the pH to rise over most depths, although the soil appears to have been originally of high pH at depth.

The dam water had a much lower salt content and lower SAR than the bore water (Table 2). The soil types in the catchment area are derived from old marine deposits, and subsurface drainage and surface runoff into the dam could account for the presence of small amounts of salt in the dam water.

Mean values for $EC_{1:5}$, sodium plus magnesium and chloride were all significantly lower in the dam-irrigated treatment than in the bore-irrigated treatment, over all five depth ranges (Figures 1, 2, 3 and 4, respectively). The dam-irrigated treatment had a significantly greater EC at the 10 to 20 cm ridge depth, compared to the non-irrigated treatment, but the differences over the other depths were not significant. Sodium, calcium plus magnesium and chloride were not significantly different, with the exception of chloride at 30 to 60 cm which was higher in the dam-irrigated treatment than in the non-irrigated treatment.

After 5 years of irrigation with the dam water, soil salinity levels fell markedly. This reduction in salinity can be attributed to the leaching action of the low salinity water and also of the rainfall. In another part of the Lockyer Valley, Talbot and Bruce (1974) found that 11 years after bore-water irrigation had been discontinued, the rainfall had similarly desalinised a clay soil. It was also found that 3 months of unusually high rainfall had substantially reduced salt levels in the top 45 cm of the profile. In each of these three cases, the existence of a low sodium hazard appears to have facilitated the leaching of the salts.

The SAR means were significantly lower in the dam-irrigated treatment than in the bore-irrigated treatment, except at 30 to 60 cm and 60 to 90 cm where the differences were not significant (Figure 5). At 0 to 10 cm, the SAR was significantly lower in the dam-irrigated treatment than in the non-irrigated treatment. The low SAR values near the surface in the dam-irrigated soil would have resulted from the valence-dilution effect and the preferential leaching of sodium.

Although the pH rose as a result of bore water irrigation, the leaching out of the salts did not result in a reduction in pH (Figure 6). The pH values in the dam-irrigated treatment were higher than in the bore-irrigated treatment at the 0 to 10 cm and 10 to 20 cm furrow depths and were not significantly different for the other depths. The higher pH may have been a result of free carbonate which could have been precipitated from the irrigation water.

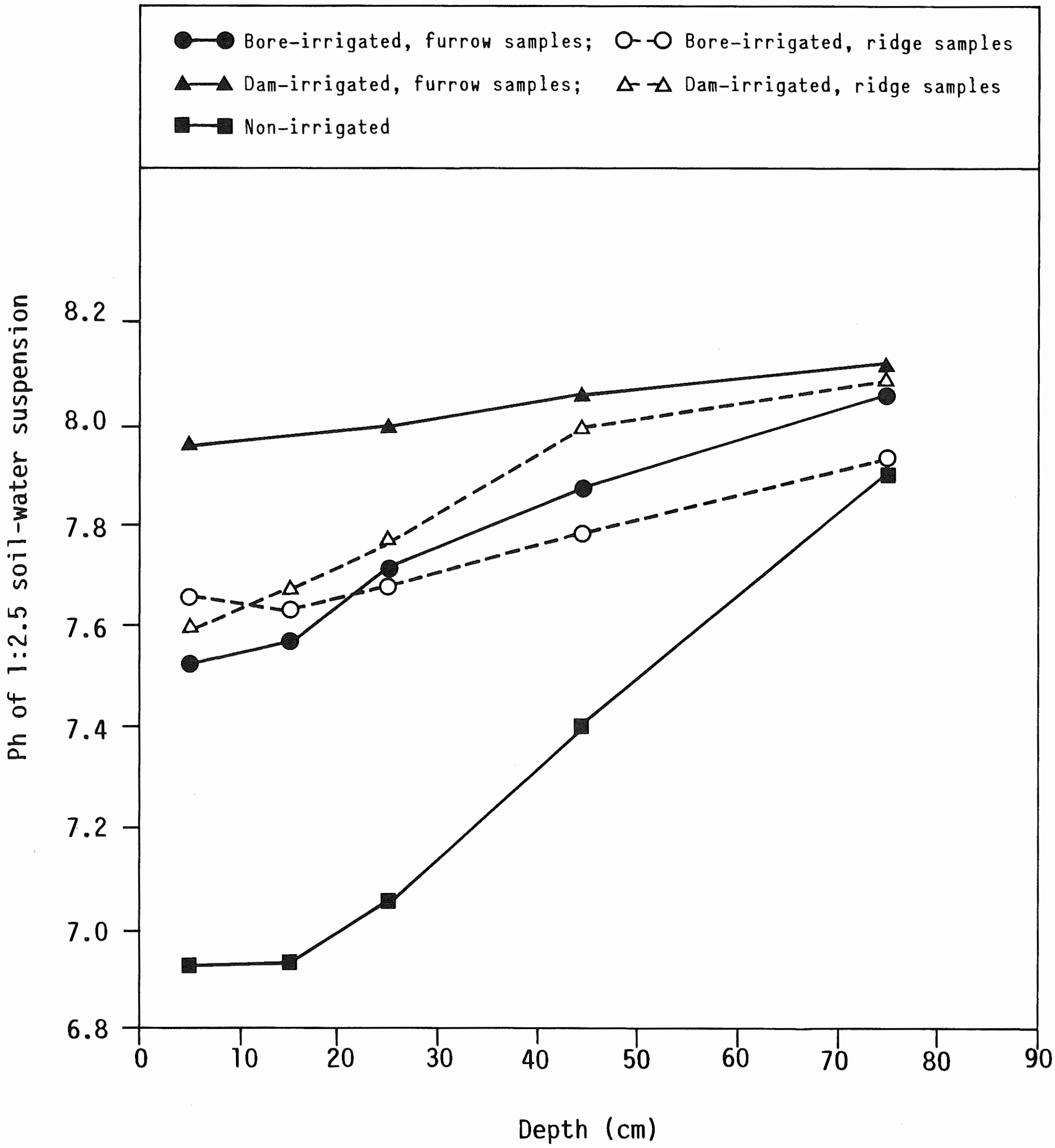

Figure 6. Variation in pH with depth for the three irrigation treatments.

3. CHANGES IN SOIL PHYSICAL PROPERTIES

Materials and methods

In April 1979, a composite surface furrow sample (0 to 10 cm) was taken from each of three treatments, care being taken not to destroy aggregate structure. Using a Rotap sieve shaker, dry sieving measurements were made on four 200 g subsamples for each treatment. Sieve sizes were 9.5 mm, 5.0 mm, 2.0 mm, 1.0 mm and 0.5 mm, and the sieving time was 5 s. The wet aggregate size distribution was also determined on four 25 g subsamples using a Yoder sieving machine (Kemper and Chepil 1965). Pre-wetting was carried out on a tension table at 10 cm tension aided by intermittent spray wetting with an atomiser. The sieving time was 20 min with an oscillation frequency of 38 cycles per minute and an amplitude of 2 cm. Sieve sizes of 10 mm, 5 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm and 0.12 mm were used. A sample from each treatment was ground to 2 mm, and particle size distributions were measured by the pipette sampling method described by Day (1965).

Surface samples were also taken from the two irrigated treatments during August 1978 for aggregate stability tests using a modification of the water/alcohol method described by Taylor and Ashcroft (1972). A 20 mL aliquot of each water/ethanol mixture was added to three 5 mm aggregates in 50 mL beakers, with three replications for each treatment. Additionally from each treatment, a sample was ground to 2 mm, and two replicate series of seven 1:5 soil: water suspensions (10 g soil in 50 mL water) were prepared to examine the response to added gypsum. The suspensions were put on a mechanical shaker for 1 h and then left to stand for 30 min. Quantities of gypsum equivalent to rates of 0, 2, 4, 6, 8, 10 and 15 t ha^{-1} (assuming 30 cm soil depth) were added. After shaking for another hour, the suspensions were left to stand again. Observations were made on the rates of setting and clearing of the suspensions over a period of 3 h.

Results and discussion

The results of the particle size analysis revealed similar fractions of clay in all three treatment samples, but slightly less silt and more fine sand in the dam-irrigated samples compared to the other two samples (Table 4). In relation to the alluvial influence (Sandy Creek) in this particular section of the Lockyer Valley, the sampling area in the dam-irrigated treatment was situated slightly further away than the sampling areas of the other two treatments, which might account for the textural difference. Surface soil structure in the field did not show any visible trend in a perpendicular direction to the creek, within any one irrigation treatment. Because the observable differences in field surface soil structure coincided with the changes in irrigation water source, it was concluded that the structural differences were a result of the different types of irrigation water used.

Table 4. Particle size analysis (%) of the surface soil (0 to 10 cm)

Treatment	Clay <0.002 mm	Silt 0.02–0.002 mm	Fine sand 0.2–0.02 mm	Coarse sand 2.0–0.2 mm
Bore-irrigated	58	23	16	3
Dam-irrigated	57	12	26	5
Non-irrigated	59	17	20	4

The bore-irrigated soil had a significantly larger portion of >9.5 mm dry aggregates than the dam-irrigated soil, whereas the latter had significantly larger portions of the 2 to 5 mm, 1 to 2 mm and 0.5 to 1.0 mm size classes (Table 5). The non-irrigated soil also had significantly larger portions of >9.5 mm and 5.0 to 9.5 mm size classes than the dam-irrigated soil, and the latter had significantly larger 1.0 to 2.0 mm and 0.5 to 1.0 mm classes. These results support the field observations of smaller surface aggregates in the dam-irrigated soil than in the other two treatments. The bore-irrigated and non-irrigated soils had similar aggregate size distributions, except for a significantly larger 5.0 to 9.5 mm size class in the latter.

Table 5. Aggregate size distributions (%) of the surface soil (0 to 10 cm) after dry sieving

Size class (mm)	Treatment		
	Bore-irrigated	Dam-irrigated	Non-irrigated
>9.5	43	24	40
5.0–9.5	20	22	24
2.0–5.0	22	31	26
1.0–2.0	10	17	7
0.5–1.0	3	4	2
<0.5	2	2	1

After wet sieving, these aggregate size differences disappeared, with no significant differences among treatments (Table 6). Furthermore, the water/alcohol stability test showed no marked difference between the two irrigated soils. In two replicates, the dam-irrigated aggregates were unslaked at 0% and 10% water, whereas the bore-irrigated aggregates were unslaked at 0%, 10% and 20% water. In the other replicate, both soils were unslaked at 0%, 10% and 20% water.

Table 6. Aggregate size distributions (%) of the surface soil (0 to 10 cm) after wet sieving

Size class (mm)	Treatment		
	Bore-irrigated	Dam-irrigated	Non-irrigated
>10.0	9	13	20
5.0–10.0	25	21	34
2.0–5.0	37	31	29
1.0–2.0	13	14	8
0.5–1.0	9	12	5
0.25–0.50	5	7	3
0.12–0.25	2	2	1
<0.12	<1	<1	<1

The results of the gypsum application experiment reflected the difference in electrolyte concentration between the bore-irrigated and dam-irrigated soils. After the initial shaking, the bore-irrigated soil suspensions began to settle out, whereas the dam-irrigated soil suspensions remained completely dispersed after 30 min. The application of gypsum to the dam-irrigated soil suspensions resulted in increased rates of settling and clearing up to the 6 t ha^{-1} treatment, with no further increase above this level. The application of gypsum to the bore-irrigated soil suspensions had very little effect, and all of the bore-irrigated soil suspensions settled faster than any of the dam-irrigated soil suspensions. The electrolyte concentration in the bore-irrigated soil, therefore, appeared to have a greater flocculating action than had gypsum, the effect of which is limited by its solubility product.

These results suggest that the two irrigated soils behave similarly during wetting, but differ in some way during the reflocculation and reaggregation phase to give different dry aggregate size distributions. This difference does not appear to be due to high exchangeable sodium, since the surface SAR and ESP values (Figure 5 and Table 3, respectively) were low in relation to the classification of Northcote and Skene (1972). Additionally, the bore-irrigated soil, which appears to have a dry aggregate size distribution approximating that of the normal unirrigated soil, had a higher ESP and a lower exchangeable Ca/Mg ratio (Table 3) than the dam-irrigated soil. The different structure in the dam-irrigated soil cannot be explained on the basis of a total loss of electrolytes, since the electrolyte levels in the dam-irrigated and non-irrigated soils were similar (Figure 1) and appear to represent the natural electrolyte concentration in this soil. Conversely, however, the high electrolyte concentration in the bore water could be beneficial in reducing swelling and dispersion and promoting flocculation under conditions of furrow irrigation.

High levels of exchangeable magnesium have been found to enhance swelling and dispersion at ESP values below 6 (Emerson 1977). In each of the soils, the magnesium saturation of the exchange complex was high, being 56%, 46% and 38% for the bore-irrigated, dam-irrigated and non-irrigated soils, respectively. The associated exchangeable calcium/exchangeable magnesium ratios were 0.7, 1.1 and 1.4. The high electrolyte concentration in the bore-irrigated soil would reduce any effect of the magnesium to enhance dispersion, but it is possible that, at the lower electrolyte concentration in the dam-irrigated soil, the magnesium saturation of the exchange complex was sufficiently high to produce some dispersion following wetting.

4. GENERAL DISCUSSION

Recent droughts have highlighted the need for a detailed assessment of soil and water salinity in the Lockyer Valley, and a Department of Primary Industries survey is currently in progress (White 1980). The survey has found that one third of the total irrigated area uses ground water of a higher than medium salinity hazard (9.9 to 19.8 meq chloride per litre). Although the total irrigated area has stabilised over the last decade, and documented increases in ground water salinity have been limited and localised, the effect of a period of sustained drought on water supply and quality could threaten agricultural production in the Lockyer Valley (White 1980).

For the farm considered in this study, underground water quality has deteriorated since 1947 (Talbot *et al.* 1971) and is currently well above the extreme salinity hazard level of 36.7 meq chloride per litre quoted by White (1980) for bores in the Lockyer Valley. In this valley, the Forest Hill/Sandy Creek district is one of the problem areas, within which Moira Farm ranks as a moderately high risk (Talbot, personal communication). In this regard, the construction of the dam storage system as an alternative water source has been fully justified. Although the capacity of the dam is insufficient to meet the full needs of the farm, any future problems could be averted over most of the farm by mixing the bore and dam waters if necessary.

The desalinisation of part of the farm through the use of dam water has minimised the salinity risk to cotton and also restored the option of less salt-tolerant crops, although sensitive crops such as french beans could still be at risk. The alteration in soil structure resulting from a change in water source has had no noticeable effect on cotton growth. Moderate applications of gypsum (<6 t ha^{-1}), however, may result in an improved seedbed; field trials would enable this hypothesis to be tested.

5. ACKNOWLEDGEMENTS

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