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LONG-TERM EFFECTS OF SALINE IRRIGATION WATER ON SATURATION EXTRACT DETERMINATIONS OF A CLAY SOIL IN THE LOCKYER VALLEY, QUEENSLAND

By R. J. Talbot, B.Agr.Sc., Q.D.H., T. Dickson, B.Sc., and I. J. Bruce, B.Sc., B.Ed.

SUMMARY

An investigation was undertaken to determine the effects of using saline water for irrigation on a heavy self-mulching clay in the Forest Hill area of the Lockyer Valley. The soils studied had been irrigated for periods of 5, 15 and 25 years respectively.

Conductivity and ionic composition of saturation extracts covering 3 ft of profile were measured to gauge the extent of salinization resulting from the irrigation treatments applied.

The increase in water-soluble salts to a depth of 2 ft is rapid during the first 5 years of irrigation, but thereafter the increase is more gradual. After 15 years of irrigation the profile to a depth of 30 in. has been salinized as indicated by conductivity determinations of saturation extracts in excess of 4·0 millimhos/cm. Highest levels of salinity are encountered in the 12–24 in. portion of the profile. Increases in salinity have been accompanied by increases in pH.

I. INTRODUCTION

The agricultural soils of the Lockyer Valley are classified as black earths and are Quaternary alluvium of mixed origin derived from basalts, sandstones, conglomerates and shales. They are predominantly very dark to dark-brown clays and clay loams with high inherent fertility. The texture of the soils varies depending on their position in relation to the watercourses. The soils show a textural gradation away from and at right-angles to the stream flow. This gradation also occurs along the valleys of the creeks, the heavier soils being found furthest from the source.

The soil studied in this experiment was a heavy self-mulching clay of high water-holding capacity. It is typical of many of the alluvial soils occurring in the Forest Hill–Laidley area and also surrounding the lower reaches of the Lockyer Creek catchment.

Supplementary irrigation of agricultural crops is carried out extensively in the Lockyer Valley, the prime source of irrigation water being underground. Talbot (unpublished data) has found that the quality of underground water is very variable, the chloride concentration ranging from 20 to over 200 grains/gal. This factor has an important bearing on cropping practice, as salt-sensitive crops such as potatoes and beans are intolerant of highly saline water.

The site for this investigation was selected because the property was in an area where underground water is generally of poor quality, and because the property owner had kept reasonable records of the irrigation history of various sections of the farm. The areas studied had been irrigated for the periods set out in the text. Since 1959 cotton has been the only crop grown. For 2 years this was irrigated by spray methods, but since 1961 surface irrigation has been used exclusively. Prior to 1959 crops grown by spray irrigation were lucerne and onions, and an occasional crop of maize was grown under dryland conditions.

This investigation was aimed at determining the effect of continued use of poor quality irrigation water on the soil and in particular its effect on salinity levels.

II. MATERIALS AND METHODS

Four sampling sites were selected to represent areas which had been irrigated for various periods. The periods involved were 0, 5, 15 and 25 years and are hereafter referred to as the treatments.

Water quality of area investigated.—During the 15-year period preceding sampling (December 1964) several new bores were developed and some old bores abandoned. For this reason it is not possible to state that any of the areas irrigated for specific periods has been irrigated with water of constant composition. The quality of water being utilized at the time of soil sampling can be ascertained by reference to Table 1.

TABLE 1

CHEMICAL COMPOSITION OF WATER USED FOR IRRIGATION

Source	Date	Conductivity (micromhos/cm 25°C)	Ionic Composition (m-equiv./litre)					Sodium Adsorption Ratio
			Ca^{++}	Mg^{++}	Na^{++}	HCO_3^-	Cl^-	
Bore 1 ..	Oct. 1964	5,181	10·9	27·7	14·8	8·2	44·8	3·37
Bore 2 ..	Oct. 1964	5,524	11·1	29·1	18·8	8·7	50·1	4·19
Bore 3 ..	Oct. 1964	6,329	10·9	30·6	LOST	9·5	57·4	..
Composite: Bores 1, 2, 3	Oct. 1964	5,434	10·8	29·6	20·0	8·8	51·0	4·45
Sample 1* ..	Nov. 1947	..	12·3	20·9	8·3 by diff.	7·4	34·1	2·04
Sample 2* ..	Nov. 1947	..	8·7	16·1	7·3 by diff.	8·2	23·9	2·07

* From farmers' records—partial analysis by Queensland Department of Primary Industries (1947).

The water which has been used on the various irrigation treatments is as follows—

25-Year irrigation

19 years—abandoned bore in vicinity of present bore 1.
5 years—bore 3.
1 year —composite of bores 1, 2, 3.

15-Year irrigation

14 years—bore 2.
1 year —composite of bores 1, 2, 3.

5-Year irrigation

4 years—bore 2.
1 year —composite of bores 1, 2, 3.

It is not known what changes in quality of water may have occurred in individual bores over the irrigation periods considered. There is some evidence to indicate that salinity levels in the underground aquifers of the farm as a whole have increased since 1947. It is for this reason that partial analysis figures for two bores in use in 1947 but now defunct are included in Table 1.

The analytical data of the three bores in use when soil samples were obtained indicate that they were too saline to be recommended for the irrigation of even salt-tolerant crops.

Soil sampling.—Fifteen samples from each of the four areas were taken to a depth of 36 in., using a hand auger. Samples were obtained for the following depths:— 0–3 in.; 3–6 in.; 6–9 in.; 9–12 in.; 12–18 in.; 18–24 in.; 24–30 in.; 30–36 in. Sampling was done on a 2·5 x 2·0 chain grid in each of the 5, 15 and 25-year irrigation areas. As the area which had not received irrigation was limited, the required number of samples was obtained on a 2·3 x 1·3 chain grid. Samples were air-dried and ground to pass a 2 mm sieve.

Chemical methods.—pH was determined on a 1:2·5 soil:water extract using a Jones Model O electric pH meter. Saturation extracts were obtained by the method set out by Richards (1954). Four hours' standing was employed between saturation and extraction, the extract being obtained by centrifuging at 3000–4000 r.p.m. rather than filtering through Buchner funnels.

The following determinations were made on each saturation extract:—

(1) Electrical conductivity by use of a Philips Conductivity Measuring Bridge Model GM4249 using immersion cell type PR9510. Conductivities are expressed in the units millimhos/cm (25°C).

(2) Calcium and magnesium by E.D.T.A. titration using Eriochrome T Black indicator after the method of Cheng & Bray (1951).

(3) Sodium by use of the E.E.L. flame photometer.

(4) Chloride by Mohr titration using silver nitrate as outlined by Richards (1954).

While analytical determinations were performed on eight samples from each profile sampled covering the depths already mentioned, results were averaged for each profile over the depths 3–12 in. and 12–24 in. In plotting values shown on Figures 1 to 6 the value 0–3 in. is plotted at 3 in.; 3–12 in. at 12 in.; 12–24 in. at 24 in.; 24–30 in. at 30 in.; and 30–36 in. at 36 in.

III. RESULTS

For each of six measured properties, treatment means at five different depths were plotted against depth. When F tests led to rejection of hypotheses of no differences among means within and between treatments, Fisher's L.S.D. test was used to examine paired differences between means. Second degree polynomials were also fitted to the data. The relevant regression equations and coefficients of correlation are shown in Figures 1–6. These were fitted in order to smooth out fluctuations in the data rather than to represent any actual relationships between the variables. In some cases the second degree regressions were not significant at the 5% level, and higher degree polynomials may in fact have given a better fit. However, it was felt that this would be of little value, as the conclusions to be drawn from the data would not be affected.

Except in the case of pH, fitted curves for measured properties show concavity upwards in the non-irrigated area. The curves for sodium ion concentration and sodium adsorption ratio after 5 years of irrigation are also concave upwards. All other curves, except those for pH, are concave downwards. The magnitude of the concavity appears to be a function of the period of irrigation.

pH.—Values for pH are shown in Figure 1.

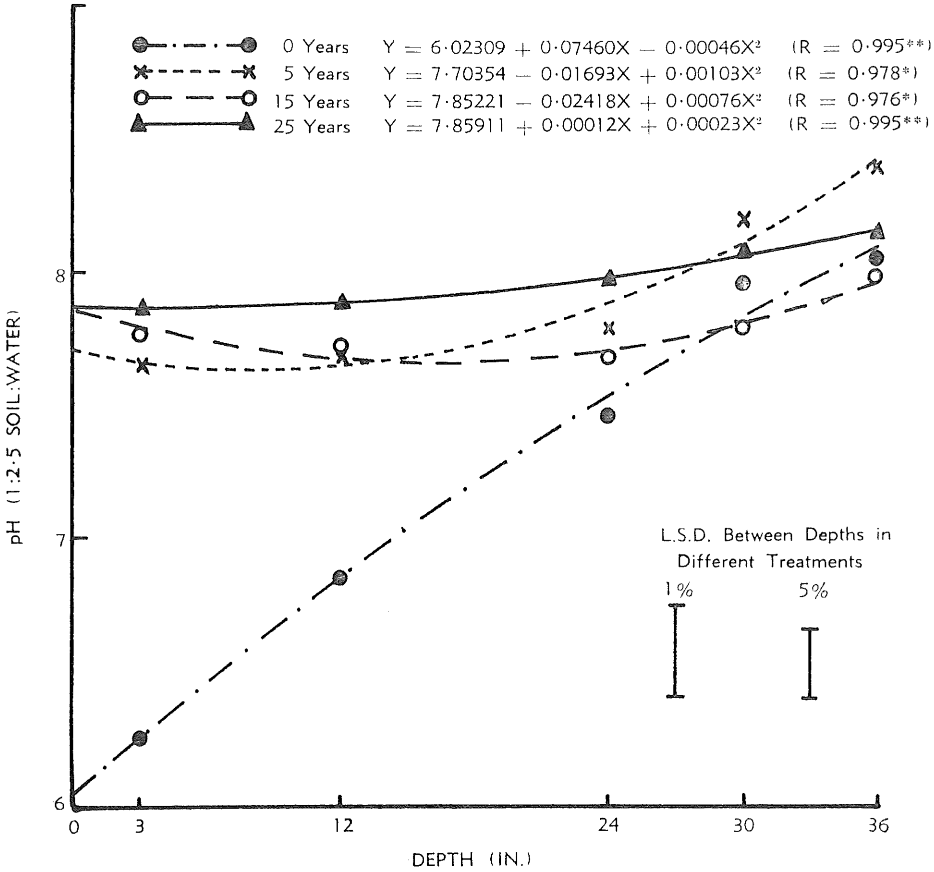

Fig. 1.—Variation of pH with depth of profile and differing periods of irrigation.

All correlations between pH and depth are significant. The fitted curves are of slight curvature, being concave downwards for the non-irrigated area and concave upwards in all other treatments. For the non-irrigated area there are significant differences between the means for the 0–3 in., 3–12 in., 12–24 in. and 24–30 in. zones, demonstrating a steady increase in pH to a depth of 30 in. The mean pH at 30–36 in. is not significantly higher than that for 24–30 in. In the 5-year treatment, the mean pH in the 24–30 in. zone is 8·22, which significantly exceeds the means of the 0–3 in., 3–12 in. and 12–24 in. zones, and which is followed by a significant increase to 8·41 in the 30–36 in. zone. The results for the 15-year treatment show a significant difference between the means of the zones at 24–30 in. and 30–36 in. At 25 years, the 30–36 in. zone mean does not differ significantly from the 24–30 in. mean, but the 24–30 in. mean exceeds the 0–3 in. and 3–12 in. means, while the 30–36 in. mean exceeds the mean pH of the 12–24 in. zone.

When comparisons are made between treatments the means for the non-irrigated area are significantly less than the means for the other treatments for the first three zones. The only other significant difference for these zones is at 12–24 in., where the mean pH of the 25-year treatment exceeds that of the 15-year treatment. In the 24–30 in. zone the means of the 5 and 25-year treatments significantly exceed the mean of the 15-year treatment. In the 30–36 in. zone the mean for 5 years is significantly greater than the means at 0 years and 15 years.

Electrical conductivity.—Values for electrical conductivity appear in Figure 2.

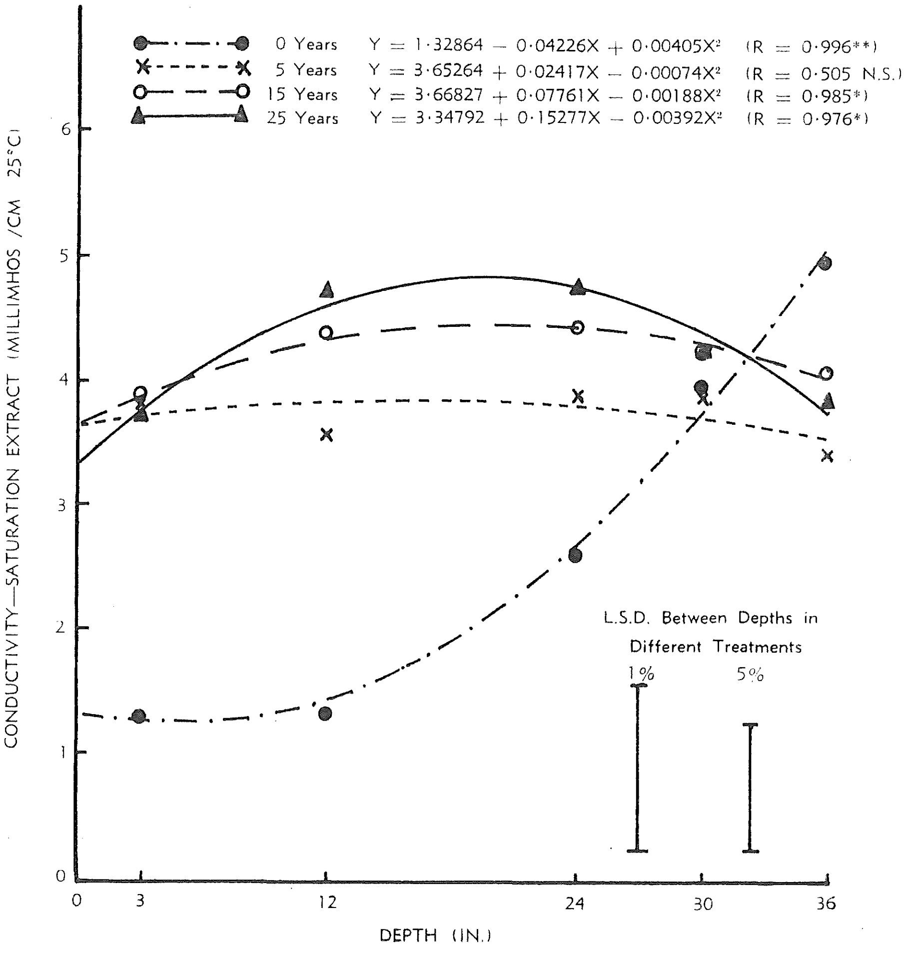

Fig. 2.—Variation of conductivity of the saturation extract with depth of profile and differing periods of irrigation.

No significant correlation between mean conductivity and depth was obtained for the 5-year treatment. Within this treatment there are no significant differences between means, the mean conductivity throughout the profile being 3·73 millimhos/cm.

The other correlations are all significant. For 0 years the curve is concave upwards, representing a succession of significant increases in mean conductivity with increasing depth. The other curves are concave downwards and reach maximum values in the 12–24 in. zone. However, the only differences which are statistically significant are for 25 years, where the mean conductivity in the 12–24 in. zone (4·76 millimhos/cm) exceeds the means for the 0–3 in. and 30–36 in. zones, which are 3·72 and 3·85 millimhos/cm respectively.

For the surface 24 in. of the profile of the non-irrigated area, mean conductivities are significantly lower than the means of the other treatments. In the 3–12 in. region the mean for 25 years is significantly greater than the mean for 5 years.

The largest value is 4·95 millimhos/cm, which occurs at the 30–36 in. level in the 0-year treatment. It is significantly greater than the 5 and 15-year means for that depth.

Divalent cations ($Ca^{++} + Mg^{++}$).—Values for divalent cations are given in Figure 3.

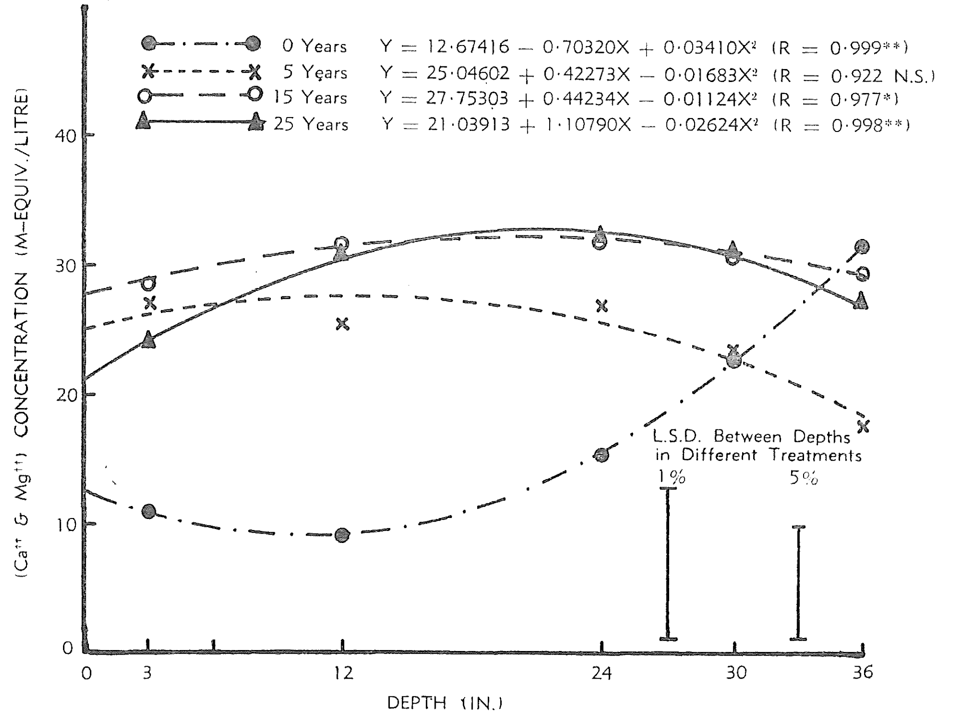

Fig. 3.—Variation of $Ca^{++} + Mg^{++}$ concentration with depth of profile and differing periods of irrigation.

Significant coefficients of correlation were obtained in this case for the 0, 15 and 25-year treatments. The curve for the 0-year treatment means is concave upwards. The others are concave downwards, appearing to reach maximum values in the 12–24 in. zone. The 0-year curve is associated with significant increases in mean concentration from 9·01 m-equiv./litre at 3–12 in. to 31·35 m-equiv./litre at 30–36 in. For 5 years the value at 30–36 in. of 17·53 m-equiv./litre is significantly lower than the means for the other zones, which do not differ appreciably among themselves. There are no significant differences among the means within the 15-year treatment, the average concentration being 30·46 m-equiv./litre. At 25 years the mean for the 0–3 in. zone is significantly lower than the means for the 3–12 in., 12–24 in. and 24–30 in. zones.

For the top three zones of the profile, the means for the 0-year treatment lie significantly below the means for the other treatments, amongst which there are no statistically significant differences. For the two deeper zones, the only significant differences are those between the 5-year mean at 30–36 in. and the other treatment means for this zone.

Sodium.—Sodium values are shown in Figure 4.

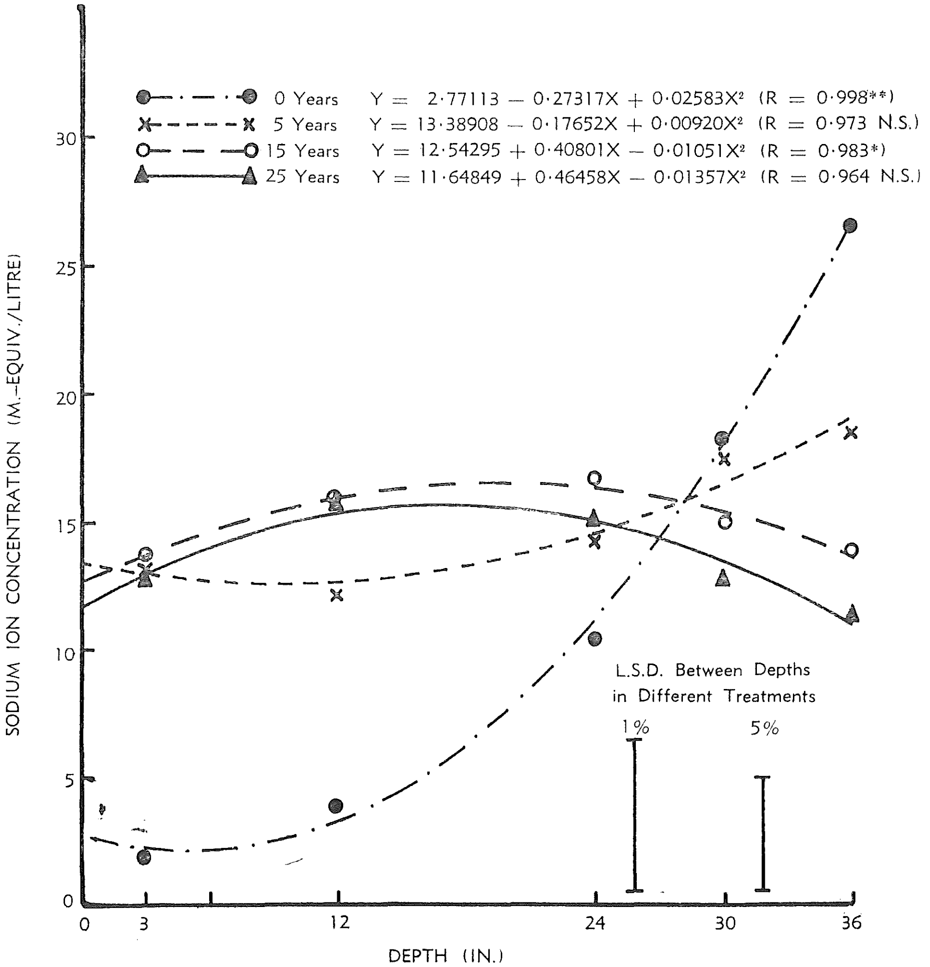

Fig. 4.—Variation of sodium ion concentration with depth of profile and differing periods of irrigation.

Sodium adsorption ratio (*S.A.R.*).—This ratio is shown in Figure 5.

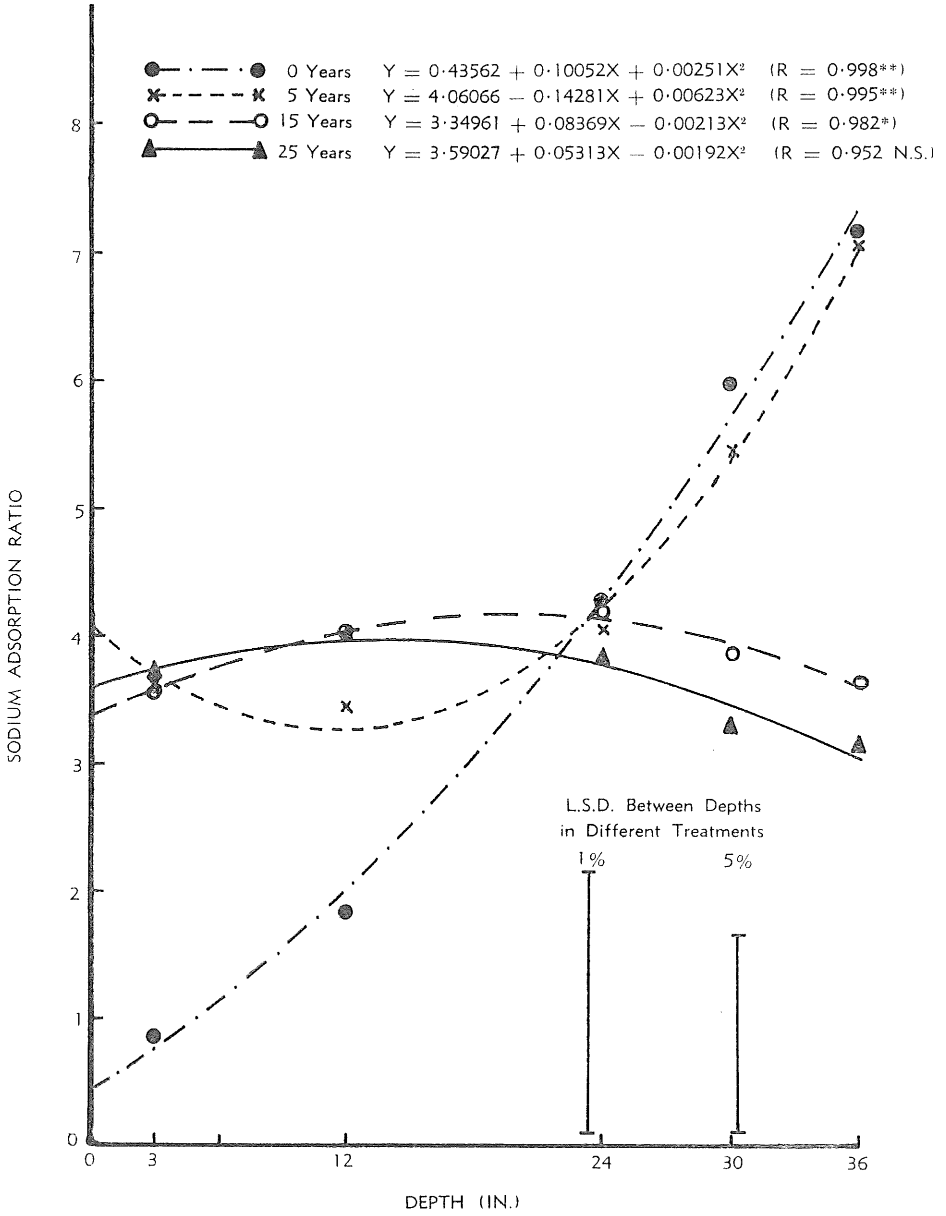

Fig. 5.—Variation of sodium adsorption ratio with depth of profile and differing periods of irrigation.

For these determinations, the fitted curves are concave upwards at 0 and 5 years, and concave downwards at 15 and 25 years. Within the 0-year treatment the mean concentrations for the 0–3 in. and 3–12 in. zones do not differ significantly, but for the other zones there are significant increases in the means of sodium ion concentration with depth, reaching a value of 26·45 m-equiv./litre at 30–36 in. The pattern is similar, but less marked, at 5 years, where the means for the 24–30 in. and 30–36 in. zones significantly exceed the means for the 0–3 in. and 3–12 in. zones, but the 30–36 in. mean is only 18·43 m-equiv./litre. In the 15-year treatment, no differences between means are significant, and in the 25-year treatment the mean for the 30–36 in. zone of 11·21 m-equiv./litre drops significantly below the means for the 3–12 and 12–24 in. zones. The maximum value recorded after 25 years of irrigation was 15·73 m-equiv./litre at 3–12 in.

The sodium ion concentration in the non-irrigated area is significantly less than that in the other areas for the top three zones of the profile, and the other areas do not differ among themselves. For the two deeper zones, the 0-year means tend to be higher than the other treatment means. The pattern is quite striking at the 30–36 in. zone. Here the 15 and 25-year means do not differ significantly, but are both significantly lower than the 5-year mean, which is significantly lower than 0-year mean.

The pattern of differences between treatments for the sodium adsorption ratio is similar to that of sodium ion concentration. Thus the fitted curves are concave upwards at 0 and 5 years and concave downwards at 15 and 25 years. No significant differences between means exist within the 15 or 25-year treatments, mean values of the ratio being 3·86 and 3·58 respectively. Within the 0 and 5-year treatments there are significant increases as depth increases, leading to values of the ratio exceeding 7.

The 0-year treatment means are significantly lower than the other treatment means in the 0–3 in. and 3–12 in. zones, but not elsewhere. In the 24–30 in. and 30–36 in. zones, the 15 and 25-year means are significantly lower than the 0 and 5-year means.

Correlations of chloride ion concentration with depth were significant for the 0, 15 and 25-year treatments. Within the 5-year treatment the mean concentration in the 30–36 in. zone lies significantly below the means for the other zones, which do not differ significantly among themselves.

For the 0-year treatment, the mean concentrations for the 0–3 in. and 3–12 in. zones are not significantly different, but each deeper zone shows a significant increase in mean concentration. At 15 years, the 0–3 in. mean is significantly below the 3–12 in. mean, but there are no other significant differences. At 25 years the mean chloride ion concentration of the 0–3 in. and 30–36 in. zones is significantly less than that of the other three zones of this treatment.

The curve for 0 years is markedly concave upwards, while the other curves are all concave downwards, reaching maxima around the middle of the profile.

At any given depth, the 15 and 25-year treatments do not have significantly different means. The means for the 5-year treatment lie significantly below the means for the 15 and 25-year treatments in the 3–12 in., 12–24 in. and 30–36 in. zones. At 24–30 in., the 5-year mean is significantly less than the 25-year mean.

The 0-year treatment means are less than those of other treatments at 0–3 in., 3–12 in. and 12–24 in. At 24–30 in. they are less than the 15 and 25-year means, while at 30–36 in. the 0-year mean is significantly greater than the 5-year mean.

Chlorides.—Values for chlorides are shown in Figure 6.

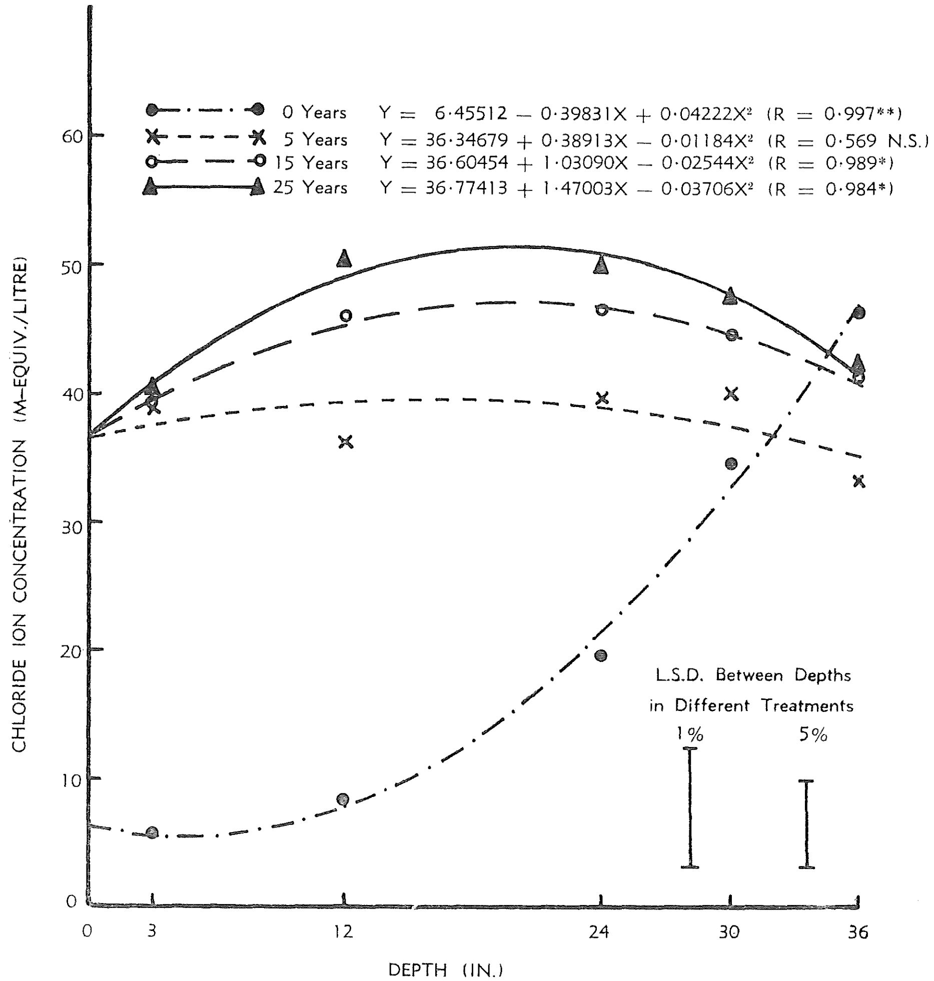

Fig. 6.—Variation of chloride ion concentration with depth of profile and differing periods of irrigation.

IV. DISCUSSION

The non-irrigated area and the 5-year irrigation area were characterized by considerable variations in the 24–36 in. zone in several of the chemical determinants which reflect general salinity levels. In the non-irrigated area this variation was evident in measurements of conductivity, sodium, chlorides, and the ratio between divalent cations and the sodium ion, as indicated by the sodium adsorption ratio. In the area which had been irrigated for 5 years, this variation was confined to sodium ion concentration and the ratio between divalent cations and the sodium ion. This resulted in sodium ion concentration and sodium adsorption ratio at the 36 in. depth of the non-irrigated and 5-year irrigated areas being statistically greater than similar determinants of the 15 and 25-year irrigation areas at a similar depth.

The question arises as to whether or not the whole of the area investigated was originally one of variable salinity at depths greater than 24 in. No records are available to indicate whether or not this was so, but data recorded suggest that such was the case, and that prolonged periods of irrigation have eliminated such variability.

It is possible that the increase in salinity in the top 24 in. of profile following prolonged periods of irrigation (15 and 25 years) has resulted not exclusively from the irrigation water applied, but in part from recycling of soluble salts, particularly sodium chloride, which were originally present at depths greater than 30 in.

Irrigation has resulted in a marked increase in general salinity levels in the top 24 in. of the profile, irrespective of which of the determinations made is used as a criterion for salinity assessment. Increases in salinity levels are rapid during the first 5 years of irrigation, after which increases are much more gradual. Fifteen years of irrigation has resulted in salinization of the top 30 in. of profile, if conductivity of saturation extract determination in excess of 4·0 millimhos/cm is accepted as representing the saline condition. The emergence of a region of maximum concentration near the middle of the profile as the period of irrigation increases to 25 years suggests that with continued irrigation there may be a further build-up of water-soluble salts at this depth, with the result that growth of even salt-tolerant crops may eventually be limited.

V. ACKNOWLEDGEMENT

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R. J. Talbot and I. J. Bruce are on the staff of Queensland Agricultural College, Lawes. T. Dickson is an officer of Agriculture Branch, Queensland Department of Primary Industries.