ACCUMULATION OF SALT IN IRRIGATED NORTH QUEENSLAND TOBACCO SOILS

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SUMMARY

High chloride content of leaf is common in furrow irrigated flue-cured tobacco leaf from the Burdekin Irrigation Area of North Queensland.

Soil chloride content to 30 in. is low at the beginning of the season but a build-up occurs during the season. This accumulation is greatest in the top 6 in. of the row or "hill" position, which is also a zone of extensive root development. The furrow shows little build-up in surface horizons.

Below 12 in. little variation occurs under either row or furrow.

It is considered that plant uptake results from soil chloride which is concentrated in the rows by lateral and upward movement of irrigation water containing moderate amounts of chloride, usually between 30 and 40 p.p.m. Cl.

I. INTRODUCTION

It has been noted over a number of years that the chloride content of irrigated flue-cured tobacco from certain areas of North Queensland is higher than desirable, with values of 2–3 per cent. Cl in leaf frequently encountered and with occasional samples containing up to 6 per cent. Cl in the lugs. Plant growth is not affected, but the detrimental effect of high chloride content in relation to quality, including leaf burn, has long been recognised (Attoe 1946; Myhre, Attoe, and Ogden 1956).

In many cases reported in the literature this chloride content has been attributed to fertilizers containing chloride, but such fertilizers are not used in this area for tobacco. Although recent work (Colbran and Green 1961) points to the importance of soil fumigants in halide uptake, chloride added to the soil in irrigation water has been recognized as important in some areas. For example, Peele, Webb, and Bullock (1960) investigated irrigation waters and their effect on leaf quality of flue-cured tobacco in South Carolina.

The greater proportion of the tobacco crop in the Burdekin area is planted out in spring between mid-August and mid-September. Harvesting generally commences in early November and is completed by the end of December. Early summer storms may occur but frequently the crop is grown completely under irrigation. The area has an average annual rainfall of 25-35 in., most of which is expected in the wet-season months of January, February and March. Evaporation

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rates during the growing season are high, particularly in October and November, when an average evaporation of approximately 8 in. per month has been measured over the past three years.

The pattern of water usage under furrow irrigation in the district varies somewhat, but commonly the first major watering of the crop is made in the planting furrows. It is common practice to withhold water for 4–6 weeks from that time. As the plant approaches maturity, water is applied as required, usually at weekly intervals from prior to first pick. In general, if appreciable rainfall does not occur average irrigation water application is in the vicinity of 20 in. Depending on the technique adopted, an unknown amount of this water runs off and actual penetration varies considerably. In most cases water penetration following irrigation does not exceed 18 in. in depth.

Because of the prevalence of blue mould and the danger of wind damage following possible early summer storms, it is considered necessary in the area to have well-formed beds. Plant rows are usually 42–48 in. apart, with each bed between 18 and 24 in. wide and bed height 5–7 in. above the bottom of the furrow. Soil fumigation about one month prior to planting is accepted practice in the area, with ethylene dibromide the most commonly used fumigant.

II. PROCEDURE AND METHODS

Investigations involved taking soil samples from various field positions and depths over a number of growing seasons. For three seasons, on the selected trial area, randomized sampling sites were taken and at each site soil samples were obtained from the row (hill), midway between rows (furrows) and on the slope of the hill as indicated in Figure 1. Samples were obtained for 0–3 in. and 3–6 in. zones, at 12 in. and in some cases at 18 in. and 24 in. Samples from the row were obtained approximately midway between plants in the row. Complete cross-section samples discussed later were also obtained from this position. For the 1956 crop, detailed leaf analyses were carried out for the experimental area. Soil samples were collected in sealed jars prior to irrigation, and moisture determinations made. Chloride was determined on a suspension of 105°C oven-dry soil by electrometric titration. Samples were allowed to stand with occasional stirring for a minimum of 30 min and titrated with N/71 silver nitrate using a silver/silver chloride electrode and a quinhydrone reference half-cell after the method of Best (1929). In the soils under examination, end point drift is not a problem. Results are expressed as chlorine (p.p.m.) in oven-dry soil.

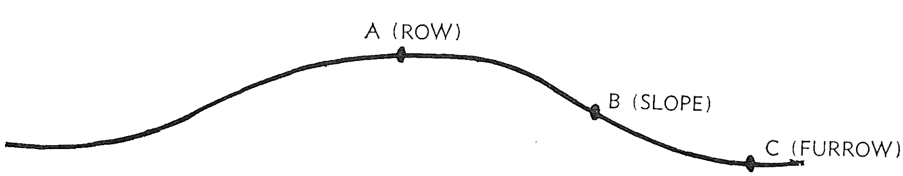

Fig. 1.—Diagram showing positions at which samples were taken in 1954, 1955 and 1956.

TABLE 1

SOIL CHLORIDE CONTENT FOR ROW, SLOPE AND FURROW, 1955 SEASON
(p.p.m. Cl in oven-dry soil (mean values))

Sampling Date	Nov. 2			Nov. 29			Dec. 19		
Position	0–3 in.	3–6 in.	12 in.	0–3 in.	3–6 in.	12 in.	0–3 in.	3–6 in.	12 in.
A—Row	80	57	17	60	35	14	56	36	16
B—Slope	18	17	14	28	19	12	53	31	16
C—Furrow	22	16	13	23	19	10	28	28	13
	A >> B, C	A >> B, C	A > C	A >> B, C	A >> B, C	A > C	no significant difference		

>> at 1% level. > at 5% level.

Leaf samples were dried at approximately 80°C and the midrib removed. The dried leaf-web material was ground to a fine state in a blender and a suspension prepared for chloride determination as in the soil analysis.

III. OBSERVATIONS

(a) Soils

Soil chloride figures quoted refer to mean values for a number of sampling sites in the selected experimental areas.

For the 1954 and 1955 seasons, work was carried out on a soil of the Burdekin Group at Claredale.

During the 1954 season, the chloride content of the 0–3 in. zone of the row rose to 95 p.p.m. Cl early in December, while this zone in the furrow reached a maximum of 65 p.p.m. Cl. For both row and furrow at 12 in., a content of 45 p.p.m. Cl was found.

Results of the 1955 season's work are shown in Table 1. The 0–3 in. zone of the row position contained 80 p.p.m. Cl early in November, while this zone in the furrow contained 22 p.p.m. Cl. Later in the season, sample variability occurred but the mean value for the row position was still twice that of the furrow in the 0–3 in. zone. At 12 in. all positions contained less than 17 p.p.m. Cl and remained below this level throughout the season. Mean values for adjacent fallow land receiving no irrigation water remained less than 23 p.p.m. Cl at 0–3 in. and less than 18 p.p.m. Cl at 12 in. throughout this period.

For the 1956 season, work was carried out on a Burdekin Series soil at Millaroo. Soil samples were obtained as previously and plant samples were taken from the growing crop at the time of each soil sampling.

As shown by Table 2, the maximum level of soil chloride in the 0–3 in. zone of the row was 70 p.p.m. Cl on December 17, while the furrow for this 0–3 in. zone contained 25 p.p.m. Cl. At 12 in., variation throughout the season was not great. Subsequent to the sampling of December 17, over 4 in. of rain fell (December 20–23) and this resulted in a marked decrease in chloride content in the 0–3 in. row position at the next sampling. At this stage three picks had been taken from the crop. Harvesting is usually completed before the onset of the wet season and chloride levels in the row can usually be expected to remain high through the harvest period.

TABLE 2

SOIL CHLORIDE CONTENT FOR ROW AND FURROW, 1956 SEASON

(p.p.m. Cl in oven-dry soil (mean values))

Sampling Date	Oct. 29	Nov. 12	Nov. 19	Nov. 26	Dec. 3	Dec. 10	Dec. 17	D. 2ec8
0–3 in.—Row ..	32	28	31	29	26	45	70	28
0–3 in.—Furrow ..	32	23	30	24	16	30	25	28
12 in.—Row	11	20	22	27	22	15	20	23
12 in.—Furrow ..	11	18	20	19	16	19	16	20

Leaf samples were obtained from a number of plants in the trial area at each soil sampling date and composite samples of each leaf position analysed. Chloride content of 6th and 10th leaf positions is shown in Table 3. These figures indicate the characteristic higher chloride content of the lower leaf position and in both cases show a marked increase in leaf chloride content coinciding with the increase in the soil chloride for the 0–3 in. zone of the rows in mid-December.

TABLE 3

LEAF CHLORIDE CONTENT OF GROWING PLANT, 1956 SEASON

(% Cl)

Sampling Date	Nov. 12	Nov. 19	Nov. 26	Dec. 3	Dec. 10	Dec. 17
6th leaf	2·1	2·1	2·0	2·0	2·0	4·0*
10th leaf	1·4	1·5	1·8	1·9	1·8	3·3
p.p.m. Cl 0–3 in. soil (row)	28·0	31·0	29·0	26·0	45·0	70·0

* Ripe leaf, ready for harvest.

For the 1960 season, a general survey was carried out on eight farms in the district. In August, before planting, soil chloride was found to be less than 20 p.p.m. Cl in all cases. Towards the end of the season, before rainfall, 0–6 in. samples from the rows showed levels generally greater than 50 p.p.m. Cl and in a few cases were greater than 100 p.p.m. Cl. At 18 in. the content remained below 20 p.p.m. Cl throughout with the exception of one farm, where some samples were slightly higher.

A number of detailed profile cross-sections through the row were also obtained. Figure 2 shows a cross-section of a Clare Series soil taken two days after the ninth irrigation of the area and about the time of fifth pick. Figure 3 shows a similar cross-section for a Burdekin Series soil. This soil had received over 2 in. rainfall some days prior to sampling. The area had received seven waterings and was sampled about the time of the third pick. Although the concentration in the better-drained Burdekin Series soil is less, a similar trend is observed in each case. The highest chloride content is found in the actual crest of the bed. Profile cuts in the row between plants have shown the most extensive

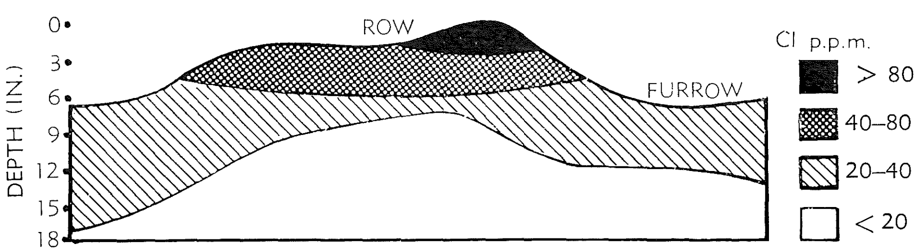

Fig. 2.—Diagram showing chloride distribution in row in Clare Sandy Loam.

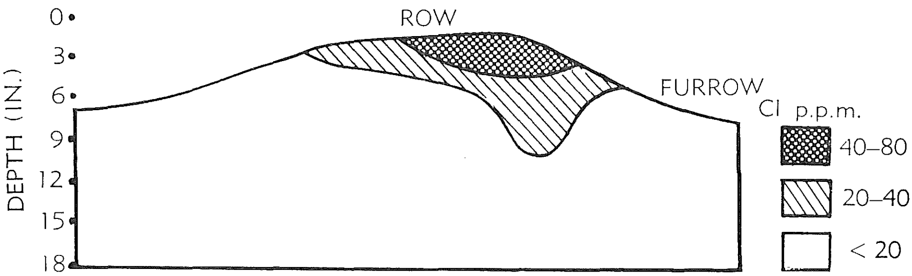

Fig. 3.—Diagram showing chloride distribution in row in Burdekin Fine Sand.

root development away from the main stem to be in the 0–6 in. zone. In Figure 2 this root development was in the zone shown to contain 40–80 p.p.m. Cl. These diagrams also indicate the difficulty in obtaining consistent auger samples for chloride measurement in an area.

Table 4 shows the chloride content of leaf samples from the areas where these profile sections were obtained.

TABLE 4

Chloride Content of Leaf from Areas of Profile Cross-section, 1960 Season

(% Cl)

Soil Type	Pick 2	Pick 4	Pick
Clare Sandy Loam (Fig. 1) ..	3·6	2·7	1·8
Burdekin Fine Sand (Fig. 2) ..	2·8	2·7	2·2

(b) Water

In the Burdekin River system, heavy summer monsoon flood run-off is expected between January and April, with little rain falling over the catchment area in winter and spring. During the period of crop irrigation and prior to the onset of the wet season, river flow is light and in dry years may cease completely from early summer. Chloride content of the river water is low during the period of flood run-off. During the tobacco-growing season, there is fluctuation in chloride content from year to year, but with the exception of 1958 the chloride content of irrigation water applied to the tobacco crops since 1954 has been between 30 and 40 p.p.m. Cl. There is evidence to suggest that the highest content can be expected following isolated early-summer storm run-off from certain tributaries.

Table 5 shows the chloride content of river water over a number of years for the September-December irrigation period and also for two wet-season periods. For the irrigation period, the total soluble solids content of the water usually lies in the range of 170–210 p.p.m., mainly as calcium and magnesium bicarbonates.

TABLE 5

CHLORIDE CONTENT OF BURDEKIN RIVER IRRIGATION WATER

Period	No. of Samples	Average Cl (p.p.m.)	Maximum Cl (p.p.m.)
1954 (September–December) . .	8	21	24
1955 (September–December) . .	10	38	45
1957 (September–December) . .	17	32	38
1958 (September–December) . .	9	50	53
1959 (February–April)	5	16	. .
1959 (September–December) . .	17	32	36
1960 (January–April)	10	13	. .
1960 (September–December) . .	20	30	35

IV. DISCUSSION

From the programme cited here and from a number of samples taken from various farms throughout the area, it is evident that in the majority of cases the level of soil chloride at the end of the wet season (April) and through to the commencement of the main tobacco-growing season (September) is low through the profile at least to a depth of 30 in. Burdekin River water has low chloride content during flood run-off but for the main irrigation period (September-December) in most years contains 30–40 p.p.m. Cl. Increase in soil chloride commences following irrigation and this increase is mainly in the top 3 or 6 in. of the row position. This soil increase and the chloride taken up by the crop can be accounted for by the chloride added in irrigation water.

Wadleigh and Fireman (1946) in field plot experiments in the U.S.A. showed accumulation of salt in the rows with very high amounts in the surface inch of this zone. In laboratory experiments, Bernstein and Fireman (1957) demonstrated the pattern of salt movement and accumulation in the beds of furrow-irrigated soil, with salinity highest in the surface of the bed at the centre. It is considered that such a pattern exists in this case, though modified by irregularities in bed shape. In general, with the irrigation techniques used in the district, water movement at least in the upper 3–4 in. of the row is lateral and upwards only. Chloride applied in irrigation water remains in this zone and is concentrated by successive waterings. Effective downward water movement and leaching occur in the furrow and at depth beneath the row. Below 12 in. little variation is found throughout the season. This pattern of salt movement has been indicated by the profile samples from row and furrow over a number of seasons and confirmed by actual cross-section sampling.

The zone of chloride accumulation has also been found in field observations in this district to be a zone of extensive fine root development. Chouteau (1959) found that irrigated Paraguay tobacco on alluvial soils in the Dordogne had over 98 per cent. of the fine root system in the top 30 cm, and most of this was in the top 20 cm. He further found most of the roots to be beneath the plant and in the rows, with comparatively few roots between the rows. In the Burdekin area, the main concentration of roots is found in the top 6 in. of the row. Below a depth of one inch or so, the zone of higher salt content and root development remains above wilting point except for short periods. As the moisture content of the zone is depleted, although still within the available moisture range, the increase of chloride concentration of the soil water is considered to be an important factor in plant chloride uptake. Wadleigh and Fireman (1948), with reference to cotton, pointed out that when a salt concentration occurs in the rows, the main water removal is from under the furrows, where, because of the lower salt content the work required to remove moisture from the soil is least. However, for the tobacco crops investigated here, the root concentration under the furrow is not great and the major part of the moisture will be obtained from the beds. Furthermore, although the relative concentration of salt is greater here, it is still not a high salt concentration by physiological standards. For the samples investigated, the maximum salt content measured in soil moisture approaching wilting point of 6 per cent. moisture would be responsible for an increase of less than 2 atmospheres in the osmotic pressure of the soil solution and this is not considered to seriously affect the ability of the plant to obtain water and nutrients, including chlorine, from this zone. It is to be remembered that the problem is not one of a salt toxicity but one of the luxury consumption of chlorine. This does not have an adverse effect on plant growth at the concentrations encountered but is important in the quality of cured leaf.

The appreciable amount of chlorine removed from the soil by the plant will affect soil chloride content in the various zones, but no measure of this removal pattern is available. It is considered likely that the greater part of the high leaf chloride content results from uptake by the extensive fibrous root system in the 0–6 in. zone of the rows where chloride has been concentrated from irrigation water by lateral and upward movement and the absence of leaching.

V. ACKNOWLEDGEMENTS

The work described was initiated in the Burdekin Irrigation Area by the late R. W. Clark. The assistance provided in the growing of the experimental crops by Messrs. R. W. George (Regional Experiment Station, Millaroo) and N. H. Adams (Senior Adviser in Agriculture for the district) is gratefully acknowledged. Some of the water analyses were carried out by the Government Chemical Laboratory and the statistical analysis for 1955 data was provided by the Biometrics Section. Mr. R. Wreczycki assisted with soil chloride determinations.

The investigation was financed in part by the Tobacco Industry Trust Account and the Burdekin Special Tobacco Fund.

REFERENCES

ATTOE, O. J. (1946).—Leaf burn of tobacco as influenced by content of potassium, nitrogen and chlorine. *J. Amer. Soc. Agron.* 38:186-96.

BERNSTEIN, L., and FIREMAN, M. (1957).—Laboratory studies on salt distribution in furrow irrigated soil with special reference to the pre-emergence period. *Soil Sci.* 83:249-63.

BEST, R. J. (1929).—A rapid electrometric method for determining the chloride content of soils. *J. Agric. Sci.* 19:533-50.

CHOUTEAU, J. (1959).—Répartition pondérale au système radiculaire du tabac Paraguay dans une terre d'alluvions profondes. *Ann. Inst. Exp. Tab. Bergerac* III:265-74.

COLBRAN, R., and GREEN, H. (1961).—Effect of nematodes on the halide content and burning time of flue-cured tobacco leaf in South Queensland. *Qd J. Agric. Sci.* 18:287-92.

MYHRE, D. L., ATTOE, O. J., and OGDEN, W. B. (1956).—Chlorine and other constituents in relation to tobacco leaf burn. *Proc. Soil Sci. Soc. Amer.* 20:547-51.

PEELE, T. C., WEBB, H. J., and BULLOCK, J. F. (1960).—Chemical composition of irrigation waters in the South Carolina Coastal Plain and effects of chlorides in irrigation water on the quality of flue-cured tobacco. *Agron. J.* 52:464-7.

WADLEIGH, C. H., and FIREMAN, M. (1946).—Salt distribution under furrow and basin irrigated cotton and its effect on water removal. *Proc. Soil Sci. Soc. Amer.* 13: 527-30.

(Received for publication June 23, 1961)