1992

Ground water quality and irrigation: a potential source of sodium in the soils of the Macon Ridge

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GROUND WATER QUALITY AND IRRIGATION: A POTENTIAL SOURCE OF SODIUM IN THE SOILS OF THE MACON RIDGE

P. M. Walthall, W. J. Day, and R. L. Hutchinson
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Ground Water Quality and Irrigation: A Potential Source of Sodium in the Soils of the Macon Ridge

P.M. WALTHALL\textsuperscript{1}, W.J. DAY\textsuperscript{1}, and R.L. HUTCHINSON\textsuperscript{2}

Introduction

Economic recommendations (Henning, 1989) favor agricultural diversification for improving the stability of farm income. This diversification includes supplemental irrigation, especially in northeastern Louisiana (Phillips et al., 1981; Hutchinson et al., 1984; Hutchinson et al., 1988). A long-term consideration for the producer is the possible damage to productive land from the use of poor quality irrigation water. The purpose of this research was (1) to determine if the natural rise and fall of saline ground water is the source of Na in the soils of the Macon Ridge, and (2) to determine if the use of saline irrigation water results in salinization (increasing levels of both Na and Cl) of the soil environment.

Extensive areas of soils on the Macon Ridge in Northeast Louisiana (Figure 1) have naturally high levels of exchangeable sodium (Na) which adversely affect crop production. Previous research on the Macon Ridge (Fleming, 1984; Goh, 1984) focused on the dissolution of Na-bearing minerals (aluminosilicates) identified in the loess parent material of these soils, as being the source of Na. Sodium accumulations were attributed to leaching and entrapment in depressed landscape positions, as well as from lateral flow of Na from adjacent soils in ridge positions. Similar situations have been reported in Illinois (Wilding et al., 1963) and Mississippi (Pettry, 1981). A source of Na not considered in either of the local investigations was saline ground water. Whitfield (1975) identified the occurrence of saline regions of ground water within the Mississippi River alluvial aquifer which underlies the Macon Ridge (Figure 2).

If the major source of Na in these soils is from ground water enriched with Na and Cl, then a similar relationship between ion composition in soil solutions and ground water would be expected across the landscape at some depth between the soil surface and the underlying aquifer. Should the source of Na originate from the weathering of Na-bearing minerals contained in the loess, one would not expect Cl to be an associated anion. The objectives of this study were (1) to determine if a relationship exists between Na and Cl in soil solutions, (2) to investigate

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similarities between soil solution composition and regional ground water, and (3) to determine if increased soil salinity results from irrigation practices that rely on saline ground water.

**Background**

**Geology and Hydrology.** The Macon Ridge is a loess-mantled, Pleistocene braided-stream terrace of the Mississippi River (Autin et al., 1991). The ridge trends north-south and is bordered by the younger (Holocene) Mississippi River floodplain to the east and the Ouachita River floodplain to the west. The loess mantle has been identified as Peoria loess (Martin et al., 1981; Miller et al., 1986). The thickness of the loess mantle is > 3 m at the eastern edge of the ridge and thins
progressively west until the loess is no longer recognizable. The loess mantle is underlain by braided-stream alluvium of the Mississippi River deposited prior to 30,000 yr BP (Autin et al., 1991; Saucier, 1968).

Beneath the Macon Ridge, coarse-textured sediments underlying the loess have a hydrogeologic connection with the sands of the Mississippi River alluvial aquifer (Figure 3, from Whitfield, 1975). The younger alluvial deposits surrounding the ridge in the Mississippi delta tend to be dominated by materials higher in clay (Schumacher et al., 1988) which restrict interactions between the aquifer and the overlying soil environment to a large degree. Rainfall and the hydrogeologic connection linking the braided-stream sediments, the alluvial aquifer, and the surrounding river systems are the major sources of recharge to the aquifer (Whitfield, 1975; Boniol et al., 1988).

A major saline region in the Mississippi River alluvial aquifer was identified by Whitfield (1975), and runs in a northeast to southwest band through the center...
of Franklin Parish (Figure 2). In much of the area beneath the present Mississippi River floodplain, Tertiary aquifers that underlie the alluvial aquifer (Figure 3) have high concentrations of chloride (Cl) (Whitfield, 1975). Discharge from these saline Tertiary aquifers into the alluvial aquifer occurs during periods of low hydraulic head such as a low river stage on the Mississippi River when the aquifer would reverse flow and discharge into the river.

Soils. The type of soil on the Macon Ridge containing high levels of exchangeable Na, is recognized by the U.S. Soil Taxonomic System as a Natraqualf (Soil Survey Staff, 1975). This soil type covers approximately 7.4 percent of the Macon Ridge.
in Franklin Parish beginning immediately west of the saline region of the aquifer (Figure 2) and spreading to the western edge of the ridge (Weems et al., 1977; Martin et al., 1980; and Soil Survey Staff, 1990). However, the taxonomic characterization of this soil type is too restrictive for agricultural purposes. High levels of exchangeable Na (15 percent) are recognized in most cases only when they occur within 40 cm below the top of the argillic (subsoil) horizon. Yield reductions between 40 and 75 percent have been reported in deep-rooting crops (soybeans [Glycine max. L.], bahiagrass [Paspalum notatum], and common and improved bermudagrass [Cynodon dactylon L.]) when grown on soils having high levels of exchangeable Na occurring below the 40 cm depth requirement (Martin et al., 1980 and Reynolds et al., 1985). A modification to the classification of this soil type, proposed by McQuaid et al. (1987), recognized the deeper occurrence of exchangeable Na. Soil series meeting the proposed criteria cover approximately 36.2 percent of the Macon Ridge in Franklin Parish.

**Methods**

**Field.** Two levels of sampling intensity were used. A general sampling scheme was used to provide information for the region of the Macon Ridge occurring in Franklin and Richland parishes. A grid distribution was used with sampling sites separated by an approximate distance of 7 km (Figure 2). A more detailed sampling scheme involved a transect approximately 2.4 km in length, consisting of 12 sites. The transect was located on the Macon Ridge location of the Northeast Research Station near Winnboro. Half of the transect was irrigated cropland (site locations were cropped to soybeans, corn, cotton, and rice), and half was in non-irrigated bermudagrass pasture. Cores 5 cm in diameter were sampled by horizon to a depth of approximately 6 m using a Giddings soil probe. Taxonomic classification of the soils sampled in both the grid and transect sampling schemes can be found in Table 1.

**Laboratory.** Samples were air-dried and ground to pass through a 2-mm sieve. Particle-size distribution was determined after samples were dispersed by suspension in sodium hexametaphosphate and shaken on a horizontal reciprocating shaker for 16 h. Clay percentages were determined using the pipette method (Gee and Bauder, 1986). Sand fractions were sieved and weighed. Silt content was calculated by difference.

Exchangeable bases (Ca, Mg, K, and Na) were extracted by leaching with 1M NH$_4$OAc, pH 7.0 solution. Cation concentrations were determined by atomic absorption spectrometry (AAS). Extractable acidity was determined using the BaCl$_2$-TEA, pH 8.2 method of Thomas (1982). A buffered cation exchange capacity (CEC) is used to express total exchange capacity and is taken as the sum of the exchangeable bases and the extractable acidity. Soil reaction was measured in 1:1 H$_2$O and in 1:1 1M KCl (Soil Survey Staff, 1984).

Soil solution extracts were obtained from 1:2, soil:H$_2$O suspensions that had been equilibrated for approximately 24 h. Concentrations of Ca, Mg, K, and Na in solution extracts were determined by AAS; Cl was determined by ion specific
Table 1.—Taxonomic classification of soil series sampled in the grid study and the detailed transect

<table>
<thead>
<tr>
<th>Series</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid study</strong></td>
<td></td>
</tr>
<tr>
<td>Gigger</td>
<td>Typic Fragiudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Loring</td>
<td>Typic Fragiudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Necessity</td>
<td>Glossaquic Fragiudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Egypt</td>
<td>Aquic Glossudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Calhoun</td>
<td>Typic Glossaqualf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Calloway</td>
<td>Typic Glossaqualf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Gilbert</td>
<td>Typic Glossaqualf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Deerford</td>
<td>Albic Glossic Natraqualf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Foley</td>
<td>Albic Glossic Natraqualf, fine-silty, mixed, thermic</td>
</tr>
</tbody>
</table>

**Detailed transect**

<table>
<thead>
<tr>
<th>Series</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dexter</td>
<td>Ultic Hapludalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Gigger</td>
<td>Typic Fragiudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Egypt</td>
<td>Aquic Glossudalf, fine-silty, mixed, thermic</td>
</tr>
<tr>
<td>Gilbert</td>
<td>Typic Glossaqualf, fine-silty, mixed, thermic</td>
</tr>
</tbody>
</table>

electrode. Ion concentrations were concentrated by a factor of four to approximate saturated conditions in a soil having 50 percent pore space.

**Results and Discussion**

**Na and Cl in the Soil.** For the regional grid sampling, a multivariate regression of Cl on Na, using a line splitting the Macon Ridge from north to south as a categorical variable, indicated that the two areas contained significantly different slopes. The two categories coincide with those developed by Miller (1986) delineating loess thickness on the Macon Ridge (Figure 2). The region west of the line has a loess thickness of less than 1 m, and the region east of the line has a thickness increasing from 1 to 4 m. A strong relationship between the two ions ($r^2 = 0.92$, slope $= 0.85$, $n = 168, p = 0.01$) exists for sites having a loess thickness of greater than 1 m. A weaker relationship ($r^2 = 0.62$, slope $= 2.19$, $n = 155, p = 0.01$) was found for the sites having a loess thickness of less than 1 m. Regression analysis of Cl on Na in soil extracts from the detailed transect produced a trend similar with respect to slope, to that observed in the sites from the grid study having a loess thickness greater than 1 m ($r^2 = 0.75$, slope $= 0.80$, $n = 176 p = 0.01$) (Figure 4).

We postulate that the loess mantle which drapes over the sandy Pleistocene alluvium acts as a protective barrier, preventing saline ground water from reaching the soil surface (Walthall et al., 1992). The effectiveness of the loess barrier increases with the thickness of the loess mantle and prevents saturation of the overlying solum in two ways: (1) physically displacing the soil environment above the saturating conditions of the underlying saline aquifer, and (2) serving as a restrictive barrier to the upward movement of ground water relative to movement within the coarser sands. The effect of loess thickness on limiting the upward
movement of saline water can be seen in the Na saturation data presented in Figure 5. In the thinner loess on the west side of the ridge (<1 m), maximum Na saturation percentages occur within a depth of 2 m below the soil surface. In the thicker loess on the east side of the ridge (1 to 4 m), maximum Na saturation percentages occur below a depth of 2 m.

**Na and Cl in the Ground Water.** The data in Figure 4 illustrate the relationship between Na and Cl in the ground water and the soil extracts. Concentrations of Na and Cl from 12 wells reported by Whitfield (1975) that meet the definition of saline
water defined by the U.S. Public Health Service (1962) of 250 mg/L Cl (7 mmol/L) were used in the comparison. The relationship between Na and Cl is very similar between the well waters and the soil extracts (Figure 4); wells ($r^2 = 0.92$, slope = 0.65, $n = 12$, $p = 0.01$); soil extracts ($r^2 = 0.75$, slope = 0.80, $n = 176$, $p = 0.01$).

Although the slope of the regression line of the well waters is slightly lower than that of the soil extracts, indicating higher Cl concentrations relative to Na, such a relationship is not surprising. Two competing processes are most likely responsible for this disparity in slope. As proposed earlier, saline ground water saturates the soil profile from below, supplying both Na and Cl. Cation exchange sites in the soil become saturated with Na over time, establishing a buffer that maintains high levels of Na in solution.

Figure 5. Distribution of Na-saturation as a function of depth on the east (loess thickness 1 to 4 m) and west (loess thickness <1 meter) sides of the Macon Ridge.
On the other hand, no anion exchange capacity is available to buffer Cl and through leaching, it is continually removed from the soil profile. This certainly seems to be the case as the slope increases from 0.65 in the wells to 0.85 in the soils from the thick loess where leaching would be most restricted. In the thin loess, the effect appears to be much greater. These soils are dominated by the more permeable sandy alluvium, and the effects of leaching are more extreme (Walthall et al., 1992). The greatest disparity between Cl and Na occurs in these soils with a slope of 2.19. Furthermore, it is this western half of the Macon Ridge in which the extensive areas of Na-affected soils occur.

**Na and Cl in the Irrigation Water.** The third objective of this study was to determine if irrigation with saline ground water substantially increases soil salinity on the Macon Ridge. An irrigation well sampled on the Macon Ridge location of the Northeast Research Station had a Cl concentration of 27.2 mmol/L (Table 2), approximately four times the defining Cl concentration for saline ground water. The screened interval of the well is between 20 and 30 m, which would place it within the Mississippi River alluvial aquifer (Figure 3). Concentrations of Na in the well water ranged from 13.4 to 15.3 mmol/L. To test the effects of potential salt loading, soil horizons within the top 1 m of each soil column were grouped into 25 cm depth intervals. A mean Cl concentration was determined for each depth interval in the irrigated and non-irrigated portions of the transect (Figure 6). In all cases, Cl levels in the irrigated cropland exceed Cl levels in the non-irrigated pasture. Use of poor quality irrigation water has resulted in a definite increase in the salinity of these soils. The highest mean Cl concentration occurs in the 75-100 cm depth interval from the irrigated sites. A distinct increase in Cl concentration occurs with increasing depth. This suggests that precipitation does have some effect in leaching Cl out of the immediate surface into the subsoil.

Reductions in crop yields grown on naturally occurring, Na-affected soils were previously mentioned. The extent of damage to crop yields from use of saline irrigation water is not well documented in the Macon Ridge area and probably varies from one crop to another as well as from one crop variety to another. Soybean variety tests in Arkansas have been developed to screen for salt tolerance (Widick,

### Table 2.---Irrigation water analyses from Macon Ridge location of the Northeast Research Station

<table>
<thead>
<tr>
<th>Year sampled</th>
<th>Na (mmol/L)</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>15.0</td>
<td>---¹</td>
</tr>
<tr>
<td></td>
<td>13.4</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>15.3</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>13.6</td>
<td>---</td>
</tr>
<tr>
<td>1985</td>
<td>15.1</td>
<td>27.2</td>
</tr>
<tr>
<td>1988</td>
<td>14.4</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>---</td>
</tr>
</tbody>
</table>

¹Not determined.
1982). What was once thought to be damage to soybean from cercospora blight and leaf spot on the Macon Ridge Location of the Northeast Research Station is now believed to be the result of salt damage from saline irrigation water or possibly a combined effect of the two (Dr. B.G. Harville, unpublished data).

**Summary and Conclusions**

The findings of this study support the argument that saline ground water is the major source of Na for the soils on the Macon Ridge. The relationship between
Na and Cl in soil solutions and a similar relationship in saline ground water support this argument. The loess “wedge” running from east to west across the ridge was found to play a major role in determining the distribution of Na and Cl with respect to depth and specific ion concentration. This argument is supported by Na saturation percentages above 15 occurring at increasing depths as loess thickness increases.

Serious consideration should be given to monitoring ground water quality where irrigation wells are in potentially high saline regions of the underlying aquifer. The potential damage due to excessive buildup of Na and Cl in these soils could be economically disastrous, considering the difficulty in reclaiming salt-affected soils. Moreover, if substantial increases in ground water pumpage occur (resulting in a lowering of the hydraulic head in the aquifer), it is possible that saline water in the underlying Tertiary strata could further intrude into what once were fresh water regions of the Mississippi River alluvial aquifer.

References


Widick, D. 1982. Salt can damage some soybean varieties. Delta Farm Press, Clarksdale, MS.
