HOW RISING WATER-TABLES CAUSE PRODUCTIVE SOILS TO ALTER TO SALINE MANGROVE SWAMP-LIKE-SOILS

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Dryland salinity and waterlogging are increasing threats to land and water quality in several high rainfall agricultural areas of South Australia. Both are usually associated with land clearing and consequent rising water tables. But another serious impact is a highly reactive soil process that involves the mobilization and biomineralization of sulphur and iron and which transforms the once productive agricultural soils into degraded saline sulphidic ones similar to those found in mangrove swamps. The degraded soils are very difficult to ameliorate given that they contain high amounts of salts including gypsum, are seasonally waterlogged, and are of low fertility status (high phosphate fixing soils). Therefore new methods for both identifying and ameliorating these soils will have to be developed in order to tackle this problem of possible national significance.

INITIAL NATURE OF THE PROBLEM

Property holders from several landcare groups approached soil scientists from the CSIRO Division of Soils to look at some recently developed soil waterlogging and salinity problems in catchments in the central and southern Mt Lofty Ranges areas, South Australia. These property holders expressed concern about the rapid increase in waterlogging and salinity especially over the past 5 years or so and believe it is now becoming the greatest threat to the productivity of their land and the water quality of streams. In fact, some property holders estimate that as much as 20% of available arable land in some catchments may be susceptible to waterlogging and salinization. Clearly, there are serious economic implications.

After inspecting numerous wet saline seep areas, the CSIRO soil scientists were puzzled at not being able to recognize and classify many of the degraded soils found in these areas. At first sight they could only be described as being just like those found in mangrove swamps (i.e. black, mushy, smelly and highly saline). These soils simply did not fit any recognized soil classification system currently being used either in Australia or internationally. They were unlike salinized soils found in other parts of Australia (e.g. Western Australia).

ACTIVE COMMUNITY ROLE OF LANDCARE GROUPS INVOLVED

Various collaborative projects (including NSCP funded landcare groups, LWRDCC grant and CSIRO/University of South Australia Collaborative Research Grant) that involve soil scientists from the CSIRO Division of Soils, extension staff from the South Australian Department of Agriculture, staff from the University of South Australia and landcare groups, have been initiated to tackle the problem.

With help from the landcare groups, CSIRO staff have installed over 150 piezometers, at depths ranging from 40cm to 25m, to monitor water-levels in a wide range of salt affected and waterlogged soils. Water-levels in the piezometers are measured weekly by property holders and the data sent to CSIRO staff for processing.
THE GENERALIZED MECHANISM OF DRYLAND SALINIZATION

It has now been widely recognised that since European settlement in southern Australia excessive replacement of deep-rooted perennial native vegetation (often *Eucalyptus* species) with shallow rooted annual plants, which not only use, but also tend to intercept, less water has led to the development of dryland salinity.

This excessive clearing has allowed more water to enter the groundwater system, causing water levels to rise and leading to a mobilization of any salt stored in the landscape. Where water rises to within one to two metres of the soil surface, and assuming that there is salt mobilization, the soil becomes salt-affected as a result of evapotranspiration.

Although this mechanism does tend to provide a common Australia-wide explanation for both soil and stream salinization, each catchment situation, particularly in southern Australia, is complicated by a host of other factors. For example, the quantity and type of salt stored in the landscape and the nature of the groundwater flow may produce different forms of salting and waterlogging. A further problem associated with dryland salinization is that the hydrological response to tree clearing while in some cases rapid, elsewhere may be very slow taking between 50 to 100 years for the effects to manifest themselves.

COMPLEX NATURE OF AUSTRALIAN SOIL-LANDSCAPES

A significant proportion of soils used for agricultural production in southern Australia (and in Australia) are texture contrast soils which have bleached sandy topsoil horizons overlying clayey, mottled, sodic subsoil horizons. Such soils are inherently subject to waterlogging because of water perching on the more impermeable clayey subsoil horizon and consequently saturating the topsoil horizons, especially where there is an increased input of water following removal of native vegetation.

Generally speaking, Australian soil-landscapes are extremely variable and complex due, in part, to much of the continent’s great age. Therefore, to proceed from a more general understanding of dryland salinization processes to a more definite understanding of the process in an individual catchment in order to predict the effects of management in such a catchment is extremely difficult. The central and southern Mt Lofty Ranges area is further complicated by the highly variable geology and weathering patterns of the soils in these landscapes. It is apparent that in adjacent landscape positions one is confronted with deeply weathered soils which contain ancient stored salt juxtaposed with very youthful soils on partly weathered rocks which are generating salt as a result of contemporary weathering processes.

UNIQUE FEATURES ASSOCIATED WITH SOIL SALINIZATION IN THE MT LOFTY RANGES REGION

The basic dryland salinization processes operating in this region are not too dissimilar from the “generalized mechanism” described above (i.e. they are primarily related to the behaviour of rising saline groundwaters). The question may be asked then, “what is different or unique about the salt affected soils in subcatchments of the Mt Lofty Ranges area?”

Occurrence and Distribution:

The incidence of dryland salinity in this region is considered to be much lower than in Victoria and Western Australia. The specific areas affected also appear to be much smaller and more scattered than in Victoria and Western Australia and tend to occur on a much wider range of geological materials.

Soil and Hydro-geological Differences:

- Salts accumulating at the soil surface do not consist primarily of sodium chloride (normal table salt) but also of gypsum (calcium sulphate) and other sulphate and iron containing salts.
- The occurrence of saline seepages are not confined to the lower lying topographic positions in the landscapes but occur also in higher positions.
- The Mt Lofty Ranges area consists of weathered sedimentary and metasediment rock types which include large areas of micaceous sandstones and schists that contain pyrite (iron sulphide or “fools gold”) bands within the geological strata particularly in the eastern side of the region.
- Rainfall is considered reliable and high by Australian standards with annual averages ranging up to 1000 millimeters and falling predominantly in winter. This rainfall pattern results in virtually no run-off in summer and early autumn. As a consequence, stream salinities are
higher in summer and much lower in winter.

Generally, groundwater occurs in fractured rock aquifers and sedimentary aquifers, many of which exist as confined aquifers (i.e., the groundwater is under pressure). The groundwater is frequently compartmentalized with hydrodynamic parameters varying strongly between adjacent structural blocks, which reflects the complex geology of the region. As a result, groundwater yield and quality are generally very site-specific. Groundwater salinity can vary from less than 300 mg/L in some areas to more than 20,000 mg/L in others.

Until now, the assumption has been that salts stored in these landscapes are derived primarily from the ocean and precipitated as part of rainfall (and windblown dry salt fall). However, it appears that this may not be the main source of salt contained in both surface and groundwater.

**Detailed Hydro-geological Mechanisms:**

As stated before there is little doubt that the salinity in these landscapes is caused by rising water tables bringing saline water to within a metre of the surface, particularly in seepage areas. However, the somewhat unique geology of these catchments with thin pyrite bands contained within the underlying geological strata has provided us with a clue as to the possible source of the sulphur-rich salts. These pyritic bands occur within low permeability beds of shale and partially metamorphosed siltstones. These structures tend to interfere with the movement of groundwater and tend to force or direct the groundwater to the soil surface.

**Detailed Soil Mechanisms:**

As they rise, groundwaters dissolve naturally occurring salts (i.e., salts with sodium, chloride, sulphate and iron) in the sub-soil layers and carry them to the soil surface where they concentrate through evaporation. The primary origin of the sulphate and iron in the groundwaters is from percolating water dissolving these ions from the relatively porous partially weathered rock types containing thin bands of iron sulphide.

Once the dissolved sulphate percolates into the surface horizons of these soils it is transformed rapidly to sulphide-containing salts (i.e., very fine grained iron sulphides or pyrite) by sulphur reducing bacteria in the presence of soil organic matter (food for bacteria). The new transformed soil is a very mushy, black soil with almost identical properties to soils found in mangrove swamps. Not only is their appearance similar to a mangrove swamp soil but so too is the smell and also the soil chemical properties. For example, as the soil dries out, particularly during the hot dry summers, sulphide converts to sulphuric acid thus creating a soil acidification problem. This process, operating seasonally, tends to completely degrade soil structure to the extent that waterlogging and salinity progressively become more and more of a problem. The hypothesized process is such that, at a depth of approximately 30-40 cms, clay is dispersed and an impermeable clay-pan formed. Hence, any saline groundwater that leaks to the soil surface horizons especially from some of the shallow confined aquifers (i.e., those under pressure) via old decomposed root channels will perch and spread along the clay-pan. In winter, this perched water-table usually extends above the soil surface creating an ever-increasing wet ponded area scattered over various parts of the landscape.

During the wet winter months a reddish-brown iron-rich gel is precipitated in the ponded water on the soil surface mainly by iron oxidizing bacteria. In contrast, during the hot dry summer months, the iron-rich gel precipitates tend to concentrate on the surface of soils and consequently coat and cement the loose sand and clay particles together to form a very thin 2-10 mm crust on the soil surface. This dense, thin crust prevents the germination of seedlings, a situation made even worse by the high salinity of the soil itself (with sodium chloride, gypsum and other sulphate containing salts being present).

A fertility problem associated with these soils is a tremendously high phosphate-fixing capacity because of the occurrence of ferrous iron in the soil. Any applied phosphate will combine with the iron and become totally unavailable to plants (i.e., form a highly insoluble iron phosphate mineral).

**Soil identification:**

The combined effect of altered soil water regime and agricultural utilization (i.e., formation of plough pans and soil puddling by stock) of these soils has been the development of compacted and impermeable sub-surface layers. Impaired drainage and perched water containing high concentrations of Na⁺, Cl⁻, SO₄²⁻ and Fe²⁺ ions during winter have induced soil processes which differ drastically from those operating before land clearing. These induced conditions tend to produce easily identifiable soils that have very black coloured sulphide smelling surface horizons with a very low physical bearing capacity (i.e., are very "squishy" or soft when wet). The subsoil horizons tend to have a high proportion of induced grey colours (or what is referred as "gley" colours) with only a few faint yellow-red mottles. These latter subtle features can easily be recognized in the field and we are currently in the process of developing further a rapid field method to identify and map the onset of
waterlogging in soils in these catchments.

Identification of non-marine secondary saline and sulphidic soils elsewhere in Australia

Recently CSIRO Division of soils scientists have identified highly saline soils with thick sulphidic horizons but which are highly alkaline and overly calcareous near Cooke Plains in South Australia. Almost identical saline and sulphidic soils to those found in the Mt. Lofty Ranges region have been observed on Kangaroo Island and Eyre Peninsula in South Australia as well as in parts of Western Victoria and Western Australia.

Management strategies:
As already mentioned, the salts forming on the soil surface are not only white salts of sodium chloride (table salt) but also of gypsum (calcium sulphate). For these reasons the soils are very difficult to ameliorate so new methods have to be developed.

Management strategies for these areas should attempt to maximise high water use through plant production to provide reduced movement of soil water to groundwater and drainage, consistent with leaching requirements. However, there are major soil problems associated with soil fertility and physical degradation that have to be overcome. For example, plant species suited to sodium chloride saline areas may not be suited to these sulphate rich soil areas. Experimentation is essential with new plants that must be halophytic, suited to a very low P soil environment, tolerant of variable and low pH and have a vigorous and deep rooting system to penetrate clay pans to draw water from as great a depth as possible.

Engineering solutions involving groundwater removal or control in these catchments are considered too costly and even too damaging to the environment.

In short, one can say that there is really no magical, quick-fix solution to the problems associated with this kind of land salinization. In fact, soil salinity is a very catchment-specific problem and the solution is the same. The unique development of the so-called mangrove swamp soils (acid sulphate soils) in these Mt Lofty catchments is a prime example of the site-specificity of dryland salinity. In other words, although the very general hypothesis that soil salinity is a result of increased recharge to groundwater as a consequence of agricultural development, there are, in addition, other important soil processes which need to be known before suitable ameliorative steps can be taken to rectify the problem specific to a catchment.

PAST AND FUTURE ACTIVITIES

In this regard, it is interesting to reflect back on the original work done in Australia regarding dryland salinity. It has almost taken a full circle. The very early work in the Division of Soils was undertaken primarily by soil surveyors to study increasing salinity in irrigation areas along the River Murray. These original surveyors, about 50 years ago, arguably focused their attention primarily on the upper soil mantle of two metres or so of soil profile.

The emphasis later switched almost entirely to looking at the groundwater hydrological processes involved in dryland salinization. More recently focus has been to study and develop saltland agronomy, using halophytic pastures and to develop species and ecotypes of *Atriplex*. This work has been developed particularly by workers in the mediterranean climates of Western Australia.

It is now very clear that a more definitive integrated approach to studying dryland salinity should be mounted to combine the efforts of soil scientists studying these specific new soil problems with vital information about the hydrology and saltland agronomy. In this way one should definitely be able to arrive at a treatment strategy to obtain better production from salt-affected land and indeed to reclaim salt-affected land for better production.

Finally, the fact that landcare groups have formed to focus on specific salinity problems shows a most positive attitude existing right now. They are already in the process of adopting research findings that are suitable to their needs.
Future work and some current publications associated with work on sulphidic saline soils

CSIRO/UNIVERSITY OF SOUTH AUSTRALIA COLLABORATIVE RESEARCH GRANT:
Development of a Geographic Information System, incorporating Remotely Sensed Data, for Identification and Study of Soil Waterlogging and Soil Salinity.

AIMS:

(1) To use Geographic Information Systems (GIS) and remote sensing data to improve field soil survey methods for the identification and distribution of waterlogging and salinity in a range of sub-catchments in the upper Bremer River and Reedy Creek catchments in the Mt. Lofty Ranges.

(2) Develop and apply a new set of quantitative field and remote sensing procedures for use by soil surveyors, extension officers, private consultants and farmers to describe and identify the onset of conditions of impaired soil drainage under changing hydrological conditions.

The research project combines the resources of industry (Thermoview Pty. Ltd. [thermal infrared (IR) methods]), several Landcare Groups (property holders/land managers), University of South Australia (GIS and remote sensing methods) and CSIRO Division of Soils (hydrogeology, distribution and properties of soils) in order to assist in the development of better land management.

The CSIRO Division of Soils team will gather field data for integration with the remotely sensed data. Specific soil macro-morphological features (including mottling patterns, munsell colour and occurrence of incipient glaebules and fossil glaebule etching) will be described and water tables monitored by piezometers. Measurements will be made of hydraulic conductivity and matric potential across a range of water contents.

Stage 2 of the research will involve monitoring of seasonal variations in soil wetness and salinity and its relations with factors such as changes in rainfall, temperature, land use practice and vegetation. This, together with results gained from macro-morphological and other hydrogeochemical methods, will be applied to develop a series of conceptual models for a range of representative soils by relating wetness to factors such as mottling, colour, iron oxide mineralogy, glaebule morphology, oxygenation and acidity. The GIS developed in Stage 1 will then be used as a basis to quantify and analyse changes in these parameters. Observed changes in ground truth parameters will be used to test the accuracy of the model for identifying and predicting the onset of waterlogging and subsequent salinity within key micro-catchment areas.

Finally, in collaboration with extension officers from the Department of Agriculture (Simon Ellis, Martin England, Trevor Dooley and Don McCarthy) and farmers associated with Landcare Groups the new methods will be applied to the preparation of management strategies.

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