PLANT AND SITE CHARACTERISTICS OF ADVANTAGE WITH SALINE SOILS

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Abstract

The paper addresses the proposal that the negative impact of soil salinity is mainly caused by a reduction in the ability of plants to take up nutrients. Morphological characteristics of plants that promote nutrient uptake in saline environments are illustrated using field examples. Site characteristics that promote plant uptake of nutrients in saline environments are similarly illustrated where many of these characteristics are generated and/or promoted by the vegetation.

Introduction

Obviously saline environments have distinctive vegetation such as mangroves and samphire. All plant species in such environments have morphological and physiological characteristics that promote survival under the particular conditions, as with exclusion and pumping mechanisms for salt, root systems that promote the uptake of oxygen and the development of protective chemicals within cells. However, most Australian soils contain appreciable levels of salt and the generally low rainfall means that the salinity of the soil solution can exceed that of sea water. Despite this few characteristics of terrestrial plants are identified as representing an adaptation to salinity as arises with mangroves and samphire.

Observations of water availability in a brigalow (Acacia harpophylla) community (Tunstall & Connor 19751) identified that the reduction in water availability in the subsoil was consistently around 1.5 times that of seawater with much of the effect being attributable to salinity. The salinity of the subsoil in a paperbark community (Melaleuca viridiflora and M. nervosa) in central coastal Queensland was greater than in a hyper-saline coastal mudflat (Tunstall et al. 19982). These extreme levels of soil salinity would be expected to significantly affect the vegetation but specific plant adaptations to the extreme environments are not readily apparent in these communities.

An analysis of soil factors affecting the competition between trees and grasses (Tunstall, 20053) suggests that the significance of differences in their rooting characteristics relates to the concentration of salts around roots. That is, plant morphological characteristics regarded as being normal can represent a significant adaptation to salinity. This paper explores how common plant morphological characteristics and site conditions promote the survival and growth of plants under saline conditions.

Context

Most such analyses examine plant response under controlled and reasonably uniform conditions when plants have evolved in association with other species and in a spatially and temporally variable environment. Most analyses seek to identify physiological optima when native vegetation represents ecological optima that arise through the interactions between the different plants as well as their environment. This analysis examines interactions between plants in communities and their environment to identify factors that can be beneficial in saline environments.

The general context is as given by Tunstall (2005). The occurrence of interactions means that outcomes cannot be reliably predicted from individual processes and must be deduced by analysing the system as a whole. This involves examining the relative significance of different factors by way of how they operate and interact to produce outcomes.

Discussion

The approach taken is to present a conceptual model and examine its applicability, which equates with hypothesis testing. The alternative of examining all possible outcomes is impractical due to the very large number of circumstances to be considered.

The proposal is that the negative impact of soil salinity is mainly caused by a reduction in the ability of plants to take up nutrients. That is, while osmotic reduction in water availability can be significant it is the effects on plant nutrition that mainly determine outcomes. Plant attributes and site characteristics that promote the uptake of nutrients should therefore be beneficial in saline environments.

Water from the bulk soil solution is drawn towards roots when plants transpire water. This water can contain all elements required for plant growth, mainly in ionic form. However, most elements are only required in very small amounts and concentrations of many ions, such as sodium and chloride, are much higher than needed by plants. The high concentrations of some ions can interfere with the uptake of essential and limiting ions. This can create nutrient deficiencies even where all necessary elements are present at levels adequate for plant growth. It can also necessitate the expenditure of energy by plants (ion pumps) to preferentially obtain some elements and exclude others.

The suggested importance of nutrient uptake is contrary to general perceptions which have plant growth being mainly reduced by the osmotic reduction in water availability\(^4\). One comment deriving from agriculture is that a requirement for fertiliser is independent of salinity. However, observations on rice identified an increase in photosynthetic capacity with increase in soil and plant salinity\(^5\). The reduction in growth of salinised plants was not due to salt reducing the physiological activity as occurs when water availability is reduced by drying. The reasons for the lower growth of plants with increased photosynthetic capacity could not be determined but one explanation related to the expenditure of energy in excluding unwanted salts.

All observations and theory identify that a reduction in water availability by way of a reduced matric potential reduces photosynthesis. The increase in photosynthesis with decrease in

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osmotic potential therefore identifies that the effect of salt on growth is not simply associated with reduced water availability. Indeed, it negates the general hypothesis that the effect of salinity on plant growth is due to the reduction in water availability by way of the reduced osmotic potential.

**Plant Adaptations**

The very large surface area of grass roots in association with soil particles, particularly colloids, is identified as being beneficial in reducing the accumulation of salt around roots (Tunstall, 2005). The uptake of nutrients is promoted by the close association between roots and soil particles and the limited accumulation of salt around roots associated with water uptake.

An extreme example is marine or salt-water couch (*Sporobolus virginicus*) which grows on hyper-saline mud flats often subject to intermittent inundation by sea water. Another extreme is *Spinifex hirsutus* which grows on frontal sand dunes that are subject to high levels of salt spray. Nutrients are exceedingly restricted in beach sands and only become available through microbial activity on the surface of sand grains. Once in solution the nutrients are readily leached and have to be extracted from a solution containing abundant sodium chloride. Obtaining nutrients requires good affinity between plant roots and sand grains.

The *Spinifex hirsutus* example identifies the importance of soil microbes in making nutrients available to higher plants. With this example the microbes initially providing the nutrients are exogenous bacteria but the combinations include ex and endogenous bacteria and fungi. Acacias have endogenous bacteria in mycorrhiza that improve the availability of nutrients provided soils do not become waterlogged. Acacias such as brigalow can occur where subsoils are highly saline.

Brigalow also illustrates the significance of the ability of plants to tolerate water stress by way of low water potentials. Water potentials for brigalow were as low as 6.5 MPa (Tunstall & Connor, 1975) when the nominal wilting point for plants is given as being 1.5 MPa. The plant exhibits extreme structural adaptation with the ‘leaves’ being phyllodes composed of very small, thick walled cells. While brigalow represents an extreme such adaptations are common with Australian sclerophyllous plant species that include the abundant eucalypts and paperbarks. Enhancing the nutrient uptake does not preclude the need to be able to develop and tolerate low water potentials.

The adaptation by Saltbush (*Atriplex spp.*) involves limited uptake of salts that are not required for plant metabolism and shedding them along with old leaves. This can improve the uptake of essential nutrients by reducing salt accumulation around roots and reducing the need to expend energy on excluding particular ions.

**Site Characteristics**

The site characteristics relate to spatial or temporal differences in environmental factors that promote the growth and survival of plants in saline environments. The main site characteristic that promotes plant growth is the development of a soil profile whereby the surface soil is leached and salts accumulate in the subsoil. Plants obtain most water and nutrients from the surface soil where the A1 horizon is most important because of the adsorption of nutrients onto humus.

Organic matter is important as it provides a means of efficiently recycling nutrients as well as improving the water relations and aeration of soils. Breakdown of organic matter makes
nutrients available while the humic compounds that accumulate in the soil limit the potential for nutrients to be leached. Organic matter mainly accumulates in the surface soil where salts are most susceptible to leaching by rainfall thus soil organic matter provides nutrients in the lowest salinity environment possible. The surface soil also has the best aeration where this promotes the mineralisation and uptake of nutrients.

Organic matter has an additional beneficial effect in enhancing nutrient availability through its buffering of pH. Organic matter tends to increase the pH of acid soils and reduce the pH of alkaline soils where a neutral pH promotes the uptake of nutrients.

The development of salinity is commonly associated with the accession of water hence salinity and waterlogging are commonly interlinked. Separation of the effects is difficult particularly since waterlogging directly decreases the ability of plants to selectively take up nutrients. It also disrupts the supply of nutrients by reducing the activity of microbes and suppressing microbial symbiotic relationships.

For brigalow the gilgaied soil is important as it prevents waterlogging of all surface roots. Gilgais can become flooded to the extent that they become wetlands containing aquatic plants (\textit{Marsillia sp.} (Nardo) and \textit{Myriophyllum sp.}) and animals (e.g. \textit{Daphnia sp.} and the back swimming shrimp \textit{Anostracus anostracus}). However, surface roots on the mounds remain well aerated.

The nature of the salinity is similar for the brigalow example from SW Queensland and the paper bark example from central coastal Queensland even though the climates and derivation of the systems are markedly different. With brigalow the deep clay effectively prevents drainage through the soil into a groundwater system (percolation) and the gilgaied topography prevents surface run off. Given the flat terrain the lateral drainage is limited to the extent of each gilgai.

With the paperbark example a young sandstone layer at around 1m largely blocks percolation to groundwater systems and lateral drainage is limited by the flat terrain and the gilgaied topography. Gilgais have developed despite the soil being coarse textured, and the gilgais intermittently support an aquatic fauna similarly to the brigalow system. In both situations the patterns of soil salinity reflect the interaction between the vegetation and soil but with the paperbark example there is sufficient lateral drainage through the coarse textured material for a geological structure to effect change.

The brigalow trees are located on the gilgai mounds. This also tends to occur in the paperbark community even though the gilgais are much less pronounced. Eucalypts are particularly affected: the density of eucalypts in the paperbark woodland varies from zero to their being common. Most are the small \textit{Eucalyptus exerta} but an occasional large \textit{E. tereticornis} occurs on the largest mounds.

The brigalow gilgai formation commences through water preferentially entering the soil down large cracks. This has been observed to artificially occur through localised runoff from a roof. The pattern is reinforced by water extraction by the plants as salt is flushed away from cracks in the depressions and accumulates under mounds (more salt is stored under mounds than depressions). The saline soil stays moister for a given water potential hence cracks repeatedly develop in the depressions. Water use by brigalow is causal in developing and maintaining the gilgai formation that promotes the development of the vegetation. The depth of gilgais has decreased where the land has been cleared and not ploughed.

The mechanism for gilgai formation for the brigalow soil is consistent with the swell-shrink characteristics of a clay soil high in montmorillonite. However, it is difficult to translate this
mechanism to the coarse textured soils associated with the paperbark example as these do not exhibit apparent swelling. One possibility is heaving of soil made thixotropic by wind vibrating trees in saturated soils but, while this effect has been observed to cause upwelling of soil around tree boles, it has not been shown to produce gilgais. Given a lack of a clear mechanism for the gilgai development there is no basis for deciding whether trees in the paperbark community take advantage of natural patterns or whether they produce them. Regardless, the gilgaied pattern reduces the extent of waterlogging and this is important for plant development.

Subsoil
The paperbark example indicates that the surface soil is much more important than the subsoil in determining the development of vegetation as the vegetation with extremely high subsoil salinity appeared little different to the same form of community where subsoil salt contents were low. The saline and non saline soils were derived from the same material with the salinity apparently arising from a geological feature impeding lateral drainage.

Despite the importance of the surface soil the existence of plant roots in the subsoil means that it must be of consequence. However, the significance of subsoil salinity often cannot be deduced from average soil salt contents. With brigalow the subsurface roots follow cracks where the preferential flow of water down such cracks produces localised reductions in salinity. The salinity experienced by plant roots in subsoils is generally lower than in the surrounding soil.

The significance usually assigned to deep roots is the uptake of water when conditions become dry. This does occur but deep roots can also be significant for nutrient uptake. Most plant roots are in the A horizon, part of which is leached and the other part primarily involved in the recycling rather than the provision of nutrients. In natural systems plant organic matter in soils does not supply new nutrients to vegetation but serves to recycle them and limit their loss. Plant roots in the subsoil are positioned where minerals accumulate and can therefore represent a prime means of plants accessing nutrients that are limiting or not available in the surface soil.

Conclusions
Plants are adapted to the environment in which they occur. Plant characteristics identified as beneficial for addressing one constraint are usually beneficial in addressing several constraints.

In much of Australia the prime environmental constraints for plants commonly include salinity as well as the limited availability of water and nutrients. Most plant morphological adaptations to salinity are therefore associated with adaptations that address the restricted availability of water and nutrients.

The beneficial site characteristics arise from spatial differences some of which are generated and/or accentuated by the plants. The prime mechanism involves the development of regions where salinity is reduced by leaching and supplies of nutrients and water are enhanced by the accumulation of organic matter, as in the surface soil. This is further enhanced by structural features that limit waterlogging, such as the gilgaied formation. For subsoils structural unconformities such as cracks appear most important.