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Compiled by C. Tang and D.R. Williamson

Australian Society of Soil Science Incorporated (WA Branch)

Dr. Mike Wong
CSIRO Land and Water
Private Bag 5 PO
WEMBLEY WA 6913

Environmental Consultants Association (WA) Inc.

Ms Michele Northover
Post Box 971
WEST PERTH. WA 6872

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Phase farming with trees: a new weapon in the fight against dryland salinity?

R.J. Harper[1], T.J. Hatton[2], D.S. Crombie[1] and W. Dawes[2]

[1]*CALM Science Division, Department of Conservation, Locked Mail Bag 104, Bentley Delivery Centre, WA, 6983.*
[2]*CSIRO Land & Water, Private Bag, PO Wembley, WA, 6014.*

Abstract

A system to overcome dryland salinization of farming systems in medium to low (300-600 mm) rainfall areas of southern Australia is proposed. Phase farming with trees (PFT) is designed to use trees grown in very short term rotations (3-5 years) to rapidly de-water farming catchments at risk of salinity, by depleting soil water while producing utilizable products such as wood fibre and biomass. The tree phase is followed by an agricultural phase of a length defined by the persistence of the hydrological buffer created by the trees. The system thus utilizes a resource (groundwater recharge) that is contributing to environmental problems while building more sustainable agricultural systems. Potential benefits include decreased salinization, improved soil structure and acting as a disease and weed break. Production of large amounts of biomass suitable for "green" electricity will decrease Australia's emissions of Greenhouse gases.

The biophysical feasibility of PFT was assessed for several sites in the 300-600 mm rainfall zone of southern Australia using the WAVES model. Several scenarios were examined, with these suggesting broad differences in likely response to the PFT system. The modelling suggests that the premise of the PFT system (*viz.* depletion of sub-soil moisture reserves under trees and subsequent recharge under agriculture) is realistic. Moreover, the outputs suggest different tree planting strategies according to soil and hydrological conditions.

Introduction

Salinity

Rising groundwaters and resultant salinity threaten agricultural land, conservation reserves and water resources across southern Australia. This problem has been induced by the widespread removal of deep-rooted native vegetation for farming, and replacement with shallow-rooted annual plants. The reduced water-use has resulted in rising water tables that mobilise salt stored in the regolith. Saline groundwaters enter plant root zones, or discharge on the ground surface (Bettenay *et al.* 1964; State Salinity Strategy 1996; Hatton and Nulsen 1999).

In Western Australia 1.8 Mha is currently salinized, with 6.1 Mha likely to be affected in the future; respective Australia-wide estimates are 2.5 and >15 Mha (Ferdowsian *et al.* 1996; State Salinity Strategy 1996; Prime Minister's Science Engineering and Innovation Council 1998). Effects of salinity include the destruction of farmland, conservation reserves, infrastructure and water resources, with the capital value of salinized agricultural land in Western Australia alone being ~$1.4 billion (State Salinity Strategy 1996).

Williams (1999) suggests that land use systems capable of reducing salinization *and* providing an adequate income are not currently available for large areas of Australia's agricultural zone. We know that salinity control can be obtained by controlling groundwater recharge and that trees can achieve this (Schofield 1990; Hatton and Nulsen 1999). Not only are trees relatively cheap to establish and maintain compared to drains or diversion systems, but they have the potential to produce saleable products such as timber, pulp or fuel-wood with the benefit of diversifying farm incomes (Shea and Bartle 1988). With the scale of the salinity problem, the area of land that needs to be revegetated is ~3 million ha in Western Australia alone, assuming that 30% of the land needs to be planted to control salinity (State Salinity Strategy 1996). Trees also provide a solution to other forms of land degradation prevalent in this region, such as wind erosion (Carter 1995).

Given the scale and increase in salinity, rapid deployment of trees is required to restore the hydrological balance over large areas and minimise the areas affected. Whereas there has been widespread adoption of trees in higher rainfall areas, adoption of trees in lower rainfall areas has been limited for several reasons. Apart from generally low initial rates of adoption of new farm technology, we speculate that reasons include (a) uncertainties about returns, (b) uncertainties about where to plant trees for best hydrological impact, (c) limitations on the effectiveness of trees, and (d) conflicts with agricultural activities.

Phase Farming with Trees (PFT)

We propose an innovative system that would use plantings of medium-high rainfall commercial species in lower rainfall areas, in ultra-short rotations (3-6 years) to quickly de-water the local area while producing biomass. We have termed this Phase Farming with Trees (PFT). In the PFT system trees would be used as temporary elements in rotations with annual cropping. They would be planted at higher densities to force use of both the annual rainfall and water that has accumulated in soils during the agricultural phase. The trees would be harvested when the accumulated water has been evaporated, probably within 3-5 years after planting. Plantings would be in wide strips, blocks or whole paddocks depending on crop rotation and land-holder preference. The harvested trees would be sold as feed-stock for industry or used for bio-energy. Annual cropping would then resume.

Despite poor long-term survival of the trees, it is expected that prior to death they will exhaust stored un-saturated soil moisture that has accumulated under annual crops and pasture since clearing. Depleting the water will help restore catchment hydrological balances. Instead of relying on water to move (slowly) through the landscape to strategically (and uncertainly) placed trees, trees in strips or blocks will be rotated across the landscape at relatively short intervals, using water locally. Because trees are moved across the landscape, optimum tree placement is of reduced importance. Conflicts with farming practice will also be reduced and traditional farming systems can be maintained in the areas not planted to trees.

If successful this system will allow the rapid expansion of tree planting in low rainfall areas across southern Australia, with:

(a) the rapid restoration of catchment water balances,

(b) the utilization of a resource (stored soil water) which is currently contributing to environmental problems, Williams (1999) suggests that land use systems capable of reducing salinization *and* providing an adequate income are not currently available for large areas of Australia's agricultural zone. We know that salinity control can be obtained by controlling groundwater recharge and that trees can achieve this (Schofield 1990; Hatton and Nulsen 1999). Not only are trees relatively cheap to establish and maintain compared to drains or diversion systems, but they have the potential to produce saleable products such as timber, pulp or fuel-wood with the benefit of diversifying farm incomes (Shea and Bartle 1988). With the scale of the salinity problem, the area of land that needs to be revegetated is ~3 million ha in Western Australia alone, assuming that 30% of the land needs to be planted to control salinity (State Salinity Strategy 1996). Trees also provide a solution to other forms of land degradation prevalent in this region, such as wind erosion (Carter 1995).

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If successful this system will allow the rapid expansion of tree planting in low rainfall areas across southern Australia, with:

(a) the rapid restoration of catchment water balances,

(b) the utilization of a resource (stored soil water) which is currently contributing to environmental problems,

(c) the production of wood fibre and non-wood products,

(d) an impact on Australia's net carbon dioxide emissions by providing both a carbon sink in the vegetation and a feedstock for bio-electricity, and

(e) the development of more sustainable agricultural systems through the reduction in salinization, providing a disease and weed break and "biological ploughing" of sub-soils.

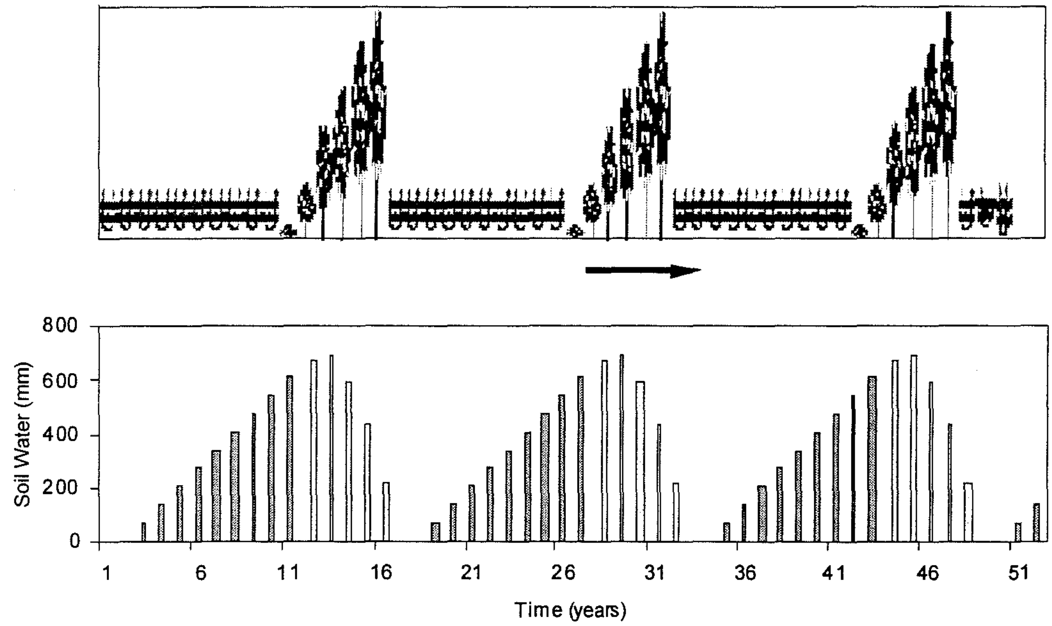

Fig. 1 *Conceptual diagram showing phase farming with trees with its associated cycle of soil water storage (mm)*

The PFT system has no direct counterpart in forestry, with short rotation systems invariably involving permanent plantings that are coppiced at regular intervals; our proposal in more akin to phase cropping with perennial agricultural plants such as lucerne (*Medicago sativa*). Similarly, the system could involve practices normally avoided in lower rainfall forestry including high planting densities and substantial inputs of fertilizer to promote early growth and water use. Although we have not made an explicit comparison with lucerne the major advantages of phase cropping with trees are likely to be a greater depth of rooting, and hence water depletion. Likewise, the development of a larger canopy which will enhance both evapotranspiration and rainfall interception, and ancillary benefits such as maintaining soil macropores and the introduction of recalcitrant forms of carbon.

A scoping study was undertaken to determine feasibility of the PFT system in medium to low (300-600 mm) rainfall areas of southern Australia (Harper *et al.* 2000). That study examined various aspects of the PFT proposal including (a) identification of likely end-products, (b) modelling of the likely effects of the system on catchment water balances, (c) identification of likely impacts on soil physical, chemical and biological properties, and (d) an overall economic analysis. In this paper we briefly describe the results of the biophysical modelling and the general likelihood of the PFT system working.

Biophysical analysis

In the absence of appropriate growth and hydrological data the WAVES model (Zhang and Dawes 1998) was used. This examined the bio-physical feasibility of the system in both Western Australia (Merredin, mean rainfall 320 mm, potential evapotranspiration 1800 mm) and the Murray Darling Basin (Walpeup, Victoria (340 mm, 1750 mm) and Hillston, NSW (581 mm, 1750mm)). The WAVES model was run using real rainfall data for each location.

Several scenarios were examined, with these suggesting broad differences in likely response to the PFT system. The modelling suggests that the premise of the PFT system (*viz.* depletion of sub-soil moisture reserves under trees and subsequent recharge under agriculture) is realistic.

1) *20 m deep sandy soils.* Here PFT depleted soil water storage and stopped the recharge under agriculture (100 mm/year) within 2-3 years of planting. The high recharge rates resumed 3 years into the next agricultural phase. PFT is not suitable for such soils with the best strategy being permanent blocks of trees.

2) *Soils with 1 m of sand overlying 2 m of clay, with and without a fresh water table and with a saline water table.* Here recharge rates returned to a maximum within 1-5 years of clearing the trees. It is likely that soil salinity will accumulate under the trees grown over a saline water-table, with this requiring leaching before another rotation is possible. Permanent plantations of salt tolerant perennials are recommended in these situations.

3) *Soils with a clayey surface horizon.* Here the rates of recharge are very low (1 mm/year) under agriculture and trees may only be required at very long rotation intervals (~decades).

4) *Soils with 1 m of sand overlying 9 m of clay.* Here PFT depleted soil water storage and stopped recharge within 3-4 years of tree planting. In contrast to the other sites, recharge did return to peak rates of 67 mm/year for 17 years following a return to agriculture. It may be possible to get zero recharge with a system with 5 years of trees and 10 years of crop.

This last situation corresponds to broad areas of southern Australia, and Western Australia in particular, where the regolith may be up to 30 m deep. The key question is whether this depth of soil is exploitable by tree roots. Limited data in higher rainfall zones suggests that tree roots have grown to at least 9 m depth within 6 years of planting *Eucalyptus globulus* (Harper and Crombie, unpub.) The effect of sub-soil conditions on the depth of rooting, and in particular the effects of stored salt, with or without water tables, is not known and needs to be resolved.

In the one case examined in this work, salt leached out of the soil profile much more slowly than it built up, and leaching caused transient but substantial increases in soil water salinity. *The presence of salt complicates the question of a sustainable and economically viable system so greatly that more detailed work is required to find any general patterns.* The concept of a critical groundwater depth may be useful in this context.

Discussion

The biophysical analysis suggests that in areas with deep, root penetratable regolith, phase farming with trees is quite likely to reduce recharge under dryland agriculture and provide storage for out-of-growing season rainfall while allowing the continuation of farming. It must therefore be considered a strong candidate technique for overcoming salinity problems and ensuring the sustainability of dryland farming systems. To reiterate from the introduction, these farming systems are under severe threat from salinization over broad areas and there is a strong imperative for action. Hydrological benefits are likely to be further enhanced by improved soil conditions that will lead to more sustainable long-term land use (Abbott and House 2000).

PFT is marginally suitable or not suitable for other hydrological situations, such as deep sandy soils or soils with 1 m of sand overlying clay, that are freely drained or are connected to either fresh or saline water tables. In these situations, although trees control recharge under the trees, it rapidly (1-5 years) returns to the pre-tree situation on removal of the trees and reversion to annual agriculture.

This analysis also has implications for farm forestry in this region, suggesting different tree planting strategies are needed according to broad differences in soil and hydrological conditions. It is feasible that these different situations can be mapped and different farm forestry treatments applied to specific sites. For example, deep sandy soils and those with an accessible fresh groundwater table may require permanent revegetation, sites with small recharge rates may not need revegetation, and sites with deep soil profiles could be treated with PFT.

The PFT system is not profitable in 300-400 mm rainfall regions if considered in terms of gross-margins alone (Challen 2000). This analysis assumed a product with a moderate return (*Eucalyptus globulus* for pulp-wood) but an assured market. Options to increase profitability by decreasing the costs of growing and harvesting the trees appear limited given that with direct seeding costs are comparable to normal crop establishment and harvesting is also a low-cost operation. The best option for profitability is to increase yields, or the value of the products obtained. Other, more valuable species may be developed in the future as a result of current investigations for commercial low-rainfall zone forestry species. Of critical importance is that any economic analysis should also bring any land conservation benefits to account. In the future access of farm products to particular markets may depend on meeting sustainability criteria or sustainability may be mandated by regulations.

Limitations and future work

The scoping study indicated several areas where further research needs to be undertaken, most of which are focused on resolving whether the basic premise of our proposal—water removal to depths of 10 m over wide areas of low rainfall—is achievable in 3-5 years using trees. These include:

- The hydrological modelling suggests that with readily penetrable soils PFT can achieve the desired aims of stopping additional recharge and depleting water in unsaturated stores. However, the root penetrability of soils in the target zone is unknown and in particular the impacts of stored salt in deep profiles and physical constraints.
- Developing techniques for removing tree stumps prior to returning to agriculture,
- Determining actual growth rates over the first 3–5 years (i.e. the likely length of a PFT rotation) need to be determined for different species and related to variations in climatic and soil/hydrological conditions.

- Determine whether growth, and water use, can be enhanced through management inputs (fertilizers, stocking) to shorten the PTF phase.

In conclusion, we suggest that phase farming with trees presents a major opportunity of producing a sustainable agricultural system for dryland areas of southern Australia. It requires investment to field-validate the modelled outputs, optimize the system for different site conditions and demonstrate its potential to landholders.

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