Land assessment to integrate trees with agriculture for biomass production, carbon sequestration and salinity control

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1. INTRODUCTION

It is well recognised that it will be necessary to revegetate large areas of Australian farmland to achieve improved natural resource management outcomes, and in particular the amelioration of salinity (Bartle and Shea, 1989; Shea and Bartle, 1988) and wind erosion (Harper *et al.*, in press). In south-western Australia it is estimated that up to 7 Mha of land will be affected by salinity by 2050 (National Land and Water Resources Audit 2001), all inland water supplies will be salinized, up to 450 species are at risk of extinction (Keighery *et al.,* 2001) and along with a significant loss of farmland productivity (Kingwell *et al.*, 2003) there is significant threat to infrastructure (Prime Minister's Science Engineering and Innovation Council 1998; State Salinity Council 2000; State Salinity Strategy 1996).

Although the scale of the problem is huge (Prime Minister's Science Engineering and Innovation Council 1998), any investment in reforestation is likely to be limited from public funds. Thus, if commercial drivers can be identified, investors will establish trees for profit, with collateral environmental benefits. Whereas the establishment of trees in higher rainfall areas is profitable, both due to relatively high growth rates and proximity to infrastructure, in lower rainfall areas (less than 600 mm/year) this is often not the case. The concept of "self funding Landcare" has thus been explored with investigations of other products available from trees such as biomass for "green electricity", carbon sequestration (Biggs and Bartle, 1999; Shea *et al.,* 1998), mallee oils (Bartle, 2001) and improved water quality (Harper *et al.*, 2001).

Irrespective of purpose–biomass production, wood production, increased water use or carbon sequestration–the benefits of reforestation depend on its survival and adequate growth. Although tree survival and growth are strongly affected by site management, they are also strongly related to soil conditions. It is thus essential that any soil constraints be identified prior to reforestation, appropriate management instigated or the site avoided.

Reforestation for multiple outcomes provides a particular challenge for designing an appropriate land assessment system as it deals with both agriculture and forestry, systems that have dissimilar requirements. Similarly, reforestation for salinity control requires the management of dissimilar soils, with both non-saline recharge and salinized discharge areas. Information is also required to allow the strategic integration of trees with agriculture

(Stirzaker *et al.*, 2002), as the aim of farm forestry is to allow the continuation of agricultural activity, rather than to displace it. It is unlikely that any reforestation in lower rainfall areas will result in large compartments such as seen in traditional plantation forestry. An understanding is thus required of (a) the nature and location of the prevailing soil and hydrological conditions and (b) an interpretation of what this information means in terms of plant performance (e.g., growth, survival, recharge control) and optimal management inputs.

In this paper we describe the climate and soil information requirements to evaluate farmland prior to the establishment of forestry for any tree-based enterprise, drawing on our experience with plantation and agroforestry systems in higher (> 600 mm) rainfall zones. We describe regional evaluations of forestry potential using existing soil and climate data and the site survey requirements for particular projects. Although our experience has been with plantations established on farmland for wood products and carbon sequestration the principles equally apply to biomass plantations.

2. REGIONAL AND PROJECT LEVEL EVALUATIONS

Prior to developing markets for new tree-based industries it is necessary to determine distribution in terms of both likely production and proximity to existing infrastructure. Similarly, understanding how groundwater recharge varies across a landscape will allow the targeting of reforestation treatments to areas where they are most needed. Using the 300,000 ha Collie Catchment of southwestern Australia as an example, we combined regional scale (1:100,000) soil-landscape mapping with pedotransfer functions describing tree survival and growth and groundwater recharge and land tenure data.

This analysis indicated broad areas where biomass plantations were either unlikely to succeed, or were not required on the basis of rates of water leakage to groundwater. For those areas suitable for forestry, pedotransfer functions were combined with climatic data to estimate risk, total yields and spatial distribution of wood, carbon sequestration and recharge reduction. Likely biomass yields, based on *Eucalyptus globulus* data, varied from 7-25 t/ha/year, with approximately two-thirds of the 47,000 ha of cleared land suitable for planting.

The actual amounts of timber production and carbon sequestration will depend on a range of factors including the participation rate of landholders and the nature of the forestry enterprise. Factors that will be important include species selected, production system (e.g., pulpwood vs. timber) and the method of integrating trees with agriculture (block plantations, strips). Much of the cleared agricultural land in the catchment is privately owned so no assumptions were made about the participation rate in revegetation by landholders, however this will be crucial in terms of actual wood production and carbon sequestration. This notwithstanding, it is estimated that complete revegetation of farmland in the Collie catchment would result in carbon sequestration of approximately 15-20 Mt CO_2-e over a 30 year time period from the plantations.

3. REQUIREMENTS OF SOIL SURVEY FOR FARMLAND REFORESTATION

During the 1990's there was a rapid expansion of plantation establishment on farmland in south-western Australia, and we developed soil survey procedures to reduce the risk of this enterprise (Harper *et al.,* 1999; Harper *et al.,* 2001; Harper and McGrath, 2000; Harper *et al.,* 1998). We can draw several key points from this experience that are relevant to farm or project scale assessments or land for biomass production:

4. NEED FOR APPROPRIATE SCALE OF MAPPING

Although 1:100,000 scale soil mapping is available across the region this is often more appropriate for regional planning than management at the paddock level (e.g., a 100 ha paddock is 1 cm^2 on a 1:100,000 scale map). Thus, regional compilations of soil and landscape data are unlikely to have any utility at the farm level.

4.1 Need for vertical resolution

In the vertical dimension conventional mapping also operates at an inappropriate scale with little or no reporting of soil materials at depths > 1 m. The requirements for agricultural soil survey differ substantially from those for farm-forestry. For example, trees growing in regions with summer drought are dependent on soil water storage for survival. A key soil attribute for farm forestry is thus soil depth, as this is a surrogate for rooting volume. Surveys for farm forestry now routinely assess soils to depths of 2-3 m, whereas agricultural soil surveys are invariably limited to the top 60-100 cm.

4.2 Redundancy of "soil types"

Soil survey, as practised, invariably results in mapping units such as "soil types". These are often accompanied by esoteric classifications, the practical utility of which is infrequently demonstrated. Not only are units such as soil types ill suited as input for biophysical and economic models (that require continuous rather than categorical data), but they involve the loss of significant amounts of information. This approach to handling soil information was developed before the advent of modern data acquisition and management systems. We argue that the "soil type" concept now represents redundant technology for local management applications.

4.3 Utilisation of new data-handling technologies

Data acquisition. Several new techniques that allow the acquisition of continuous data have been developed. These include ground-based, airborne or satellite systems and with instruments that measure, for example, gamma-radiometric, magnetic or electrical-magnetic spectra (AEM) spectra. Digital terrain models obviate the need for most detailed ground assessments and descriptions of landforms.

Data management. There has been considerable work on the management of continuous data sets, such as soil and terrain data. Although geographic information systems are often used to manipulate soil data comprising "soil types", at inappropriate scales, a range of statistical techniques has been developed for analysing and portraying these data.

Data portrayal. Much progress has been made using geographic information systems and portraying complex spatial data sets.

4.4 Changed data requirements

Similarly, we suggest that soil information can be used for more than yield prediction alone. An increasing role for soil surveys will be in providing information for simulation models, such as for plant growth, the prediction of erosion, water movement in landscapes and the leaching of nutrients or herbicides.

4.5 Use of surrogates

Surrogate variables are used as they provide a cheaper alternative than direct measurement. A better focus is required on the range of attributes that are assessed either in the field or electronically, on the basis of their importance. Although soil attributes such as soil colour, texture and structure are routinely assessed, the relationship between these factors and plant performance is poorly documented for many Australian soils. The fundamental assumption is that the factors assessed (surrogates) are somehow related to an underlying more important variable (Gibbons, 1961), irrespective of whether assessed in the field or by remote sensing. This assumption holds for some attributes (e.g., soil texture and soil hydraulic properties (Smettem *et al.*, 1999), gamma radiometrics (Wong and Harper, 1999) and available or total potassium, soil texture and soil organic carbon (Harper and Gilkes, 2000) but not for others (texture and soil chemical fertility (Colwell, 1963)). These latter properties are often those affected by soil management.

4.6 Need to measure the right attributes

We have found that many soil attributes measured in traditional soil surveys do not affect the growth of trees, whereas factors that do (e.g., soil depth and fertility) have not been routinely measured. Similarly, current soil surveys do not distinguish between the different types of discharge land. This is unsatisfactory as plants have widely differing tolerances to various stresses, and salinity, waterlogging and inundation affect plant growth on salt land. Whereas salinity can be rapidly assessed using EM meters, routine prediction and measurement of waterlogging and inundation are more problematic. These often vary widely in incidence both within and between years.

4.7 Balancing the cost and utility of soil survey

It is well known that the utility of soil survey information increases with investment, however the information requirements have to be balanced with what is achievable within a farming budget. Many new techniques require both investments of time and resources such that they are more likely to be used for teaching and simulation rather than to make practical land-use decisions.

5. CONCLUSIONS

With the *a priori* assumption that the key factors driving plant performance are water supply (controlled by soil water storage, climate and local hydrology), soil fertility and the expression of hazards (e.g., salinity). We suggest land evaluation for biomass production, and indeed any reforestation, should have the objective of identifying key (and easily obtained) surrogates for these vectors. These surrogates may be based on ground assessments, existing modelling (e.g., hydrological models) or remotely sensed (e.g., radiometrics, satellite imagery). Whatever attributes are selected; the key criteria for acceptance will be practicality of routine measurement, accuracy and cost effectiveness.

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