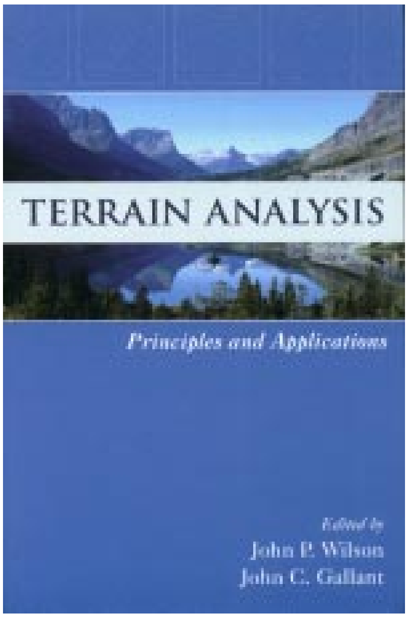

geographers, geomorphologists, environmental engineers, hydrologists and soil scientists. A final chapter considers future directions for terrain analysis.

The main terrain analysis tools considered are ANUDEM and TAPES and participants in ACLEP's Technical Workshop on Terrain Analysis will recognize much of the material. This is a really useful book with a very strong Australian connection – it is bound to become a standard.

"Terrain Analysis: Principles and Applications" is published by John Wiley and Sons.
(ISBN 0-471-32188-5).

Neil McKenzie

Using soil survey for farm forestry and greenhouse sink site selection and management

Richard Harper and John McGrath

Overview

Trees are being established on substantial areas of Australian farmland for both environmental conservation (salinity and erosion control, carbon sequestration) and profit. It is essential that site constraints be identified prior to planting so the trees are planted where they will survive and grow well. The delivery of both environmental benefits and commercial viability depend on adequate growth.

In this article we describe the application of soil survey to farm forestry as it has been used for Tasmanian blue gums (*Eucalyptus globulus*), radiata pine (*Pinus radiata*) and maritime pine (*Pinus pinaster*) on farmland in south-western Australia. Soil survey has advantages in that it can provide information in a relatively cheap and timely manner. Whereas in the past it has mainly been used for the prediction of tree performance it can be extended to form the basis for site-specific management. Management decisions can be made on the basis of actual crop requirement rather than general prescription. Sites with un-manageable constraints (e.g. with shallow or saline soils) can be avoided; those with manageable constraints (e.g. poor fertility, poor drainage, root constraints from shallow pans) can be treated as required.

Much Australian soil survey has relied on observations and interpretations of soil morphology on the basis that this provides surrogates of underlying factors. In some cases this assumption does not hold and site assessment procedures should incorporate field and laboratory measurements of pertinent chemical and physical attributes. A pragmatic approach to field survey is required, with data gathering (whether morphological or analytical) being based on demonstrated benefit rather than routine prescription or tradition. Calibration of soil morphological, physical and chemical attributes with tree performance provides considerable research opportunities.

Introduction

The establishment of trees on farmland represents a major change in land use in Australia. In Western Australia alone it is estimated that 130 000 ha of trees have been planted in the last 10 years with a mean rate of establishment of

26 000 ha/year over the last three years (Love *et al.* 1999). These trees are being established both for land-conservation and profit. Having a commercial outcome allows tree planting, and hence land-conservation, to be funded by investment rather than subsidy (Shea & Hewett 1997). The success of the Western Australian farm forestry industry has paved the way for similar expansion to occur in other states.

Planting has, until recently, been concentrated in the >600 mm rainfall zone, with species such as *Eucalyptus globulus* and *Pinus radiata*. In the future, it is planned to plant upwards of 600 000 ha of trees (*Pinus pinaster* and various oil mallee species) in the <600 mm rainfall zone as part of the Western Australia response to salinity (State Salinity Strategy 1996). Emerging drivers of revegetation include the establishment of plantations as Greenhouse carbon sinks and as sources of biomass for "green power". Similarly, various species are being planted for habitat restoration and aesthetic purposes.

Irrespective of purpose - wood production, increased water use or carbon sequestration - the benefits of revegetation depend on survival and adequate growth. While survival and growth often reflect management they are also strongly related to site conditions. Site is usually considered as a range of environmental attributes (climate, soil and geomorphology). Whereas most climatic attributes vary at regional scales, soil and geomorphological factors vary across paddocks. The aim of site survey is thus to systematically gather a range of information about a site and identify areas that are similar enough to be managed consistently.

It is essential that any site constraints be identified prior to revegetation, appropriate management instigated or the site avoided. Major issues thus revolve around identifying (a) sites where trees will not survive, or grow poorly, (b) site constraints that require specific management and (c) where trees should be planted to maximise land conservation benefits.

Table 1. Potential use of soil information for farm forestry.

Issues	Outcomes
Site selection	Prediction of tree performance (survival, growth, wood quality) Identification of hazards (flooding, salinity, windthrow) Matching genetic material (tree species, provenances) to "site" conditions
Site management	Predicting responses to ripping, mounding, fertilization and drainage Thinning trees with respect to site capacity Predicting trafficability at harvest (roading) Prediction of erosion (water and wind) hazards at establishment Reducing environmental impact of plantations (nutrient and herbicide leaching, predicting fate of run-off waters) Providing stratification framework for timber inventory
Integration	Farm-planning and integration of trees with farming systems
Technology transfer	Spatial extension of research results

In this article we describe the applications for soil survey in resolving these problems as we have tackled them in Western Australia. Particular issues covered include (a) a description of the soil information requirements of farm forestry and (b) the degree to which soil survey can realistically meet these requirements and (c) some future research challenges.

Soil information requirements for farm forestry

The evaluation of land prior to the establishment of trees is commonly termed "site assessment" (Valentine 1986) and is a well recognised prelude to plantation establishment in many countries. This has also always been an integral part of both Conservation and Land Management (CALM) and its predecessor, the Forests Department, systems of plantation establishment. In Western Australia site assessment has mainly concentrated on the prediction of tree performance (particularly survival and growth) (Havel 1968; Inions 1991; McGrath *et al.* 1991; Edwards & Harper 1996) for pre-selected species. Site assessment has variously involved combinations of soil, climatic, vegetation and geomorphic (i.e. slope, aspect) information.

Soil surveys are often advocated as a tool for agricultural land management and can have a similar role in farm-forestry. Data collected at the site selection stage could, therefore, provide information for an array of other decisions, ranging from site-species matching, to modifying management both at tree establishment and the ensuing rotation (Table 1). Profitability will be increased by applying inputs where they are needed rather than on a uniform or prescription basis. This is site-specific silviculture. Examples include only applying fertilizers or deep-ripping where there is likely to be a response, rather than routinely applying these treatments.

Soil survey

Using soil morphology as a surrogate for other variables

The basic premise of soil mapping, and much land evaluation, is that the soil properties observed in the field (such as texture, depth, colour and structure) are related to other underlying factors (Gibbons 1961). Rather than relying on time consuming (and expensive) field and laboratory measurements the values of the factors of interest are inferred from field observations. It is also assumed that these observations, and the resultant maps, are replicable between operators.

For example, field texture is related to clay content, which is often in turn related to other factors. In a study at Jerramungup, Harper and Gilkes (1996) found that clay content was related to other properties such as water holding capacity, organic carbon content and potassium fertility, and soil management problems such as hardsetting, non-wetting and wind erodibility. As soil mapping units were based on field texture, soil mapping could depict the distribution of these attributes, and possibly be extended to encompass other issues such as the fate of different types of herbicides. The strength of such relationships may vary from area to area with local calibrations of soil surveys required.

Some variables, however, have a poor relationship or are independent of field properties. In such cases no amount of description or classification in the field will enlighten us as to their distribution (Gibbons 1961). Such variables are often those that have been modified in the soil by past management, or vary markedly over time. At Jerramungup, for example, plant available phosphorus and clay content were poorly related. The phosphorus content was mainly determined by past fertilizer applications, hence soil mapping was not useful for depicting the distribution of that variable.

Interpretation of soil information

A traditional approach has been to interpret field information through qualitative ratings. For some attributes this approach is relatively straightforward, whereas for others there may be no underlying relationships between the field observations and the factors of interest.

A recently completed CALM study examined how various site properties affect the growth of blue gums (*Eucalyptus globulus*) planted on farmland in south-west Western Australia (Harper *et al.* 2000). Several interacting factors were found to affect the performance of the blue gum plantations. These included climate (rainfall, evaporation), soil volume (estimated by soil depth, occurrence of ferricrete gravel), soil fertility (total N content) and plantation stocking. These factors all point to water supply as being the critical factor in plantation performance in this region, with growth increasing with increasing rainfall and decreasing evaporation. Similarly, they suggest that both the location of trees in the landscape (slope position) and planting conformation (strips integrated with farming) will become more important with decreasing rainfall and increasing evaporation.

Apart from the depth to basement rock or saprolite, soil attributes which were consistent indicators of tree performance included the occurrence of deep (>2 m) sands and the presence of ferricrete gravel. The soil depth considered critical for blue gum survival (at least 2 m) is much deeper than that traditionally measured in soil surveys in this region. We introduced the use of backhoes, to allow deeper examinations of soils prior to afforestation, in this region in the late 1980's, and this is now standard industry practice. Survival and growth of *P. radiata* also increases with increasing soil depth (McGrath *et al.* 1991). It is not always clear, however, what defines a root-restrictive layer and hence the effective depth of the soil. Field inspections may also readily identify cemented pans in terms of depth, thickness, continuity and distribution and judge whether ripping is appropriate. In contrast, this approach may not identify compacted layers in sands, and hence allow prediction of ripping response.

Deep sands are likely to affect growth through poor nitrogen fertility as a consequence of poor previous pasture growth and poor water holding capacity. The occurrence of ferricrete is related to the occurrence of deep weathering profiles. Several soil attributes that are traditionally measured in soil surveys such as colour, structure and field texture did not appear to be associated with differences in blue gum performance across the region, although some of these will be important at localized scales.

Although soil fertility and salinity are factors of key importance in this region field inspections tell us little about them. Where such poor, or ill-defined relationships exist with field attributes, a more appropriate strategy is to sample the soil and measure the attribute through physical or chemical analyses. Tree response thus needs to be calibrated with soil properties, either described or measured. This has long been recognised in agriculture with fertilizers applied in response to soil chemical analyses rather than soil survey.

Salinity is a major issue in Western Australia, but is not adequately defined by traditional field inspections. The current salinity of the soil is assessed using either soil analysis or more commonly field electromagnetic techniques (Bennett & George 1995), as these allow more intensive sampling. Prediction of future risk of salinity due to rising groundwater tables is more problematic and requires an understanding of hydrological processes.

Discussion

The findings in Western Australia have implications for the use of regional soil surveys to predict blue gum performance. Many soil attributes that are important for blue gum performance (soil depth, soil fertility, soil salinity) are not measured in regional scale (1:50 000 – 1:100 000) soil surveys. Those soil attributes that are measured (soil profile form, texture, colour) are not, or only poorly, related to blue gum growth. Thus, apart from considerations of inappropriate mapping scale for management purposes (a 100 ha paddock is 1 cm^2 on a 1:100 000 map), the regional mapping may be of limited use in predicting blue gum productivity. Site surveys of key soil attributes are required at scales of 1:10 000 to 1:20 000 prior to planting, with an appropriate observation density.

Currently CALM's farm forestry soil survey (Harper *et al.* 1998) relies on a staged approach. Initially a range of issues such as climate, slopes and land-holder preference are considered to identify target areas. These areas are then surveyed and areas with limitations likely to affect tree performance such as shallow, saline, waterlogged or grossly nutrient deficient soils are identified. On sites where trees are considered likely to survive, tree performance is considered in terms of the effects on water supply (deficiency or excess) and site fertility. Tree growth can be predicted from key soil and site variables (Inions 1991; McGrath *et al.* 1991; Harper *et al.* 2000) and fertilizer requirement can be estimated following soil analysis.

Another set of issues relates to the placement of trees in the landscape for greatest environmental benefit. The problem of where to plant trees for wind erosion control is straightforward, as wind erodible soils can be identified relatively easily. Salinity, however, is a hydrological problem and there are difficulties in predicting the optimal distribution of trees in the landscape to control its expression. In this case, the role of soil surveys may be to provide some inputs for hydrological models rather than directly solving the problem. We are investigating these issues as part of a new Natural Heritage Trust Farm Forestry Program project, “Putting Trees in Their Place”, in conjunction with Associate Professor Keith Smettem from The University of Western Australia and Dr Tom Hatton from CSIRO Land and Water. This is aimed at resolving the best strategies for the placement of trees on farmland in the <600 mm rainfall zone of Western Australia, to maximize both water use and tree production.

As the time and resources available to undertake soil surveys for farm forestry are limited, data gathering has to focus on those attributes which have demonstrated importance in terms of the framework provided in Table 1, and deliver this in a timely manner. As already described, soil morphology may not adequately describe all factors of interest. A pragmatic approach to field assessment is thus required using a combination of techniques including soil morphology and an array of pertinent physical and chemical measurements. Some attributes (pH, salinity) may be measured in the field, whereas others (soil fertility) will require laboratory analysis. Information requirements from soil surveys will evolve as models which describe factors as diverse as tree yield, landscape water movement and herbicide sorption are refined, and key input attributes identified.

The need for cost-efficient and timely surveys has also generally precluded the use of some recent innovations in soil survey. Thus, while precision techniques which use information from soil analysis and an array of electronic instruments are promising, they are still confronted with the problems of traditional soil surveys - that of converting the instrument output (or field observation) into sensible advice. Successful site-specific farm forestry will require the calibration of various soil conditions with tree performance, and it is here that considerable research opportunities arise.

Farm forestry is moving into areas across Australia where plantation forestry has not been practised and site selection standards are not available. We have almost completed a project with Drs Phil Ryan, Trevor Booth and Neil McKenzie of CSIRO and Professor Bob Gilkes from The University of Western Australia. This project, “The Australian Farm Forestry Site Selection Manual”, funded by the Joint Venture Agroforestry Program, will outline the principles of farm forestry site selection developed from previous studies. It will specify the best methods for site-selection for farm forestry at the regional and paddock scales. These methods will be proposed as industry standards to be used by landholders, extension advisers and the farm-forestry industry. They will also be suitable for other forms of farmland revegetation and in the description of experimental sites by scientists. The manual will also be suitable for use as a component of farm forestry studies at the TAFE and undergraduate level.

Acknowledgements

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New agricultural systems for salt affected land

Edward Barrett-Lennard

Introduction

Australia has a major future salinity problem (about 15 million hectares are threatened). Current farming systems appear unlikely to substantially prevent these increases. It is therefore essential that capacities for productively using this resource are developed.

For saltland industries to flourish we need an understanding of three capabilities; that of land, plants and markets. What we need is the right plant (or combination of plants) at the right location in the landscape, producing products of greatest commercial value. Realising the potential of salt-affected land for productive use will require a major future commitment to research and development (R&D). These three capabilities are a useful framework around which to reassess priorities.

Defining market capability

There is an urgent need to assess the relative marketability of different saline agricultural options. No such analysis has ever been done for prospective saline agricultural

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The environmental imperative for large-scale land-use change in southern Australia has been clearly recognized by government, industry and community groups alike. Farm forestry is seen as a key element in strategies for land-use which aim to diversify farm income and solve dryland salinity. The very rapid expansion of farm forestry has created a demand for new forms of land resource information. In this issue, Phil Ryan and Richard Harper provide an overview of current developments.

Rob Bramley and Simon Cook have responded to our previous edition on soil testing and fertility assessment with a challenging article that questions current practice. Further responses on this topic and others presented in the Newsletter are very welcome. Finally, readers with an interest in quantitative methods of land evaluation will be pleased to know that the long-awaited text on terrain analysis edited by John Wilson (University of Southern California) and John Gallant (CSIRO Land and Water) has been published – a summary is included in this issue.

Inside

Issue theme: 'Land evaluation for new farming systems'

Recent developments in land evaluation for farm forestry (page 2)

Terrain analysis - principles and applications (page 7)

Using soil survey for farm forestry and greenhouse sink site selection and management (page 8)

New agricultural systems for salt affected land (page 13)

*Australian **E**arth **D**ata **O**n-**L**ine, inexpensive access to spatial data over the WWW (page 17)*

SOTER - The global SOils and TERrain database (page 22)

Some comments on the utility of soil test data for fertility management and resource assessment (page 27)

Parent material and soils: a guide to the influence of parent material on soil distribution in eastern Australia (page 35)