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OPINIONES

Sustained productivity of plantations: science and practice

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The prospects of plantation forestry are good. They are strengthened by several inter-related developments including the expanding role of plantations in meeting the global needs for wood, urgent concerns about the loss of native forests, the potential value of plantations as an integral part of land and environmental care, and the contribution of plantation forestry to economic growth in many countries. Furthermore, timber has many advantages as a construction material over other products including steel, aluminium and bricks, in terms of desirable criteria for low energy requirements and carbon emissions.

Chilean forestry has been in the forefront in recognising the need and opportunity of plantation forestry and has developed a large resource base within a relatively short time. This achievement has been based on exotic species, mainly *Pinus radiata* and *Eucalyptus globulus.* These species have many attributes in terms of growth potential, responsiveness to management practices and wood properties. *P. radiata* wood exceptionally versatile and suitable for a variety of end products and *E. globulus* is recognised as a premium quality pulpwood. Plantation forests in southern Australia are also based on these species and it appears that the land base in Australia and Chile have several environmental factors in common. What can we then learn from our combined experience?

PLANTATIONS IN AUSTRALIA AND CHILE

Australia has grown *P. radiata* plantations for more than hundred years on a range of soil types and in environments that are typically low in available water and nutrients. Large parts of the forest estate are already in second rotations and some in third rotations. Growth rates of these plantations vary form 15 to 35 $m^3 yr^{-1} ha^{-1}$ MAI with rotation length ranging from about 20 years (pulpwood only) to 30 to 45 years (pulp-saw log). There is a significant body of knowledge about managing productivity of plantations on a sustainable basis. There are also difficult challenges and pressures to increase yield per unit area, reduce the unit cost of wood produced, reduce rotation length and ensure greater environmental care in land use.

The supply of hardwood timber in Australia has been dependent on harvesting native eucalypt forests. Area under these has decreased dramatically since European settlement which began in 1788. Although there have been many small-scale and experimental plantings of eucalypts in the past, Australia did not invest in the development of a eucalypt plantation resource until very recently when serious constraints began to be imposed on harvesting of native forests. There is now a slow but steady increase in eucalypt plantations in southern regions of Australia, mostly as a pulpwood crop with and expected rotation length of 15 to 20 years. There is an increasing interest in growing plantations for saw log production. Available evidence points out that there are several opportunities for developing hard wood plantations in Australia, the growth rate of *E. globulus* plantations in the mediterranean environment in Western Australia range from 15 to 30 $m^3 yr^{-1} ha^{-1}$ MAI at age 10 years. *E nitens* grown in Tasmania achieve similar growth rates. These growth rates are similar to those achieved by *P. radiata* in southern Australia. In experimental plots in sub-tropical Australia, *E. grandis* has been found to grow at rates of 32 to 35 $m^3 yr^{-1} ha^{-1}$ MAI at age 10 years; these rates are significantly higher than those achieved by sub-tropical pine (15 to 20 $m^3 yr^{-1} ha^{-1}$). *E. globulus* plantations in coastal areas of central Portugal are reported to have attained the current annual increments ranging from 10 to 17 t $yr^{-1} ha^{-1}$ (stem wood without bark), the yield being strongly dependent on rainfall and winter temperature (Tome and Pereira, 1991).

Estimates of productivity from Chile are *P. radiata* 20 to 30 $m^3 yr^{-1} ha^{-1}$, *E. globulus* 20 to 40 $m^3 yr^{-1} ha^{-1}$ (Report by Instituto Forestal, Santiago, 1986). As these relatively short rotations, fast growing plantations are harvested and second rotation crops are established, issues concerning sustained productivity should warrant major attention. The trends in the interplay of science and politics of forestry give rise to two lines of arguments. The first one calls for further understanding of long-term productivity based on scientific analysis of soil, environment and genetic interactions while the second allege undesirability of "exotic monocultures" and is compounded by social and political perceptions unsympathetic to industrial forestry. Although the latter issue is not a theme of this paper, I do suggest that it would be prudent to be prepared with adequate information and appropriate communication techniques to deal with it in order to foster the business of forestry and its value to our society.

SUSTAINED PRODUCTIVITY OF FORESTS: WHAT SHOULD BE THE GOAL?

There is now a widely recognised requirement and expectation that all forests should be managed sustainably. Furthermore, strategies of forest management are now expected to be based not only on principles of sustained productivity but also on an understanding of the impacts of forestry on broader ecosystem values. From a biological point of view, sustainable productivity can be achieved, given a sound knowledge of the ecology of the forest environment and its interaction and integration with the ecophysiology of forest productivity. However what is meant by management of sustainable forestry or management of sustainable ecosystem embodies a kaleidoscope of ideas and expectations giving rise to many definitions. There are many questions about the relevance and meaning of those definitions. In the context of today's discussions, it is more appropriate to consider what is the goal of plantation management.

I suggest that the goal should be to ensure that the trend in plantation productivity is non-declining, or positive, over successive rotations and harvests while maintaining or enhancing the quality of the soil resource base.

To achieve this goal, site management practices should be guided by a set of key principles including:

- the soil base should be protected from physical damage and loss of fertility,
- disruptions to water and nutrients cycles should be managed within known boundaries of the resilience of site and soil, and
- stresses on stand productivity should be ameliorated through inputs appropriate to achieve a desired level of growth rates.

Thesee principles and their applications should be placed in the context of the economic realities of the business of forestry and the need for environmental care.

SPECIES AND ENVIRONMENT

In general, high levels of productivity are obtained when the genetic and ecophysiological attributes of the species are matched with management practices that promote high growth rates. In plantation forestry, the choice of species, exotics in particular, has been governed by the choice of desirable wood properties and then by the matching of the environmental requirement of the species with the environment at a particular site. The usual assumption has been the site and soil constraints can be managed with appropriate technology including genetic selection and breeding and judicious site and stand management practices.

When the climatic requirement of *P. radiata* and *E. globulus* are matched with the appropriate climatic zones in Australia, there is remarkable degree of overlap of sites suitable for both species. This finding and the similarity of the range in productivity mentioned earlier suggested that the abiotic environmental variables that influence productivity of biotic factors, including insect pests and fungal diseases, pose different kinds of problems for each of the species. Soil and environmental constraints on production, and the potential for alleviating growth stresses through management, appear to lead to similar kinds of responses and outcomes in both species. For example, the genetic gain ghrough various breeding options range between 13 and 16% per decade for *P. radiata* and *E. globulus* (Cotterill *et al.*, 1990). Similarly, the measured responses to site preparation, weed control and fertilization shows that the growth of eucalypts can be improved substantially with appropriate management, on a range of sites (Baker, 1993). The nature of the responses (e.g. additive or interactive) seems identical to those found earlier in *P. radiata* (Snowdon and Waring, 1984). This is not surprising given the overriding influence of environmental factors that determine productivity in Australia. There are few plantation sites where there is no temporary or persistent stress related to the limitations imposed by availability of water, nutrients or both. Most site management practices including weed control are designed to improve the rate of uptake of water and nutrients by crop trees. While we have a considerable amount of knowledge about the long-term productivity of *P. radiata,* such information about eucalypt plantations is limited.

ECOPHYSIOLOGY OF PRODUCTIVITY

One useful approach for understanding productivity and its potential is to relate biomass accumulation to intercepted radiation (e.g. Beadle and Inions, 1990; Cromer, 1993). Pereira (1990) showed that the progressive increase in net primary production (NPP) of young *E. globulus* from 23 to 36 t yr^{-1} ha^{-1} by increasing the availability of nutrients and water was correspondingly related to increases in intercepted radiation within the range of about 3800 to 4600 MJ n^2 yr^{-1}. Similar relationships between NPP and photosynthetically active radiation (PAR) has been found in *E. grandis* (Leuning *et al.,* 1991). The main stand factors, especially water and nutrient interactions have an overriding influence on leaf production and canopy development (Nambiar, 1990, 1990/91); Cromer *et al.,* 1991; Raison and Myers, 1992; Pereira, 1990). Stand nutrition and water relations also influence rates of photosynthesis (Leuning *et al.,* 1991) and light use efficiency (Raison and Myers, 1992). Discussions on the ecophysiology of eucalypts (Cromer, 1993) and *P. radiata* (Raison and Myers, 1992) are available.

In may areas where fast growing species are grown, soil water availability is often limited, while evaporative demand is high; consequently the effects of nutrient management on growth can be overridden by the amount of available water (Nambiar, 1990/91; Hingston, 1994). There are direct and linear relationships between stem diameter, leaf area and the amount of water transpired (Teskey and Sheriff, 1995). In some experiments, growth rates of stands have been found to be directly related to the amount of water received (Snowdon and Waring, 1991). However, Nambiar (1994) discussed the nature of uncertainties in defining the amount of water available to a stand and relating it to productivity. Nutrients, apart from their direct effects on plant growth, influence plant water relations. For example, improved foliar nitrogen concentration in *P. radiata* needles have been found to improve tree water relations in both irrigated and rainfed trees in the field (Myers, 1988; Nambiar, 1990/91; Fife and Nambiar, 1994). Inions (1991) and Hingston (1994) found that for *E. globulus* plantations in Western Australia, the variation in productivity between sites is closely related to soil and environmental factors that determine water availability in the stand. Thus in many instances, management practices that fail to recognise water x nutrient interactions would lead to lost opportunities for improving productivity.

SITE MANAGEMENT FOR SUSTAINED PRODUCTIVITY

The goal of plantation management stated earlier is especially relevant to fast-growing and relatively short rotation plantations. Because this kind of forestry is a major departure from "traditional" forestry (e.g. as practiced in Europe) and leads to frequent and intensive site disturbances, it is understandable that some people express concerns about its sustainability.

Long-term productivity of forest plantations can be influenced by site and stand management at any stage during the rotation. However, the most striking impacts on soil and site environment and hence productivity of successive crops (i.e. long-term productivity) occur in response to harvesting operations, site preparation and early silviculture from planting to stand establishment. A single site preparation practice (e.g. heavy windrowing) can leave lasting effects (Balneaves *et al.,* 1991). These practices affect soil and site processes that govern water and nutrient availability, and subsequent uptake by trees. (Powers *et al.,* 1990; Nambiar, 1990; Dick *et al.,* 1994). Similarly, the profound influence of weed control on stand productivity can be largely explained in relation to competition for site resources especially water and nutrients (Nambiar and Sands, 1994). Long-term impacts on sites would be greater in fast-growing, short-rotation eucalypt forestry (Barros *et al.*, 1992; Birk, 1993). However, the period of change between rotations can also provide a window of opportunity for applying improved forestry practices and new ideas. What is important is to understand both the risks and opportunities. What are the critical questions we need to consider?

Nutrient removal: What are the potential impacts of nutrient removal through harvests?
Are there large differences between pine and eucalypt?

Site disturbance: What are the impacts of harvesting and site preparation on soil?
What are the effects on organic matter?

Competition for site resources: How can we manage vegetation to maximise the uptake of water and nutrients by crop trees?

IS INCREASED AND SUSTAINED PRODUCTIVITY ACHIEVABLE?

It is being claimed in popular writings that intensively managed monoculture plantations face higher risks to sustainability than those managed under "low intensity-multispecies regime".

Here again a detailed analysis of the complex issues of sustainability is not attempted. However, I wish to draw your attention to one relevant example. From broad considerations of "ecological principles" it could be argued that sustainability of plantations would face higher risks if fast-growing exotic species were planted in sites low in available nutrients and water and were harvested regularly. The large areas of *P. radiata* plantations established in South Australia and Western Victoria in podzolised sandy soils, low in organic matter, nutrients and water could be described to have these risks. These plantations had a history of yield decline in the past (Keeves, 1966), but there is now an impressive record of reversing that decline. (Boardman, 1988; Woods, 1990/91; Squire *et al.*, 1991; Nambiar, 1994). Experience from large-scale trials and operations clearly show that the application of improved forestry practices has resulted in improvements in productivity of second rotation sites to levels higher than those in the previous rotation. There are several management options for achieving sustained productivity (e.g. Nambiar *et al.*, 1984; Woods, 1990/91; Hopmans, 1993).

Eucalyptus and other hardwood plantation forestry in Australia and elsewhere have not reached a stage of development when experimental research on productivity of successive crops have been undertaken. Research on this issue is now needed. The knowledge from studies carried out on conifers (Smethurst and Nambiar, 1990a; 1990b; Powers *et al.*, 1990; Dick *et ai*, 1994) are highly relevant to research on eucalypt plantations (Nambiar and Booth, 1991; Birk, 1993). The critical processes at the site and in soil that determine the long-term productivity of exotic plantations of pines and eucalyptus can be identified for further research from our current knowledge. There are several unifying principles enunciated by recent reviews and research (Powers *et al.*, 1990a; Beets *et al.*, 1994; Dyck *et al.*, 1994).

CONCLUSIONS

There is no panacea for achieving high sustained productivity in plantations. The success of sustainable plantations forestry is inextricably linked with the development and adoption of a package of practices that integrates the genetic potential of the species with availability of water and nutrients from soil, over the long term. The maintenance of the productive capacity of the soil is considerable influenced by forest management practices, some of which can cause lasting influence, negative or positive, on productivity at a site. Therefore, indices of 'site-quality' should be seen as a snap-shot in time and not as an immutable reference point. Plantations in southern Australia and Chile share a common set of species. Furthermore, the nature of the land base of plantation forests in both countries seem to have several environmental factors in common. Australian experiences with *P. radiata* clearly show that increased and sustained productivity of successive rotations of exotic species is achievable if research results are applied to soil and stand management.

Based on available knowledge, further research and development should strive to establish unifying principles applicable to management of both pine and eucalypt plantations.

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