Is plantation forestry good or bad for soils?

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ABSTRACT

Plantation forestry can be either good or bad for soils and site productivity. Plantation forestry is likely to improve soils where it results in increased nutrient availability; and to reduce soil quality where it leads to soil nutrient imbalances or depletion. Forests generally improve soil physical properties; however, machinery used for site preparation, establishment, and harvesting has the potential to reduce site productivity due to soil compaction and erosion. A classification system proposed for New Zealand soils and the potential for site degradation under plantation forestry provides a preliminary, conservative basis for preventing site productivity declines. The validity of this classification system is being tested at several locations throughout New Zealand.

INTRODUCTION

The requirements of the Resource Management Act (RMA) of 1991, public involvement in forestry issues, and criteria for financial investments require the forestry community to examine whether plantation forestry is sustainable from both social and biological perspectives. Forest managers need to be able to demonstrate that their silvicultural systems will sustain the productivity of the forest estate, and maintain or improve environmental quality. The evidence for demonstrating whether plantation forestry management practices will maintain or improve soil quality and site productivity must be scientifically based.

This paper will explore the utility of two proposed soil classification systems (Hunter *et al.* 1988; Hunter *et al.* 1991) for predicting the effects of plantation forestry on site quality; and review the adequacy of New Zealand trials to provide a scientific basis for determining sustainable forestry management practices. In this paper, the term "plantation forestry" will be used in the broad sense of management practices used to produce even-aged crops of trees over several rotations. This context will by necessity include forestry-related activities at establishment, tending, and harvesting phases of plantation management.

PLANTATION EFFECTS ON SITE QUALITY – GOOD OR BAD?

As foresters, we must be careful to distinguish between the terms site "quality" and "productivity", since they are estimated with different units of measure. Site "quality" can be defined as the potential for a site to produce high volumes of timber in a short period of time; but must be quantified by measuring soil properties and climate. Foresters cannot change the climate easily; but can easily improve or degrade soil properties. Site "productivity" is determined by the combined influences of site quality, tree genotype, and forest management practices (Figure 1); and is estimated by measuring tree growth rates. Each of these three factors must be favourable for productivity to be high in any one stand. At an earlier ANZIF conference, Dyck (1991) discussed how difficult it can be to measure "site quality" using "productivity" as the unit of measure, because of the confounding effects of tree genetics and weed competition. To answer questions about the effects of plantation forestry on site quality, we should consider what determines the properties and response of various soils.

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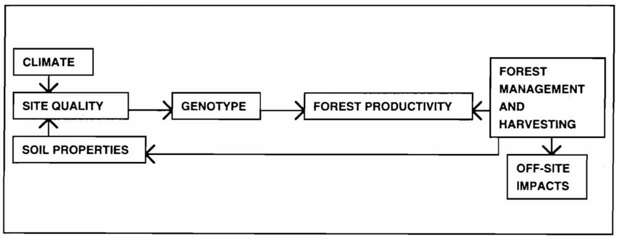

Figure 1. Conceptual diagram of the relationship between factors affecting site productivity and off-site impacts of forest management and harvesting (after Dyck and Bow, 1992).

Soil classification

New Zealand North Island soils have been classified by Hunter *et al.* (1988) according to the potential for soil degradation due to harvesting, assuming that the most significant effects of harvesting are nitrogent removals and soil compaction and topsoil removal by logging equipment. They propose three hypotheses for their classification system. First, soils that have low availability of a particular nutrient are more likely to show reduced growth after successive rotations due to a deficiency in that nutrient than soils with greater nutrient supplies; and the magnitude of radiata pine response to fertiliser should be a good indicator of the susceptibility of the soil to nutrient depletion by harvesting. Second, nitrogen depletion is more serious than depletion of other nutrients because of high growth responses to nitrogen additions and fertiliser cost. Third, soil texture and moisture content are the main properties affecting compaction by logging machinery. According to this system, loamy soils that were previously covered with native bush and receiving adequate rainfall are least likely to show productivity decline due to nutrient removal. In these soils, we would predict availability of potassium (K), magnesium (Mg), and boron (B) would be high in the parent materials, and nitrogen (N) availability high due to adequate soil organic matter. However, soils with high phosphorus (P) retention capacity, little to no organic matter, and parent materials lacking certain elements have higher potential for nutrient depletion with harvest removals. Risk for soil compaction during harvesting is high for clay and silt soil textures; and low for sands and gravels.

Hunter *et al.* (1991) used a Geographic Information System (GIS) approach to link the New Zealand Forest Research Institute (NZFRI) radiata pine foliar nutrition data base with New Zealand Soils Bureau (1968) soil maps. For both North and South Islands, soils were ranked according to average radiata pine foliar nutrient concentrations, and the probability of encountering a stand deficient in a particular nutrient. Maps were developed for N, P, K, Mg, and B. The strength of this atlas over conventional soils maps is the inclusion of tree foliar data, because of the combined influences of soil parent material and climate on nutrient availability. For example, B availability to trees can be low due to deficient parent materials, excessive leaching losses under high rainfall, or low mobility in dry soils.

Both classification approaches of Hunter *et al.* (1988 and 1991) should be viewed as working hypotheses that should be tested and refined with field trials. They are useful for highlighting those soil types and regions where there may be high risk of harvesting associated with plantation forestry causing reductions in site productivity because of limiting soil properties. Efforts should be made to incorporate such information into forest management decision support systems aimed at maintaining high site productivity.

Tree and forest effects

There is little question about whether trees affect soil. Trees affect soil chemical and physical properties through nutrient and water uptake, litterfall, and rhizosphere activity of roots and associated mycorrhizae and fauna. Further, Stone (1975) noted that "the very definition of soil declares it to be in some measure a product of vegetation, so that the significant questions about its responses to forest cover are not whether, but at what rate, how profoundly, and with what consequences". How does the literature and our experience in New Zealand suggest we might expect exotic pine plantations to affect soils? What do these sources of information suggest about productivity changes under pines?

Stone (1975) concluded that relatively recent research does not support the claim that successive rotations of conifers cause decreased site productivity. This conclusion is supported by van Goor (1985) in his review of Central and Western European research with the generalisation that exotic species do not differ from indigenous species in their effects on soil productivity. Both authors indicate that the effects of tree species on soil productivity are minor compared with the effects of silvicultural chemicals and mechanical site preparation and harvesting operations. However, both reviews indicate that poor experimental design has confounded the results of most research on species effects on soils. Evidently there is some need to clarify species effects with a high degree of experimental rigour.

However poor the ability of past research to determine the effects of various tree species on site productivity, there is good evidence that specific ecosystems contain plants that suppress nutrient availability and tree growth. For example, the cedar-hemlock forests of the Pacific Northwest, comprised of western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), some amabilis fir (*Abies amabilis*), and an understorey of salal (*Gaultheraia shallon*), are an ecosystem where tree productivity is reduced after harvest by salal through a complex of species and rhizosphere interactions. These interactions are thought to include mycorrhizal antagonisms and root exudates (Weetman *et al.* 1989; Prescott *et al.* 1993). A recent review of ecosystem studies indicated that plants reduce nutrient availability in low-nutrient habitats; and enhance nutrient availability in high-nutrient habitats (Hobbie 1992). According to Hobbie, plants in nutrient-poor ecosystems grow slowly, use nutrients efficiently, and produce poor-quality litter that decomposes slowly; while plants in nutrient-rich ecosystems grow rapidly and produce litter that decomposes readily and enhances nutrient cycling. Lamb (1975 and 1976) described differences in radiata pine litter decomposition with soil type that seem to support the ideas of Hobbie.

Plantations have been shown to increase the productivity of degraded, impoverished soils such as found on heath, peat, and abandoned agricultural lands (van Goor 1985). In addition, van Goor concludes afforestation can increase soil quality and site productivity on previously bare land. This conclusion is supported by recent results from field trials conducted on coastal sand dunes in New Zealand (Smith *et al.* in press) where site nitrogen supplies (Figure 2) and productivity (Figure 3) were increased following afforestation with a plantation forestry system that included marram grass, lupin, and radiata pine.

van Goor (1985) hypothesises that the net effect of trees on soil quality should depend on the starting point for the ecosystem, and whether the new rotation is likely to alter the equilibrium between inputs and outputs of nutrients and organic matter. This suggests that soil quality could be improved, reduced, or not changed by plantations.

Radiata pine can be expected to affect soil nutrient status through nutrient uptake and return to soils via above- and below-ground litter inputs. Fast growth rates will result in high nutrient demand (Beets and Pollock 1987), and have the potential to induce nutrient deficiencies after several rotations on sites with low native fertility (after Hunter *et al.* 1988). In addition, high demand for selected nutrients may result in uneven nutrient depletion, and the onset of imbalanced tree nutrition. Soils with high K:Mg ratios and fast growth rates due to high N fertility may be high-risk sites for nutrient imbalances. Field trials are required to test hypotheses concerning the net effect of radiata pine nutrient demand and return via litter inputs on soil fertility.

ECOSYSTEM N POOLS

	WOODHILL First rotation (42 yrs old)	WOODHILL Second rotation (5 yrs old)	KAINGAROA fertile soil (29 yrs old)
Foliage	68	93-185	117
Branches	78	20-64	79
Stem	130	18-36	217
Slash	0	0-56	0
Forest floor	462	19-878	302
Soil	836	470-784	3049
Roots	48	27-117	85
TOTAL	1700	647-2123	3849

Figure 2. Total amount of nitrogen (kg N/ha) contained in above- and below-ground components of plantations of first (Dyck *et al.* 1991) and second rotation (Smith *et al.* in press) stands of radiata pine at the Woodhill Forest on sand dunes, and at a fertile site in the Kaingaroa Forest (Webber and Madgwick, 1983).

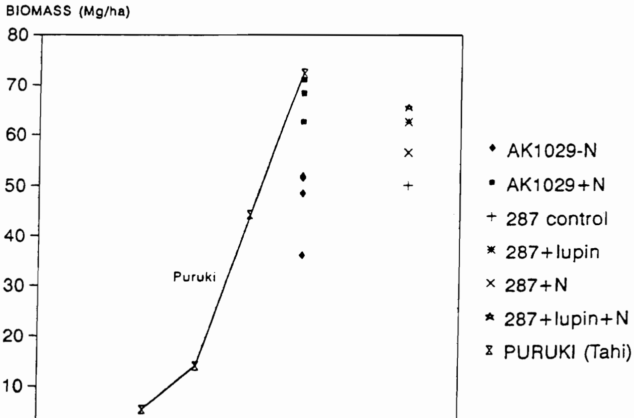

Figure 3. Above-ground biomass (tonnes/ha, Mg/ha) contained in plantations of radiata pine at a fertile site in the Tahi sub-catchment at Puruki at ages 2, 3, 4, and 5 years (Beets and Pollock 1987), in a first rotation stand at the Woodhill Forest (AK287) receiving fertiliser, lupins, and no amendments (control) at age 7 years (Beets and Madgwick 1988), and in a second rotation stand at age 5 years at the Woodhill Forest (AK1029) receiving no fertiliser (AK1029-N) and 200 kg N/ha per year (AK1029+N) (Smith *et al.* in press).

Management effects

Plantation management can be expected to alter soil fertility by changing nutrient inputs and removals with silvicultural chemicals and harvesting, and physical properties through machine-related disturbances. As discussed by Stone (1975) and van Goor (1985), these effects have been shown to have a far greater effect on soil quality and site productivity than pure species effects. The critical questions about the sustainability of nutrient removals with plantation harvest relate to determining the amount of organic matter and nutrients that must be retained on site; and to determining the degree to which plant-available supplies of nutrients can be replaced by mineral weathering and plant litter inputs. Recent research at the Woodhill Forest indicates that forest floor removal causes a decline in site productivity as a result of nitrogen removals (Figure 4) (Smith 1994). These results confirm hypotheses proposed by Hunter *et al.* (1988) for sand dune forests. Additional field trials have been installed in Tarawera and Kinleith Forests on the North Island; Berwick, Burnham Forests on the South Island; with one being installed in Golden Downs (Figure 5). These trials are designed to determine which soil types are susceptible to productivity decline due to nutrient removals associated with tree removals and soil disturbance during harvest.

Harvest machinery effects on soil physical properties is currently under investigation by scientists at Landcare and NZFRI. These studies are seeking to determine the relationship between soil properties and potential for compaction by harvest machinery; and are designed to determine whether soil compaction related declines in soil productivity can be ameliorated. Recent results in Kinleith and Tarawera Forests (McQueen *et al.* 1993) have supported the hypotheses of Hunter *et al.* (1988) concerning the susceptibility of certain soil types to machine compaction.

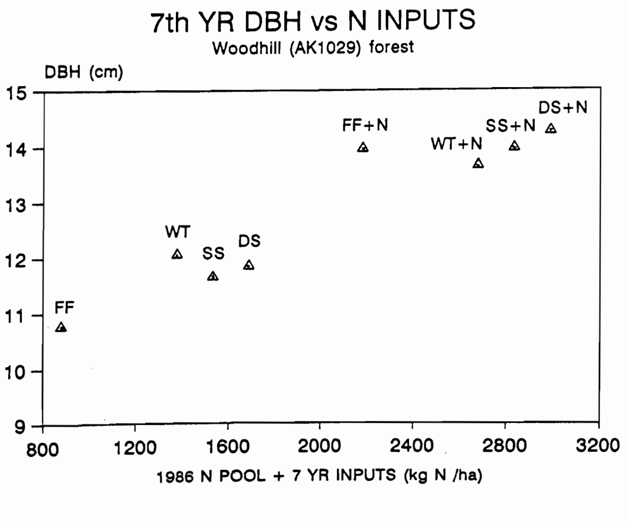

Figure 4. Average DBH of radiata pine at age 7 years in a second-rotation stand at the Woodhill Forest (AK1029) following various levels of harvest residue removal and urea fertiliser additions (Smith 1994). Harvest residue removal treatments evaluated were whole-tree harvest plus forest floor removal (FF), whole-tree harvest (WT), stem-only harvest (single layer of harvest slash) (SS), and stem-only harvest plus slash (double layer of slash)(DS). Urea was added in a split-plot design to harvest residue treatments at 200 kg N/ha per year for treatments FF+N, WT+N, SS+N, and DS+N.

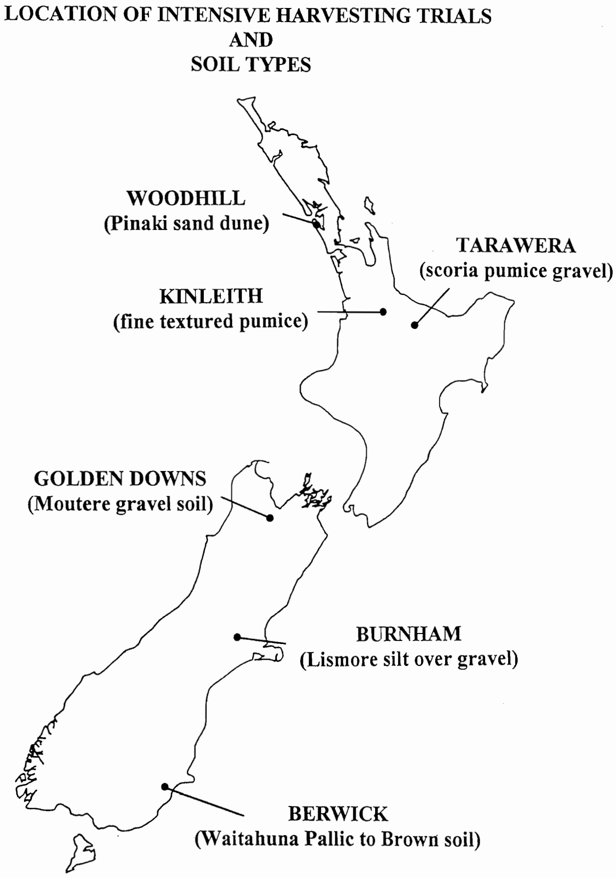

Figure 5. Location of intensive harvesting trials being conducted by the New Zealand Forest Research Institute, in collaboration with the forest industry and Landcare Research, to determine the effect of harvest removals of nutrients on long-term site productivity in radiata pine plantations. The soil type associated with each trial is indicated.

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CONFERENCE PAPER

Past, present and future forest land management practices in New Zealand

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INTRODUCTION

The New Zealand economy and way of life depends largely on the land resource and what comes from it (Coad, 1975). Plantation forestry is one form of land use that is now a major contributor to the New Zealand economy and social infrastructure.

Since the first plantings in the late 19th century, land for forest expansion has come from alternative use. In the first instance this was indigenous cutover and scrubland of various types. During the mid 20th century it was reverted farmland, typically on steeper terrain and not needed or unsuitable for other uses (albeit not for a want of trying in some instances). The last decade has seen a further change with more productive land being planted in direct competition with other forms of primary produce.

As this change in land-type use occurred, increasing public awareness of environmental values has brought about changes in the attitude of forest managers to the way they manage land in consideration of likely effects of operations.

This paper will present details on past forest management activities focusing mainly on land preparation and harvesting, and describing how these practices have changed. Particularly in the last two decades, changes came through necessity and some through the changes in land type and cover. The effects of these activities will be discussed in relation to water and soil values with the emphasis on sustainability.

Finally what does the future hold? Do we know enough about the effects of our management practices and the effects of plantation forestry as a land use. Is plantation forestry sustainable, are other industries sustainable and where do we as a major land user sit? What are the consequences of getting it wrong?

PAST LAND MANAGEMENT PRACTICES

The type of land management practices carried out in plantation forestry in past years has in part reflected the type of land being apportioned to the industry. Land for forestry was largely in the hands of the Land Use Advisory Council which tended to mean that it was unsuitable for any other primary production. Forestry has always been recognised as a legitimate land use, but opinions have changed as the size of the industry has increased with attendant social implications (Coad 1975, Baumgart 1975).

The land itself was predominantly steep (the exception being the Bay of Plenty/Volcanic Plateau) with a high content of scrub and secondary growth. Conversion from indigenous forest to plantation forest was also occurring in parts of the country as native timber was extracted for commercial use.

Land Preparation and Development

One of the major tools in preparing land during this time period was fire. At a FRI symposium on land preparation held in 1969, representatives from virtually all NZFS Conservancies and private companies commented that burning was an integral part of establishment, with one comment that all planning for new establishment be based on the use of fire. Controlled burns were often carried out over large tracts of land, some greater than 500 ha in size.

Land was prepared for burning using a variety of techniques. Firebreaking around the burn area was carried out by tractor, blading down to mineral soil, with cleared widths anywhere from 10 m to 40 m common. If vegetation required treatment prior to burning, machine preparation using crushing or slashing, hand felling and chemical spraying were common

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