SOIL FACTORS THAT SHOULD INFLUENCE ALLOCATIONS OF LAND FOR FORESTRY AND AGRICULTURE*

D. S. JACKSON†

SYNOPSIS

The paper is written from a forester's point of view, considering how better use can be made, in land-use decisions, of information provided by the soil scientist. The particular requirements for determining productivity under forest management are outlined, and illustrated by a recent New Zealand survey.

The relevance of pedological data to decisions between forestry and agriculture as alternative means of primary production is considered on the basis of two sets of criteria: (a) The factors controlling crop productivity; (b) Those factors that affect the hidden or intangible costs of alternative forms of land management.

Costs in the narrow sense are not detailed; nor is an economic evaluation of the alternatives presented.

The intent of this paper is to consider some of the pedological factors that should be given more weight in making land-use decisions. Attention will be concentrated on primary development, comparing particularly the requirements of pastoral management and forestry. Horticulture and intensive cropping, together with such other forms of land-use as transport, industry and urban development, are recognized as having specifications that are both much narrower and contingent on preceding development. It is precisely because the allocation of land to farming or forestry is very often the first authoritative decision for a particular tract of land, and because it has such far-reaching and irreversible effects if acted upon, that we consider it merits fuller examination and discussion. The contrasts drawn between farming and forestry are not intended to perpetuate a conflict of ideologies, but to provide a convenient framework for the pedological illustrations. In the sequel it is indicated that what may hitherto have been a conflict between uses is now merging in a very much wider appreciation of benefits, many of which have hitherto been taken for granted.

However, it is convenient to start with what is probably the simplest type of comparison, in which crop productivity is taken as the criterion. A problem immediately arises from

*Modified version of a paper delivered at the 12th N.Z. Science Congress, Section E5, January 1972.

†Scientist, Forest Research Institute, Rotorua.

any proposed extrapolation of knowledge regarding productivity relationships. Because of the historical sequence of land development, there will be few sets of soils in sub-montane New Zealand for which agricultural ratings are not available, either as potential yields of butterfat or of ewe-equivalents per hectare, or both. For forestry, there are many soil types for which productivity data are not yet available, so that a sound basis for extrapolation becomes essential. Moreover, while pastoral productivity may be rated on a continuous scale up to, say, 15 ewes/ha, by increments of 4 or 5%, the 1968 General Survey of South Island Soils, for example, gives only three categories of forest site quality for the commonest commercial species, radiata pine, and none at all for other species.

Thus there is need not only for an improved scale of forest productivity but also for quantitative appraisal of the major site factors that affect it. The most fertile soils, from an agricultural point of view, are not necessarily the best for tree growth. As a perennial crop, developing over a period of 25 to 60 years or more, trees are not only able to accumulate much of their nutrient requirements and redistribute them within the tree at need, but can also recycle them to the roots through litter fall. Being extensively and deeply rooted, they are able to tap resources of nutrients and soil water at considerable depths, well beyond the range of most agricultural and pastoral crops. Taken together, these characteristics imply that tree crops are much less dependent on soil fertility, defined in terms of high concentrations of nutrients in the surface soil, and are much more restricted by factors that limit their root range, such as indurated or gley horizons, or seasonal waterlogging and poor aeration.

This can be illustrated by some results from a recent extensive survey of radiata pine productivity in New Zealand. In order to reduce the effect of annual weather variations, productivity was measured over a standard interval of seven years. It is expressed as volume increment per individual dominant tree at a mean age of 15 years. The salient features that are brought out in Fig. 1 are:

(1) At any given level of mean annual precipitation, the productivity increases as effective soil depth increases.

(2) It is the deepest and most freely-drained soils that are most productive and, on these, productivity increases virtually linearly with rainfall.

(3) On the shallowest soils there is a point at which increasing rainfall leads to a drop in productivity, presumably owing to deficient aeration in a waterlogged soil.

The fact that forest crops require a greater available volume of soil in order to maximize productivity also reflects the need for a supply of soil water that is maintained well into the autumn. Most agricultural crops make their grand period of growth in the spring and early summer when, in addition to current rainfall, there is also a plentiful supply of winter-stored water in the soil. As depletion of these reserves sets in,

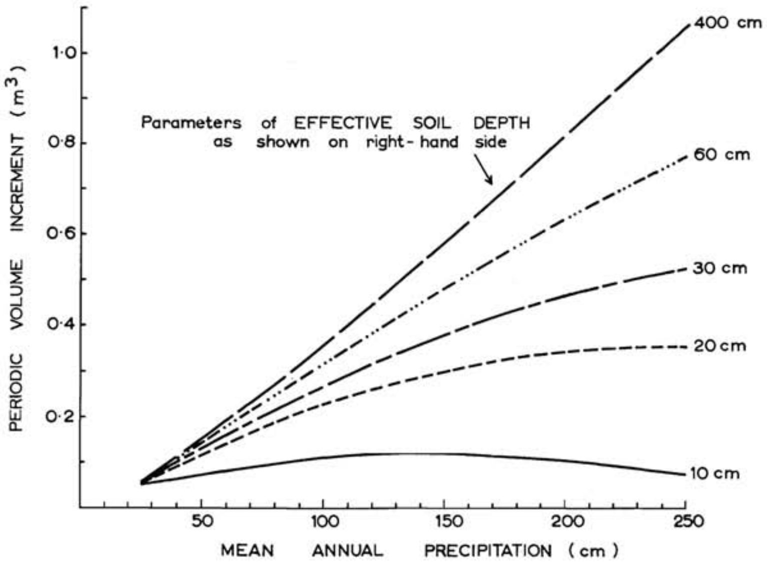

FIG. 1: *Seven-year volume increment per dominant tree against mean annual rainfall and selected parameters of effective soil depth.*

root crops are maturing, grain crops ripening, cows drying off and lambs being despatched to market — but radiata pine goes right on growing well into the autumn. Although the cycle of height growth is more or less coincident with that of annual crops, there is a temporal displacement of cross-sectional growth such that its peak occurs after the surface horizons have been depleted of water and the tree becomes dependent on supplies at depth. In drier climates, on sites with high runoff, or on soils where an indurated horizon eliminates such reserves, productivity is markedly affected, the quality of the yield is reduced (owing to a reduction of latewood), and the whole form of the tree is altered.

In speaking of the need for a sustained supply of soil water to meet the seasonal transpirational demand, it is also understood that soil water is the medium for mass flow of nutrients, and that this must be correspondingly more important on the less fertile soils. Likewise, the emphasis on effective depth of soil is not intended to imply that the A horizon is any less important as the zone of interchange between atmosphere and solum for water, air, energy and nutrient recycling. However, its properties will determine, to a much greater extent, the productivity of annual crops (wherein much of the nutrient uptake is removed annually) than the eventual yield of a perennial crop that is able to carry most of its nutrient requirements over from one year to another, by internal translocation.

The relationship between total N and P content of the A horizon and productivity of radiata pine, in the survey already mentioned, is shown in Fig. 2. It is evident that the response surface flattens out at relatively low levels for both N and P, for the reasons already outlined. This accords well with the available experimental evidence: Kessell and Stoate (1938), for example, rate growth of radiata pine as unsatisfactory when total N in the top 7.5 cm of soil falls below 0.1%, and Waring (1962) states that growth responses to applied N are exhibited below this level. Above 0.2% Kessell and Stoate expect "normal good growth". The effect of root extension is reflected by the experimental data for available P in the topsoil, as determined with Olsen's extractant. Thus, for seedling growth after planting, responses are attained in the range from 9 ppm downwards and Ballard (1971b) recommends increasing superphosphate applications below this level. For mature stands he indicates (Ballard, 1971a) that the point above which no positive responses to superphosphate occur lies between 3.1 and 8 ppm. It should be mentioned that Ballard, in an earlier report (1970) on methods of estimating soil phosphate available for tree growth, had concluded that the Olsen and Bray No. 2 extractant techniques gave the best correlations with site index. In the survey on which the above figure is based, we estimated total P and available P by Olsen, Bray No. 2 and citric acid techniques. The Olsen method showed highest correlations.

These analyses were all for the top 7.5 cm of soil, but similar analyses were also done for a bulk sample of the remaining

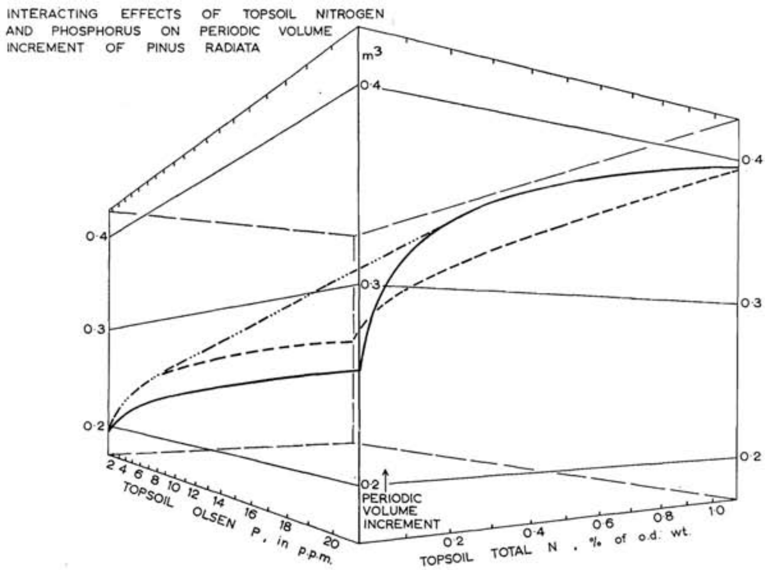

FIG. 2: *Seven-year volume increment per dominant tree, against total nitrogen and available phosphorus in the top 7.5 cm of soil.*

soil down to the horizon of major textural change. When the concentrations were weighted for the depth of soil from which the sample was taken, and aggregated, we obtained an index of the overall supply of N and P. When this was compared with the correlations with surface concentrations only, we found that it showed a considerable improvement on the latter, further indicating the need for an integrated value of overall nutrient supply. We are at present working towards such an index, that will also incorporate adjustments for bulk density and a measure of root occupancy.

Probably the most spectacular applications of soil science have resulted from the detection of trace element deficiencies — the benefits achieved with cobalt and molybdenum for pastoral management on the yellow-brown pumice soils, and with boron and zinc for forest production, spring immediately to mind. Once such effects have been demonstrated, they are relatively quick and easy to diagnose, correctives measures are usually cheap, and the economic returns are very favourable. By the same token, they can result in rapid changes of opinion about land-use allocations — the extensive areas of "bush-sick" (cobalt-deficient) pumice lands that were allocated to forestry in the late twenties and early thirties, and the political pressure that was reimposed to release these same lands for pastoral development after the discovery of corrective measures, are such an example.

The lack of stability, and the relatively simple means by which such changes are brought about, are both evidence of an early stage of resource development, historically and often even accidentally determined. The next stage invokes economic criteria: an evaluation and comparison of financial yields from different alternative uses — pastoral, agricultural, forest, industrial, etc. (*e.g.*, the Maraetai study by Ward *et al.*, 1966) Along with this goes a cost-benefit analysis of methods of increasing or improving yield — *e.g.*, by the application of fertilizers, or the use of irrigation. Production forestry in New Zealand has moved into this phase only during the last decade or so, whereas the agricultural industries have passed through it and are now entering a much more sophisticated phase of sociological and environmental evaluation. Some of the consequent readjustments of land use are represented, for example, by changes within the region of the Waikato Valley Authority, particularly where there is accelerated runoff and erosion on some of the pumice lands in the Reporoa area. Protection forestry, so-called, has always been based on these broader criteria, rather than the simple profit motive — the axiom of "multiple use management" expresses it succinctly — but New Zealand forestry is now undergoing a real merger of productive and protective criteria, impelled by the new public awareness of environmental issues. One of the implications of these trends is that additional soil factors are pertinent for land-use decisions, and that more complex information will be required for a true interpretation and wise decisions.

We may conclude with a few examples. First, the pastoral industry in New Zealand is, with the notable exception of the tussock grasslands, based on a ryegrass/clover pastureland supported by superphosphate topdressing. It has been shown that, on certain soils, forest productivity can benefit greatly from this too, so that any comparison between the two as alternative systems of land use must take the augmented yields into account. But what if one is confronted with such alternatives in the context of the Lake Taupo basin, or the Rotorua lakes? Eutrophication rates are now a major issue in these regions, and phosphate input to such lakes is of particular concern. Data collected by Fish (1969) for the streams flowing into Lake Rotorua indicate that nitrate and phosphate contents of normal inflow are increased two or three times by pastoral development, and may increase one hundredfold during the two or three days following aerial topdressing.

The hydrologist might contend that topdressing should therefore be accompanied by measures to reduce runoff, or the land be converted to production forest if accelerated eutrophication is to be arrested. Slopes, infiltration rates, structure and porosity are all soil factors that must be taken into account; but one might take it further and ask how much phosphate goes out in sub-surface flow, how much is wasted and a pollutant, how much is used, and how much is fixed? Similar questions have been posed by O'Connor (1968).

On the yellow-brown loams derived from volcanic ash, the phosphate-fixing character of the main mineral colloid, allophane, may provide some control of eutrophication through sub-surface flow, although the data for the spring-fed Hamurana Stream at Rotorua do not support this. However, the yellow-brown sands of coastal Manawatu and Woodhill do not possess any such retentive properties, and the relatively small size of the lakes of the coastal dunes makes them correspondingly vulnerable to accelerated eutrophication. There is a considerable number of these lakes, and their value as wildlife refuges and for various forms of recreation (many being close to expanding urban areas) far outweighs their usefulness as watering-points for stock. As wildlife refuges it may initially be desirable to increase biological productivity by nutrient enrichment — but, obviously, soil factors and type of vegetation cover are very cogent for any decision that might be made.

I am reminded here of a recent visit to the wheat belt of Western Australia, where extensive tracts of the native wandoo and salmon gum have been cleared — substituting flash runoff and surface evaporation for the natural regime of infiltration and deeply-derived water for transpiration. Considerable tracts of country have already been rendered sterile by salinization. This is such an old chestnut that one is incredulous that pedologists were not consulted, and if they were, that they were ignored. To bring the example closer to home: most are aware of the pakihi problem of Westland, as a consequence of logging and destroying the podocarp forests on the old fluvio-glacial terraces. Anyone who has examined the complex reticulation of surface drainage and ground vegetation that exists in the untouched forest must be impressed by its efficiency on terrain of such low relief — and by its vulnerability to interference. In these circumstances one cannot but feel that the Forest Service's cautious experiments with methods of proper management must not be hurried. The problem of land use here is a crucial one, for which both pedological and ecological appraisals take precedence in any evaluation.

One could cite many further instances where a more complete evaluation of soil factors would have avoided much environmental deterioration, and consequent cost to this and succeeding generations. In many of these cases the corrective action has required a switch of land use back to forestry — *e.g.*, for the stabilization of coastal sands in the Manawatu and West Kaipara, after periods of pastoral mismanagement, or of slumping mudstone in the Mangatu catchment of Poverty Bay, or of unstable greywacke country in mountain lands, after destruction of beech forest and tussock grassland.

One hopes that increasing recognition of the stabilizing roles that forestry can play, together with the new public awareness of environmental issues and costs hidden behind the appearance of a quick profit, will lead to a reduction of the primitive conflict between forests and agricultural clearance, through closer integration of their separate benefits.

Examples of composite management, in which both agriculture and forestry utilize the same area of ground, are well known for the poplar growing regions of Europe, where row-cropping and horticulture are combined with intensively-tended trees. Similar systems are used in the tropics. The widespread and age-old practice of grazing under open forest, that has led to so much dissension in unstable regions where soil and water conservation are critically balanced, is now being re-examined in both Australia and New Zealand. Current experiments with grazing under a widely spaced tree crop not only hold promise of economic returns from both meat and timber — they also lead one into some interesting speculations about management systems that might combine the nitrogen-fixing capabilities of clovers with the phosphate-unlocking powers of mycorrhizae. The implications of this are great, and they indicate that, in our research at least, we should look more closelv at such ecological interactions — anticipating the time when our simplistic, dollar-chasing systems of radiata pine cropping and grassland farming must give way to more complex systems of land management. These will be truly profitable — not just in terms of dollars gained, but of waste and pollution prevented, of ecological balances maintained, of harmony and beauty preserved, and sanity regained.

REFERENCES

Ballard, R., 1970: A preliminary investigation of the phosphate status of Riverhead Forest soils. *N.Z. Jl Sci., 13:* 312-22.

——— 1971a: Soil P testing in forestry: 1. In mature stands of radiata pine. *N.Z. For. Serv. For. Res. Inst. Soils and Site Productivity Rep. No. 29* (unpubl.).

——— 1971b: Soil P testing in forestry: 2. At establishment. *N.Z. For. Serv. For. Res. Inst. Soils and Site Productivity Rep. No. 30* (unpubl.).

Fish, G. R., 1969: Lakes: the value of forest research to measure eutrophication and to indicate possible causes. *N.Z. Jl Hydrol., 8* (2): 77-85.
Kessell, S. L.; Stoate, T. N., 1938: Pine nutrition. *W. Aust. For. Dept Bull. No 50.*
O'Connor, K F., 1968. The role of agricultural land use in affecting water quality. *Water Res. Symp., 40th ANZAAS Congr. Proc.,* Part I: 52-65.
Ward, J. T.; Parkes, E. D.; Fenton, R. T.; Grainger, M. B., 1966: An economic analysis of large-scale land development for agriculture and forestry. *Lincoln Coll. Agric. Econ. Res. Unit Publ. No. 27:* 157 pp.
Waring, P. F., 1962: The nitrogen requirements of *Pinus radiata. Proc. 3rd Aust. Conf. Soil. Sci., 1* (38).