TREES ON FARMS

UNIT 3: AGROFORESTRY SYSTEMS

CONTENTS

UNIT 3
AGROFORESTRY SYSTEMS

1 LEARNING OBJECTIVES

- Have a good understanding of the interactions between trees, pasture and livestock in agroforestry systems.

- Be able to discuss the management of trees in agroforestry systems which maximise wood value, including the control of livestock grazing and tending regimes.

- Be able to discuss the benefits and management of trees in agroforestry systems for other than wood production.

2 INTRODUCTION

"Agroforestry" is the term generally used in New Zealand to describe combinations of trees and pasture with livestock. This is much the most important form of combined land use for trees and agricultural production in New Zealand. Strictly speaking, this combination is best described as "Silvipastoralism" and the term agroforestry used to describe a range of combined agricultural and arboricultural activities – for example, the combinations of trees and crops common in some other countries. However, it is probably best to remain with common usage. Here we are largely concerned with the characteristics of systems based on sown grassland and tree plantations, though combinations of invasive grassland under native trees as a consequence of under-storey damage by grazing animals in established native bush may have many of the same characteristics.

3 ECOLOGY OF SILVIPASTORAL SYSTEMS

The management of tree/pasture/animal systems of this kind is influenced by a series of interactive effects, as follows:

Competition between trees and surface vegetation for light, water and nutrients.

Impact of animals on trees: browsing and rubbing damage, and nutrient recycling.

Influence of trees on animals: shelter, health, quantity and nutritive value of pasture.

The relative importance of these factors varies with site, choice of species or "varieties" of plants and animals, and age of stand as well as management strategy. We will look at these effects in turn before considering the ways in which they balance out in silvipastoral systems.

See if you can identify an agroforestry block near you, or an area of woodland with understorey pasture, preparatory to working through the rest of the module. Can you get access to it so that you can investigate the tree, pasture and animal populations? Please ask permission first! Try answering the following questions before reading any further. (You may have to look for "help" later in this study guide, but try anyway):

EXERCISE

What are the characteristics of the tree population relative to trees in single-purpose wood lots? List at least two main contrasts.

1.

2.

EXERCISE

Can you see any obvious effects of the trees on the pasture under-storey? List at least three main effects.

1.

2.

3.

EXERCISE

Can you see any evidence of animal effects on the trees? List at least three.

1.

2.

3.

EXERCISE

What do you think will be the main effects on animals grazing between the s? List at least three effects.

1.

2.

3.

EXERCISE

Is there any evidence of activity to prune, lop or thin out trees in the stand? What have the consequences been to pastures and livestock?

1.

2.

3.

3.1 Tree and Pasture Interactions

The main effects of trees on ground vegetation are:

3.1.1 Interference with incident sunlight – shading effects

3.1.2 Competition for water and nutrients

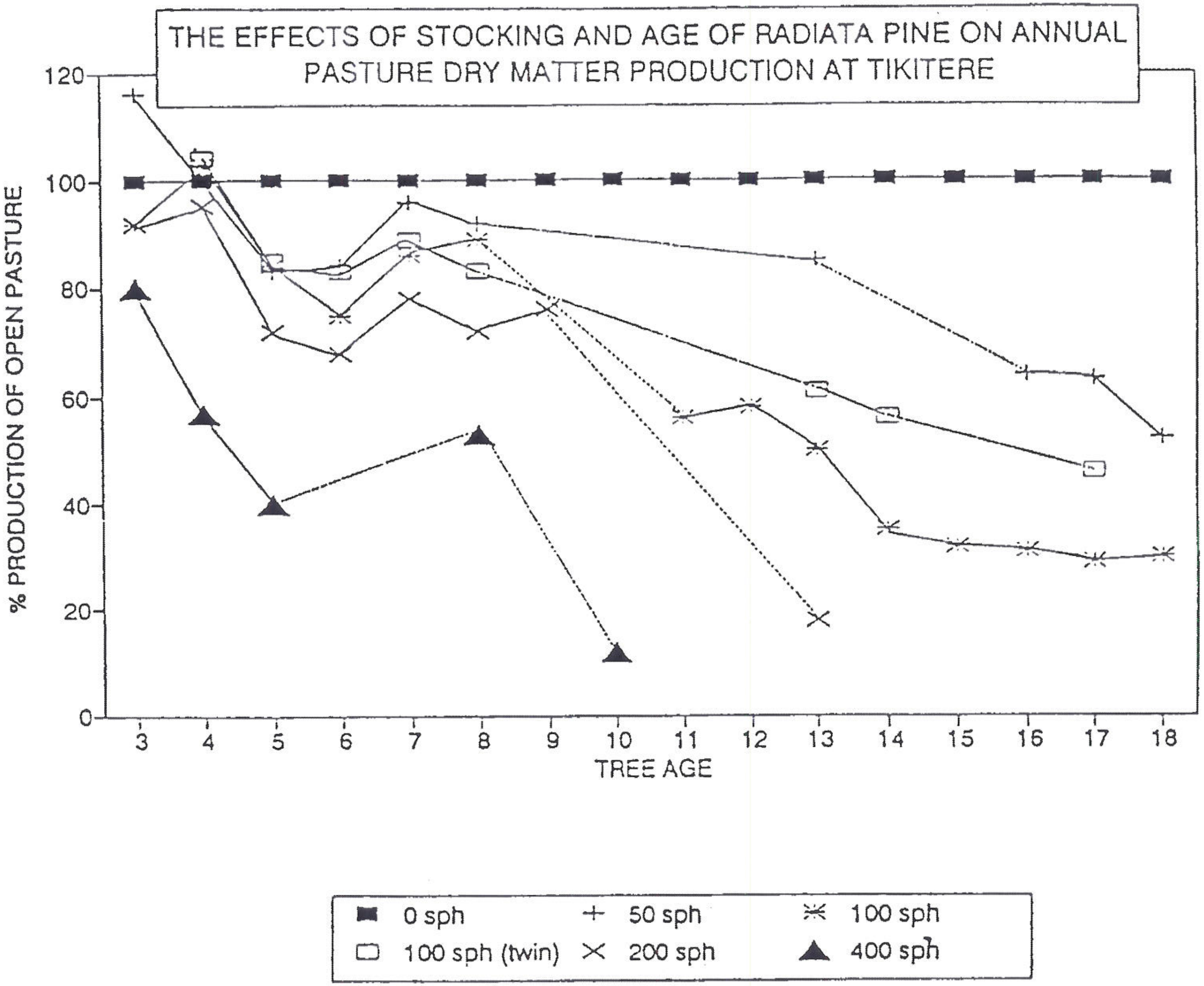
3.1.3 Amelioration of wind speed and temperature variations

Of the three effects, item 3.1.1 usually has the greatest impact on pasture production and species survival. It can be difficult to disentangle the other items from the dominating influence of canopy shading, but they are nevertheless likely to be real. Aspects of 3.1.1 and 3.1.2 were outlined in UNIT 1, and effects of shelter (3.1.3) were considered briefly in UNIT 2. The consequences in agroforestry systems are outlined here.

3.1.1 Shading

All green plants depend upon access to sunlight in order to drive the photosynthetic conversion of light energy into the sugars which fuel growth and sustain the basic physiological processes of the plant. This is not the place to deal in detail with the process of photosynthesis – there is a brief outline in UNIT 1, – but it is a potent factor in the competitive interactions between trees and ground plants. As the trees grow and their crowns expand, a greater and greater proportion of the incident sunlight is intercepted by the tree canopy and fails to reach the pasture below. The effects on pasture production over the life of a stand of trees are shown in Figure 1.

Figure 1 **Long term effects of tree age and density on pasture production.**

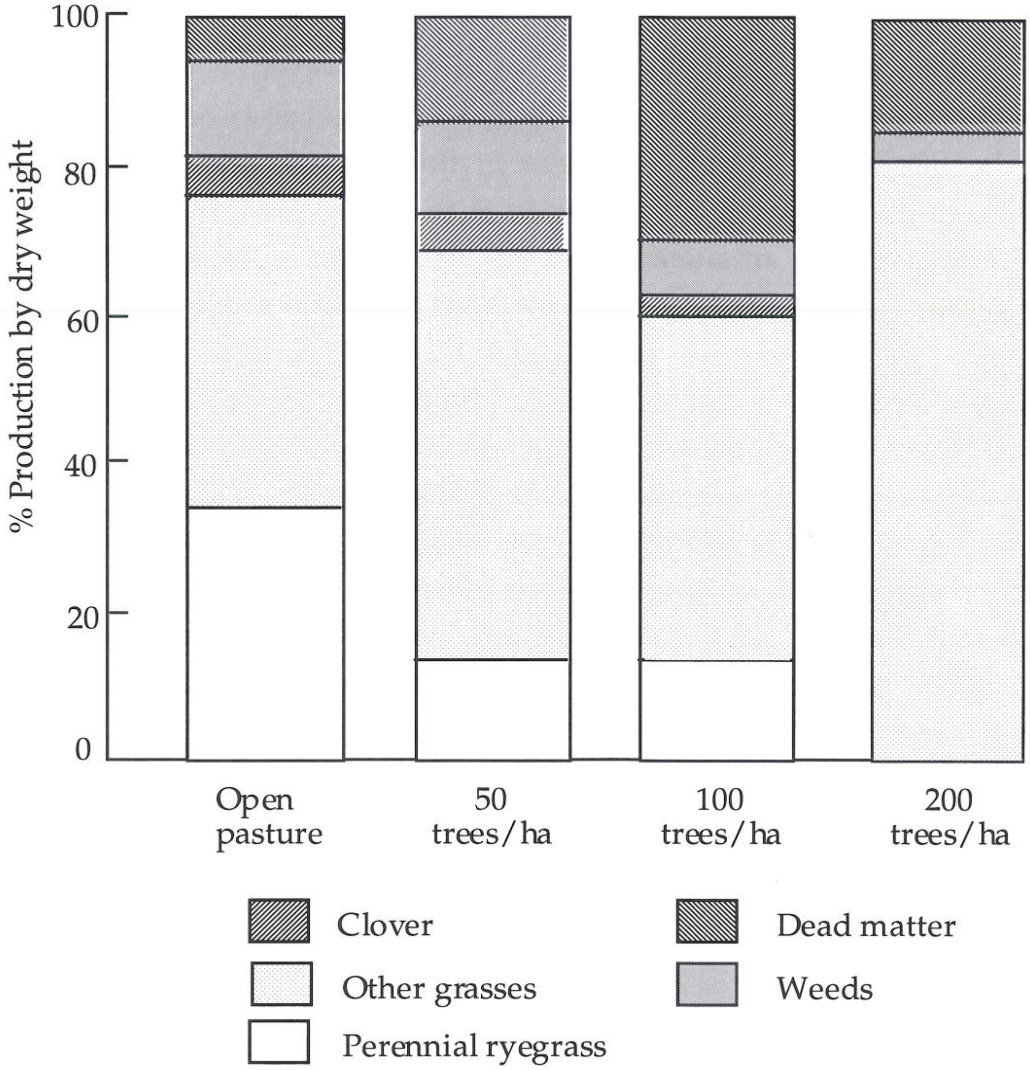


Source: **M.F.Hawke (1992) Agroforestry Research Collaborative Proceedings**

The rate of canopy closure is affected by tree spacing (original planting density and subsequent thinning policy), by pruning management and by factors like plant genotype and nutrient status which influence growth rate. In Fig 1 canopy closure was largely complete, and pasture production had fallen to a low level, within 10-15 years from planting (or 30-50% of the effective life-span of the trees), except at the low planting densities. The relatively slow changes in pasture production over the period 5-10 years reflect the effects of early tree pruning on light interception even at the higher tree densities. However, as a general rule pasture production would be expected to decline to low levels over the first two-thirds of the life of the trees. The trees in this example are *Pinus radiata.* Deciduous trees like poplar would be expected to have a more limited shading effect than evergreens on an annual basis, but their effect is likely to be just as great during the main period of pasture growth in spring and summer.

Plant species differ in their tolerance of shade, and the result is that shade-tolerant grasses like *Holcus lanatus* (Yorkshire fog) and *Anthoxanthum odoratum* (Sweet Vernal), and weeds, tend to increase with time at the expense of shade-intolerant species like *Lolium perenne* (Perennial ryegrass) and *Trifolium repens* (White clover). The shade-tolerant species tend to be inherently less productive than the shade-intolerant, and to have lower nutritive value, so the net effect is a compounding of reductions in pasture production and quality. Vegetation changes under tree canopies are illustrated in Figure 2.

Figure 2. Effect of tree density on pasture composition (% of annual production). "Other grass" species were Yorkshire fog, sweet vernal, meadow grass, bromus, browntop and cocksfoot; at 200 trees/ha, primarily native rice grass.



Source: M.F. Hawke (1992) Agroforestry Research Collaborative Proceedings.

3.1.2 Competition for water and nutrients

These effects are less easy to demonstrate, though rings of dry grass round the boles of trees in the summer time are evidence of the consequences of either water interception by the tree crown or capture by roots. Competition for water and nutrients is closely inter-linked, because plants cannot take up nutrients except in an aqueous medium.

Trees will help to control water run-off and thus protect the soil surface from water erosion, and also help to enhance stability in soils of poor structure or those on steep slopes (see UNIT 4). The performance of the underlying pasture can be safeguarded by reduced risks of both surface erosion and bulk soil movement.

In addition, the impedence of surface water flows by tree roots can help to improve water use efficiency by ground vegetation.

The degree of competition will depend to some extent on the rooting habit of the tree species concerned. Deep rooting species like the Eucalypts will tap water in relatively deep horizons in the soil, and will be expected to interfere less with the shallow-rooted grasses than would shallow-rooted trees like the pines. Conversely, plant nutrients applied to the soil surface are likely to be trapped by the surface mat of grass roots before reaching underlying tree roots.

It has been claimed that some tree species are capable of extracting mineral nutrients from deep soil horizons and returning them to the surface soil in leaf-fall, thus benefiting the surface vegetation. This effect may be difficult to demonstrate except in impoverished soil conditions. Concentrations of phosphorus, and sulphur (important plant nutrients) are observed to be higher under tree stands than on open pasture with similar fertiliser management, though it is not always clear whether this effect is attributable directly to the beneficial influence of the trees or indirectly to the fact that effective stocking rate and pasture utilisation may be lower in tree plantations than in open pasture (see Table 1).

Table 1. The effects of tree density on soil pH and nutrient status.*

	Trees/ha					
	0	50	100	200	400	SE
pH	5.6	5.4	5.4	5.3	5.0	0.1
Calcium	5	4	4	3	2	0.5
Phosphorus (Olsen test)	23	38	53	48	50	13.6
Potassium	8	7	6	8	6	1.4
Magnesium	22	18	17	13	14	2.7
Sulphate	6	9	13	14	20	3.5

** Concentrations in top 75 mm of mineral soil under Pinus radiata plantation, 18 years after planting.*

Nutrient concentrations are g/kg of dry soil.

Variability of estimates indicated by SE value in final column.

3.1.3 Wind speed and temperature effects

Generally speaking, tree cover will reduce wind speed overall and substantially reduce variability in wind speed. It is not easy to demonstrate a direct benefit to pasture production from shelter, but Figure 6 in UNIT 2 illustrates one set of data on the effects of shelter on pasture production. In an agroforestry plantation, of course, shelter effects are more diffuse and widespread than in the lee of a shelterbelt. The greatest benefits may actually come in terms of the reduction in wind damage to other trees. However, one of the difficulties in agroforestry plantations is that wind damage is greater in open stands of trees than in dense blocks. This is one of the factors influencing decisions about planting density.

Tree cover will also reduce variation in ambient temperature at ground level. Grass minimum temperatures tend to be higher under trees than in open pasture at all seasons of the year though, paradoxically, soil temperatures at 10 m depth tend to be lower under trees than under open pasture. The net effect is likely to be an increase in pasture production during the winter; effects on summer production will depend upon the balance between shade effects on temperature and water balance in the underlying vegetation.

The effects of shade and shelter on grazing animals are considered in Section 3.3

3.2 Animal Effects on Trees

Direct animal effects on trees are usually damaging, but indirect effects may be benign. The consequences of keeping animals in agroforestry plantations are:

3.2.1 Physical damage, leading to distortion of growth or, in extreme cases, death of trees.

3.2.2 Control of ground vegetation.

3.2.3 Cycling and redistribution of mineral nutrients.

The first two items are the ones to which we normally pay most attention, the balance between the two in particular enterprises having a major effect on management decisions.

3.2.1 Tree damage

Most animals will browse if they are hungry enough. There is also a suggestion that animals which are particularly well fed will tend to browse occasionally to provide variety in the diet, and all populations have their "vandals". Some people only put hungry animals in young tree stands and remove them when fully fed. In either case, young trees with leading shoots within reach of browsing animals will be particularly susceptible to damage. For this reason, it is normal practice either to keep grazing animals out of new plantations until the leading shoots are out of reach, or to fit protective tubes to the trees to prevent browsing.

Once this susceptible stage is passed (lasting up to one year in the case of sheep grazing and 2-3 years in the case of cattle), the major risk of tree damage is linked to branch breakage, bark stripping, or breakage or uprooting as a consequence of scratching or pushing. Deer and goats are likely to be more serious causes of bark stripping than cattle or sheep, other things being equal. Cattle, particularly bulls, can create problems in pushing over young trees, and rubbing damage by cattle may be serious for soft-barked trees in spring.

Several paint-on products have been tried in attempts to make bark unattractive to animals, but none have been successful over extended periods of time. Alternative physical protectors are available, particularly for young trees, but in many cases the costs are prohibitive – at least for commercial forestry operations.

Many strategies have been tried to overcome these kinds of damage, but none are completely successful. Effective lice control will limit scratching damage, and judicious pruning will control breakage and bark stripping. Often the problem is confined to a few animals, and can be reduced if the offenders can be identified and removed. However, the difficulty of preventing tree damage is often cited as a reason for preferring to keep tree blocks and grazing areas as separate entities.

There is evidence that animals show greater preference for some acacia and eucalyptus species than for *Pinus radiata*, thus increasing the risk of browsing damage. Preference for cupressus species may be lower than for Pinus radiata.

3.2.2 Control of ground vegetation

Grazing animals perform a useful function, particularly in the early life of a plantation, by controlling the growth of ground vegetation which may otherwise smother young trees or at least reduce their growth as a consequence of competition for light or nutrients. Thus there is an incentive to put grazing animals into a plantation as early as possible, and in this respect there is a difficult balancing act to perform between the benefits of this practice and the risks of physical damage.

The effects of ground vegetation control on tree growth decline as a plantation matures, but the advantages are likely to continue in terms of reduced fire risk, and improved access for silviculture. In practical terms, cattle may also damage access tracks and surface drainage.

3.2.3 Nutrient cycling

Grazing animals can enhance the productive performance of any ground vegetation be re-cycling mineral nutrients in their dung and urine. The major nutrients of importance to plants (both pasture plants and trees) are nitrogen (N), phosphorus (P) and potassium (K), though sulphur (S) is also of substantial importance. The main effect of the grazing animal is that these nutrients become available to sustain plant growth much more quickly when herbage is chewed and digested than if it simply returns to the soil as a consequence of death and decay.

Of the nutrients, P is largely present in the faeces, K in the urine and N in approximately equal proportions in both. In mainly livestock enterprises, 90% of the N, 95% of the P and almost all of the K eaten by the animal are returned to the soil. Thus the effects of re-cycling can be very substantial.

Over a long period of time the nutrient status of the soil may be eroded by steady removal as animal product (meat or wool), or by loss of the volatile components to the atmosphere (N) or ground water (N and K). The question of the environmental impacts of these losses cannot be dealt with here, but it should be noted that agroforestry systems generally run at lower animal stocking rates than conventional "open field" systems, and this would be expected to result in lower loss rates of plant nutrients. However, the need to replace plant nutrients in tree systems as well as pasture systems is an important management consideration (see later).

The other major effect of animals on plant nutrient status is the tendency to move nutrients around and concentrate them in some areas to the detriment of others. At its simplest this is a consequence of the discrete nature of individual defacations and urinations (Discrete, meaning deposited in defined patches; **not** Discreet, meaning careful or secretive). This effect tends to concentrate nutrients and can result in faster rates of loss than if the same nutrients were spread uniformly on the paddock. However, a more serious effect may be the tendency of animals to defecate and urinate with greatest frequency round their resting sites or water troughs, a practice which progressively concentrates nutrients in limited areas and removes them from other, more extensive areas.

This is not simply a characteristic of agroforestry systems of course: it tends to occur in any grazing system, though its effects can be minimised by subdivision and grazing control.

3.3 Tree Effects on Animals

The effects of trees on grazing animals are difficult to quantify, and our evaluation of these effects often has as much to do with our own perceptions of comfort as on any objective criteria. The effects can be sub-divided into four sections:

3.3.1 Shade and shelter

3.3.2 Quantity and nutritive value of pasture

3.3.3 Access

3.3.4 Animal health.

3.3.1 Shade and shelter effects

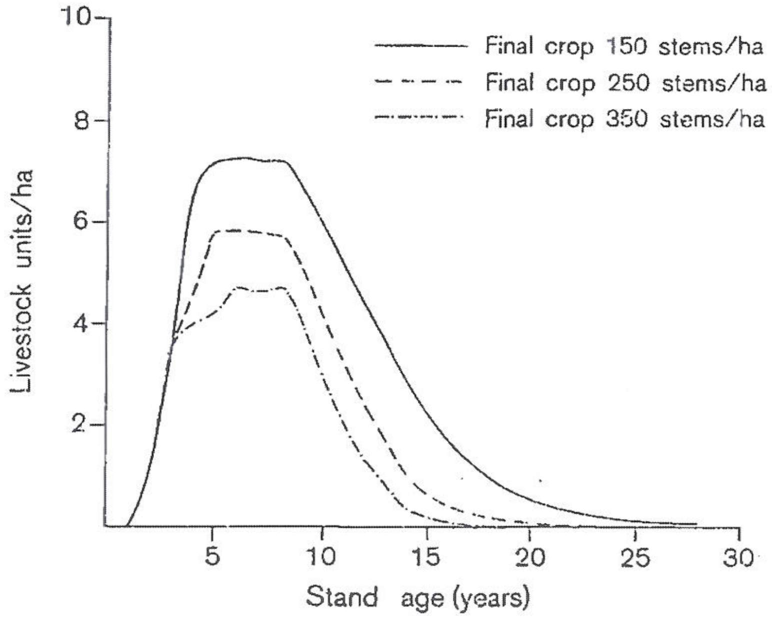
Generally speaking farm animals are very efficient at regulating their own environment, and it is difficult to show any clear advantage from the provision of either shelter or shade in the relatively temperate climate which New Zealand enjoys. Exceptions would be the loss of young lambs or weak adult animals in severe snow or frost conditions but, even here, the major cause is often shortage of food rather than the adverse elements *per se*. Thus, although the presence of trees in agroforestry plantations may reduce wind speed and chill factor in winter, and reduce summer temperature, there is no unequivocal evidence to show that this influences animal performance in the long term. However, this is partly a consequence of the difficulty of disentangling shade and shelter effects from the other factors dealt with in this section, and it is perhaps advisable to keep an open mind on the potential advantages of protection in more extreme environments. Advantages have been claimed, for example, from the short-term benefits of shelter for newborn lambs or newly shorn sheep. Benefits usually appear to be greater for sheep than for cattle.

Although animals frequently make use of shade when it is available, particularly on hot summer days, it is even more difficult to demonstrate measurable advantages in animal performance from the provision of shade under New Zealand conditions. However, increasing numbers of farmers are growing shade trees as a contribution to improved animal welfare.

3.3.2 Quantity and nutritive value of pasture

We considered the influence of light interception by the tree canopy on production by the underlying pasture in Section 3.1.1. This of course has direct consequences to the feed supply for grazing animals, and the normal result is a steady reduction in the number of animals per hectare (the stocking rate) until by year 20 of a normal productive cycle of 30 years the carrying capacity of a plantation may effectively be zero (Figure 3). The impact on animal performance in the earlier stages depends upon whether or not moves have been made to adjust stocking rate to take account of the reduced feed supply. Production thinning of the stand at 20-25 years (see UNIT 2) may help to maintain forage production late in the rotation, because by that stage new canopy growth is not nearly so vigorous.

Figure 3 **Effect of tree stocking on understorey livestock.**



Source: R.L. Knowles (1990) Agroforestry Research Collaborative Proceedings.

There are also more insidious effects on the nutritional status of pasture, however. Generally speaking, the more productive grasses, like perennial ryegrass, are less tolerant of shade than the less productive, like sweet vernal, and legumes like white clover are less tolerant than the grasses. In addition to effects on productive potential, these differences in sensitivity also result in a progressive decline in the nutritive value of the pasture, thus reinforcing effects of declining herbage quantity on animal performance.

A further effect on the nutritive value and the palatability of the diet results from the presence of fallen leaves, needles in the case of conifers (see Table 2). These leaves almost invariably have a lower nutritive value than pasture, and they may also contain biochemical compounds which interfere directly with digestion. Thus, the consequences are likely to be a progressive reduction in the nutritive value of ingested herbage, in parallel with the decline in the quantity of herbage produced.

Table 2. The effect of tree density on the relative ground cover of vegetation and pine needles.*

Tree density (trees/ha)	% cover	
	Vegetation	Pine needles
0	100	0
50	43	37
100	24	76
200	7	93

* *Pinus radiata plantation 20 years after planting.*

3.3.3 Access

Access by grazing animals to ground vegetation may be inhibited by low-growing branches or, more frequently in managed plantations, by trash from normal pruning activities. The extent of this trash interference (which can inhibit pasture production as well as accessibility) can be markedly affected by tree spacing, pruning and thinning policy, and by choice of tree species, but trash can cover up to 25% of the ground area after the final thinning and pruning stage in a silvipastoral plantation. It may be minimised by pruning frequently or by removing thinnings and prunings, but at the cost of increased labour commitments.

Cattle are less susceptible than sheep to interference from trash, and may indeed help to accelerate its breakdown by direct treading action.

3.3.4 Animal Health

The presence of trees may have a number of direct and indirect effects upon the health of grazing animals, most adverse but some beneficial.

The generally cooler but moister ground environment under trees is likely to create more favourable conditions for the survival of the free-living infective larval stages of worms which parasitise the gastro-intestinal tract of grazing animals, thus increasing the risk of clinical or subclinical effects on the animal. These effects vary seasonally, and are normally likely to be most severe in young, susceptible animals. They are also often bound up very closely with effects on nutrient intake. This adverse effect may be offset by the generally lower infection risks following from lower stock numbers.

Tree shade helps to reduce irritation and sometimes more serious damage from insect attack. However, it is also true that affected animals frequently tend to hide in shade when it is available, and this may make them more difficult to identify. Shade effects may also encourage the development of shade-tolerant poisonous plants, and there is some evidence of greater animal losses to poisoning in plantations than in open paddocks. However, it would be unwise to make too much of this particular effect.

The net effect of these factors on animal performance is illustrated in Table 3, which demonstrates some reduction in both ewe and lamb weight gains under trees, and some reduction in wool growth, compared to results from open pasture. There is no evidence of effects on meat quality from grazing under trees, but clear evidence of increases in wool damage. Reproductive performance of animals grazing under trees does not appear to be affected either positively or negatively, except for occasional reports which suggest that consumption of radiata pine foliage results in abortion in cattle.

Table 3. **Effects of tree density in a silvipastoral system on sheep performance.**

	Tree stocking (stems/ha)			
	Nil	250/50	500/100	1000/200
Ewe weight change (g/day)	15	13	-5	-16
Wool weight (kg/ewe)	3.4	3.0	2.7	2.4
Lamb weight gain (g/day)	185	164	151	157

Column heads show tree density at planting/final stocking.
Results shown refer to trees ten years old.
Animal numbers adjusted for tree effects on pasture production (see Fig. 3).

Source: R.L. Knowles et al., (undated) Agroforestry Research at Tikitere.

There is consistent evidence of better calving performance of deer under trees, presumably because the enhanced cover reduces stress for these animals.

3.4 Conclusions

Taking all of these factors together, we can see that the most important interactions influencing the successful combination of timber and pasture enterprises are:

(a) the progressive effect of tree canopy shade on pasture production, and

(b) the rather unpredictable nature of the balance between control of ground vegetation and tree damage as a consequence of browsing in the early life of a new plantation.

The other factors considered in this section may be of consequence on some occasions, and in some localities. Though of less general impact, they may nevertheless be important when and where they do occur.

In this section we have reviewed briefly some of the main interactions between trees, ground vegetation and livestock populations which may affect the ecological balance and/or the productivity of a silvipastoral system. Now look carefully again at "your" agroforestry area, and look for the effects we have described. See how many other interactive effects you can suggest. For instance, we have said nothing in this Unit about the potential advantages to tree growth of the mycorrhizal fungi which inhabit rooting zones and can enhance nutrient uptake by the tree (see UNIT 1). In particular, make comparisons of shade and shelter effects on temperature and wind speed within the plantation and in the open (and, if possible, in more densely planted forestry blocks). Check back to the questions listed at the start of this section and see how successful you were in working out the interactions between trees, pasture and livestock.

4 ESTABLISHMENT AND MANAGEMENT OF AGROFORESTRY BLOCKS

Many of the principles of tree choice, establishment and management for efficient and profitable timber production were covered in UNIT 2 of this Study Guide. These principles are no different for the management of agroforestry blocks though some of the details differ, primarily to take into account the effects of lower tree population densities and the needs of the grazing animals.

In New Zealand there has been a move away from agroforestry plantations towards separate woodland and pasture blocks, mainly because of the management difficulties surrounding tree establishment, the problems of controlling the size and shape of wide-spaced trees, and the fact that trees have been seen to be more profitable than livestock. However, there may still be cash-flow advantages to the introduction of trees into grazing areas, and many people appreciate the amenity value of trees on pasture. Thus, there will continue to be a place for this form of tree use.

4.1 Tree species

Much of the agroforestry research in New Zealand has been done with *Pinus radiata*, and this is a popular species for agroforestry blocks though it can be difficult to control branch size of the species in wide spacings. The eucalypts make attractive trees in grassland settings and are popular agroforestry subjects. Poplars (*Populus* spp.) are increasingly being recommended for this purpose, and their deciduous habit provides some benefits to understorey pasture production. This is a particularly useful species for wet sites. Alternative species for agroforestry use are listed in UNIT 2.

4.2 Tree establishment

The main difference between agroforestry plantations and single-purpose timber blocks is in the tree density – the number of trees per hectare. This applies to both the initial planting density and the final establishment density.

Early work on agroforestry blocks suggested that established tree populations should be as low as 100 stems/ha to optimise the output value of timber and livestock products. This figure is now being revised upwards, and target densities of up to 200 stems/ha may be recommended. It is just as important to provide the opportunity to remove sub-standard or damaged trees in agroforestry plantations as in timber blocks. An initial population three to four times the mature target population may be recommended (effectively 800-1000 trees/ha which may be planted in rows and columns 3.5 m apart). Square spacing is not essential, however, and distances between rows and columns can be varied to suit requirements for contour planting, machinery access, and so on.

Modern tree breeding and selection procedures (see UNIT 2) mean that trees are more uniform in growth and form than they used to be, so that it is possible to reduce initial tree populations to only 200-300 trees/ha, and thus reduce also the wastage associated with thinning. There has also been some reduction in the need for pruning to correct poor growth and form in young trees.

The relatively low stocking density advocated for agroforestry plantations tends to encourage large individual tree size and increase the risk of wind damage. For these reasons plantations are best sited on moderate fertility, sheltered areas.

EXERCISE

What does a tree population density of 200 stems per hectare look like? What distances between trees? And what would the spacings be for (a) 100 stems per hectare and (b) 300 stems per hectare?

EXERCISE

Construct a table of appropriate spacing options for yourself. Can you suggest – before we reach the comments in the text – how tree growth and shape might be affected by planting configurations? What other factors might influence decisions?

EXERCISE

List three alternative "row x columns" spacings for:

(a) 100 stems per hectare

(b) 300 stems per hectare

EXERCISE

List four possible effects of planting configuration on tree growth and shape.

1.

2.

3.

4.

The principles of tree planting were discussed in UNIT 2 and will not be repeated here. However, it is important to emphasise that these principles are even more important in agroforestry because of the greater risks of uprooting or "throw" as a consequence of direct animal interference, wind action, or high growth rates resulting from the high nutrient status of a grazed block.

Protection from grazing is the main requirement for a newly established agroforestry block. Generally grazing animals should be excluded from unprotected trees for 1 year (sheep) or 3 years (cattle). Use of deer or goats for understorey grazing requires particular care. The use of tree guards to protect crowns and/or stems is continually under investigation, but the cost of such protection can be prohibitively high. As indicated earlier, no really effective repellent is available though many have been tried.

The absence of grazing control in the critical first year or two of establishment can give rise to serious crowding and shading problems from surrounding vegetation. Consequently, close attention to weed control over this period is likely to be important. Instructions for alternative weed control procedures are given in the references text.

4.3 Tending in Agroforestry Systems

The need for timely thinning and pruning in agroforestry regimes cannot be over emphasised. Combining low stocking and fertile sites means that particular care is required to ensure target DOS is achieved and that the impact of trees and slash on pasture availability is minimised. The general principles of thinning and pruning have been covered in Unit 2 and you are encouraged to go back and ensure you are familiar with these.

Generally all regimes in agroforestry systems will have the production of pruned butt logs as the primary objective. All care must be taken to ensure that maximum value is extracted from this log because in many cases it will be the only marketable log produced, 2nd and 3rd logs usually have little or no value due to large branch diameter.

Low stocking and high fertility mean that for many tree species, diameter growth will be high but height growth may be reduced. Table 7, Unit 2 demonstrates this effect. Consequently trees will usually reach target DOS at relatively young ages and, because they are young and may have reduced height growth, will not be very tall. This means that pruning lifts are small if a minimum length of green crown is to be retained. After a pruning lift it may only be a matter of a few months before target DOS is reached again and another lift is required. Again little canopy is able to be removed because height has not increased much. As many as 5/6 pruning lifts may be required to reach a pruned height of 6.0m. This is expensive if you are paying for labour or very time consuming if doing the work yourself. Either way the opportunity to mis-time a lift is very high. A lot of monitoring of tree growth during this time is necessary to ensure all targets are met.

Form pruning may be useful in agroforestry regimes, particularly when initial stocking is close to final stocking. Defects such as multiple leaders and ramicorns (steep angled branches) can be corrected before they seriously impact on the trees form. While high initial stocking may help overcome this problem of high incidence of stem defects on fertile sites it will also have a greater negative influence on pasture production (See Figure 1). The effects of form pruning on growth and form of *P. radiata* is outlined in tables 4a and 4b.

Table 4a. The effect of supplementary pruning done prior to normal clear bole pruning in 6 year old trees at 400 stems/ha in Canterbury.

	Height (m)	DBH (cm)
No Pruning	9.1	18.4
Form Pruning Plus Normal Pruning	8.3	14.7
Normal Pruning	8.6	16.7

Table 4b. Percent of acceptable stems after form pruning. Trees were assessed at age 6, 2 ½ years after form pruning. Kaingaroa site.

	Form Pruned	Not Form Pruned
%Acceptable Stems	64%	51%

Source: What's new in forest research No. 171.

Clearly form pruning improves the proportion of acceptable stems but does have a negative influence on growth, particularly diameter growth. On fertile sites reduced diameter growth may be acceptable particularly if it allows more effective control of DOS. (See Unit 2).

In some of the alternative species form pruning may be essential if the required number of acceptable stems is to be achieved. There is less genetic improvement amongst the alternative species compared with *P. radiata* so the % of acceptable stems is often low. In some species this may be compounded by poor growth habit. A good example is *Acacia melanoxylon* which has poor apical dominance and in full light tends to form a bush. It is notorious for poor form. In these situations form pruning may be essential. Table 5 provides an example of the benefits of form pruning in this species.

Table 5. The effect of no form pruning, annual form pruning and triennial form pruning on the % of acceptable stems of *A. melanoxylon*.

	No Pruning	Annual	Triennial
%Acceptable Stems	25%	55%	42%

Source: What's new in forest research No. 241.

The form pruning consisted of removing all heavy branches and competing leaders. Form was assessed 3 years after treatment when trees were 7 years old. A notable feature of the form pruning in this example is that it had no effect on tree growth despite significant loss of leaf area. As can be seen annual form pruning doubled the % of acceptable stems.

4.3.1 Pruning and Thinning

Pruning and thinning programmes follow much the same sequence as for trees in timber blocks (see UNIT 2), though with greater emphasis on the need to control branch development in the bigger trees growing at wider spacings, and on early pruning and thinning to maximise grazing opportunity.

A conventional pruning programme is shown in Table 4, illustrating the combination of frequency of pruning and height of "lift" (the vertical distance between one prune and the next). The object of the exercise is to achieve as great a length of branch-free stem as possible without reducing the size of the crown to a level which restricts the growth of the tree as a consequence of a limited supply of assimilates from leaf photosynthesis. In practice it will be preferable to prune to specified DOS (Diameter over Stubs – see UNIT 2), limits of 20cm or more may be viable in agroforestry regimes because of the rapid diameter growth and the need to reduce the number of pruning lifts required.

Table 6. **Examples of pruning and thinning programmes for Radiata pine on pasture site: (a) conventional, (b) innovative. See text for description.**

Initial stocking (trees/ha)	800	400
First pruning (years)	5	2-3
First thinning (years)	5	2-3
Last pruning (years)	9	10
Pruning height (m)	6	12
Last thinning (years)	14	3
Final stocking (trees/ha)	200	200
Rotation length (years)	30	30

Conventional management of agroforestry plantations requires thinning on two or three occasions to produce the final production tree density by about halfway through the production cycle. In this case the first thinning normally takes place between 3 and 6 years of age, and the last between 12 and 16 years of age, depending on site. At this stage (particularly close to the top end of the age range) the culled trees have potential market value, but it is also possible to select on tree shape and size and it would be usual to remove poorer specimens, thus reducing sale value.

If only two thinnings take place, around one half of the population should be removed at each stage to establish the final production density. With three thinnings, about one-third of the population would be removed at each stage. Choice of thinning programme will depend upon terrain, access to markets, and current log prices. Thinning sawlog prices are particularly sensitive to market fluctuations because the logs tend to be suitable only for low-value sectors like boxing, packaging or small saw logs. Thinnings should be timed as far as possible to coincide with main pruning periods to ensure uniform development of the tree populations.

Managers of agroforestry blocks may prefer to prune earlier, more frequently and in smaller "lifts". An example is given in Table 4. This is partly because more frequent pruning reduces the amount of trash lying on the ground which inhibits access to pasture, and partly also because it helps to catch at an early stage branches which might tend to become too heavy, affecting tree shape and trunk value. Early pruning and thinning minimises the effects of the tree canopy on pasture production, but depends for its effectiveness upon the more reliable form and growth of modern tree selections (see UNIT 2). A significant problem with this practice is increased cost (if using outside labour) on increased workload.

Decisions about pruning programmes should be determined as far as possible by the balance between labour costs and the enhanced value of the pruned tree. However, owner-managers of small blocks may find that the convenience and flexibility of frequent pruning is a real advantage.

EXERCISE

Can you list the possible advantages and disadvantages which might follow from using strategy (b) rather than (a) in Table 6? Use information from UNIT 2 as well as UNIT 3 in drawing your conclusions. Make separate lists for effects on wood production and value, and on pasture and animal production. Use the space below for your lists.

4.4 Harvesting

The optimum age for harvesting trees from agroforestry plantations in New Zealand is similar to that for timber blocks – usually between 28 and 30 years. Harvesting policies and procedures were described in UNIT 2 and will not be repeated here. The likelihood is that understorey pasture production will have been too low to sustain a viable livestock population for the last third of the tree production cycle, unless some variant of the innovative management outlined in Table 4 column (b) is used or a proportion of the trees are removed for a production thinning at 20-25 years.

If the area is to be re-established in pasture for a new agroforestry cycle there will be need for more care in tree felling and trash clearance than would be strictly necessary where a wood block is to be re-established. There is little direct experience of cycles of agroforestry in New Zealand as yet. However, by definition a substantial degree of clearance and levelling is likely to be necessary before re-sowing pasture.

4.5 Fertiliser

The fertiliser requirements of trees growing in grazed pastures should be low, particularly if they have been planted in established grassland. It is usually difficult to demonstrate any growth response by the trees to use of N, or K fertilisers in these circumstances, and the major benefit to fertiliser use is likely to come from enhanced pasture and livestock production. The main exception to this generalisation may be magnesium (Mg), deficiencies of which are increasingly being noted on re-established plantations and particularly on trees with high growth rates on high-fertility sites. Table 1 in this Unit illustrates the depletion of soil Mg under a *Pinus radiata* canopy.

Conventional pasture levels of phosphate fertiliser would normally be used in agroforestry plantations (200 – 250 kg/ha of superphosphate each year), but this would only be worth while during the first third of the production cycle, before pasture production is seriously impaired by increasing shade levels.

Note the contrasts with comments in Unit 2 about fertiliser requirements of forestry blocks.

4.6 Pests and Diseases

Most tree pests and diseases are likely to be less serious in agroforestry plantations than in timber blocks, because of the more open canopies and the generally more varied land use practices, though some (e.g. Diplodia) may have dramatic and serious effects. However, most pests and diseases are a potential hazard in both sets of circumstances, and control measures are also similar. Look in the reference text for information on disease and pest identification and control.

4.7 Livestock Management

This is not the place to dwell at length on details of livestock management. Rather, comments will be confined to aspects of management which require particular attention in livestock grazing in agroforestry plantations.

The first and perhaps the most obvious point is that animals can be more difficult to muster and control in plantations than in open paddocks. Thus, fences and raceways need to be carefully planned and well maintained. Poor pruning and thinning practices can accentuate wear and tear on fences, and harvesting procedures are clearly likely to create major fencing damage.

The major animal health hazards in agroforestry blocks probably result from: (a) the greater survival rates of the free-living larvae of gastro-intestinal worm parasites in the shady environment, increasing the risks of serious worm infestation, and (b) the greater risk of development of poisonous weeds.

Enhanced worm burdens require greater attention to routine drenching procedures, particularly for young animals; detailed recommendations for drenching routines are given in publications listed in the reference section. Poisonous weeds are less easy to guard against routinely. Early recognition of poisonous plants and adoption of control measures is important; for information on both aspects see the reference section. With this background, it is probably realistic to think of agroforestry grazing as suitable for breeding sheep or cattle, rather than as a production feed for young stock.

5 AGROFORESTRY SYSTEMS UTILISING SPACED POPLARS FOR EROSION CONTROL

5.1 Introduction

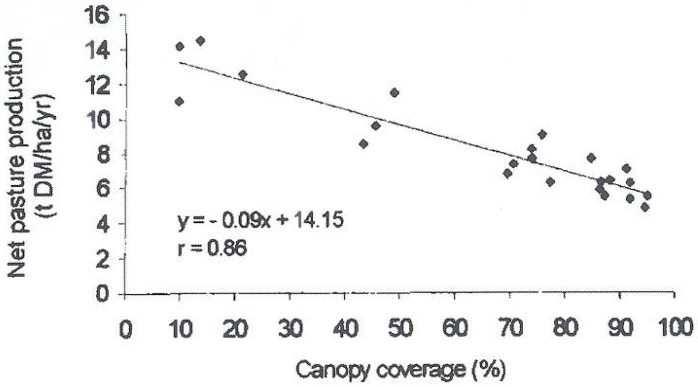
The use of poplars for slope stabilisation is outlined in Unit 4 Conservation and Amenity. You may find it useful to read section 2.3 The Prevention of Soil Erosion at this stage. Section 2.3 outlines the benefits of tree roots for soil stabilisation, the advantages of poplars (and willows) for stabilisation and issues concerning establishment.

In this section the influence of poplars on pasture production and the use of poplars and willows as fodder for livestock will be outlined. Information used was compiled by Andrew Wall, a post graduate student at Massey, and Dr Peter Kemp, one of Andrews supervisors.

5.2 The Effect of Poplars on Pasture Production

As we have seen (Unit 3, Section 3.1.1) the most significant influence of spaced (or dense planted) trees on pasture is shading, though low soil moisture may also reduce growth. Shade decreases tiller density but under poplars pasture composition appears to not alter much. This is unlike the results usually found when pines are grown on pasture (Figure 2). As with pines though pasture nutritive value declines under poplars which reduces utilisation during grazing. Stock prefer to graze on unshaded pasture. The relationship between pasture production and shade under poplars is shown in Figure 4. Figure 4 comes from data collected at Kiwitea, North of Fielding. Shade is expressed as % canopy coverage. Zero canopy means no shade while 100% canopy means complete shade.

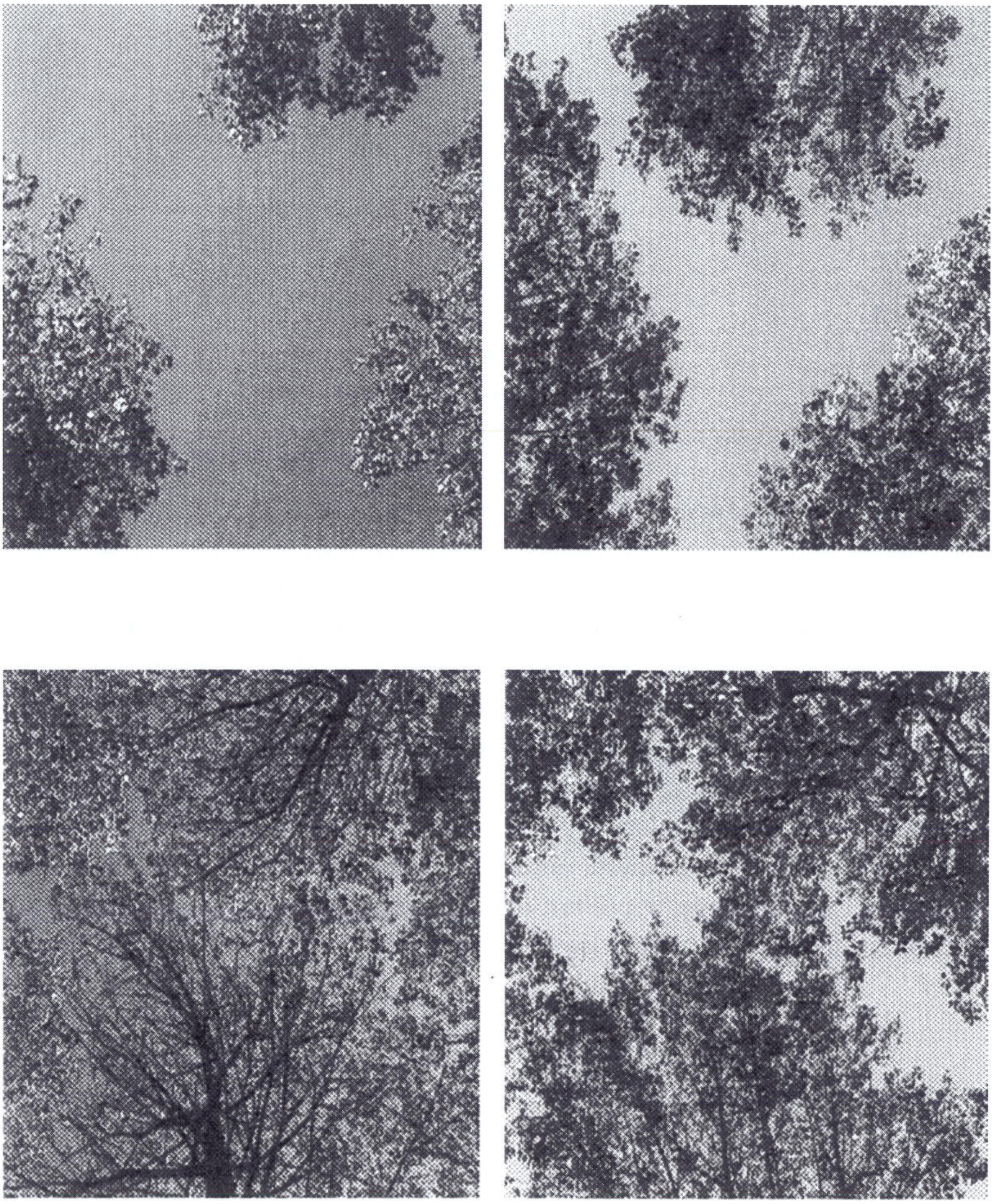
Figure 4: **The relationship between annual pasture production and canopy closure of mature poplars, the Manawatu. (Andrew Wall, unpublished).**



Source: Wall, A. 2001, Unpublished

Clearly pasture production declines as canopy % increases. So if we have a stand of poplars with 50% canopy closure, pasture production is around 40% lower than unshaded areas. In the autumn leaf fall can temporarily bring pasture growth to a stand still. Poor production at this time is highly undesirable because of the need to accumulate feed reserves prior to winter. Farmers can control shading to a certain extent by managing the final stocking and pruning lower branches. Trees can be thinned as they mature. This retains the soil conservation benefits while minimising shading. The level of shading produced by poplars is associated with canopy closure. What do different canopy closures look like when standing under poplars looking straight up. Figure 5 provides some examples. These images represent canopy closures of 36%, 58%, 77% and 80% going from the top left in a clockwise direction.

Figure 5 Examples of canopy closure in poplars.



5.3 The Use of Poplars and Willows as Fodder

Poplars and Willows planted for soil conservation have the potential to be a significant source of fodder on many hill country farms, particularly in late summer and early autumn when droughts often limit pasture growth. The edible parts of both poplars and willows include the leaves and fine stems up to 5mm in diameter. While thicker stems will be eaten by stock, particularly cattle, digestibility declines very quickly as the proportion of wood in total intake increases. How much might be available? Measurements in the Wairarapa suggest that at 50 trees/ha edible dry matter ranges between 150kg DM/ha and 1100kg DM/ha depending on tree size and harvesting method. Coppicing the trees provides maximum fodder but alters the canopy structure. Autumn leaf fall also represents a fodder source, though nutritive value will be lower than for green leaf. Leaf falls at over 3000kg DM/ha may occur under mature poplars. Removing at least some of this helps to prevent the depression in pasture growth that results from the covering of pasture by falling leaves.

The nutritive value of poplar and willow is shown in Table 7. The metabolisable energy content is adequate for maintenance feeding in both species. For comparison the metabolisable energy content of hay is often around 8.0 and silage, 9.0 MJ/kg of dry matter. Spring pasture will usually have metabolisable energy content of 12.5 MJ/kg dry matter, however in late summer the buildup of dead material (such as seed heads) may mean that pasture metabolisable energy will be less than that of poplar and willow.

Table 7 **Estimated Metabolisable Energy Content of 9 Poplar and 3 Willow Clones in Summer**

	Metabolisable Energy (MJ/Kg DM)
Poplar	
Edible fodder	9.9
Fallen leaves	7.4
Bark	9.0
Willow	
Edible fodder	9.8
Bark	9.6

It has been noticed that there is considerable variation in preference and intake of animals offered poplar and willow fodder. Sheep appear to be particularly sensitive to differences in palatability. For example, sheep offered edible fodder of the poplar clone 'Eridano' consumed only half the amount as those offered 'Kawa' and 'Argyle' in a recent study. It is highly likely that the reason for the reluctance to eat Eridano is due to the high concentration of phenolic glycosides, a chemical found in many plant species, in this clone. However the high phenolic glycoside content provides resistance against browsing by possums and some insects. So possum resistant clones may not make particularly good fodder. Much more research is needed on this aspect though.

Feeding poplar and willow fodder to livestock can be combined with thinning and pruning operations needed to manage pasture shading but needs to be done during the first 10 years of growth.

6 THE FUTURE

Despite the advantages claimed for agroforestry systems in terms of efficiency of land use and maintenance of cashflow on the farm, the development of agroforestry blocks on farms has been extremely slow. There are several reasons for this. These are the practical problems outlined earlier of managing grazing animals without damaging young trees, and of controlling heavy branching in spaced trees and the consequent risks of wind damage and loss of timber value (Table 9). Table 9 highlight the high proportion of low value log grades (L Grade and pulp) at low stockings. Just as important however, is the evidence that high growth rates in individual trees in a spaced population do not in fact compensate for low tree stocking density (Table 8), and the realisation that on many farms a limited area of land (usually of limited productive capacity) can be taken out of the grazing area and planted as a timber block with minimal impact on livestock output. Furthermore, it is coming to be recognised that *Pinus radiata* is probably not the tree of choice for agroforestry systems anyway, because its growth form is not suited to low density planting, it tends to lead to progressive depression in soil pH and its canopy is of little value from the point of view of animal nutrition. Much the same limitations apply to Eucalyptus species. From this point of view it is unfortunate that most of the experimental evidence in the ecology and management of agroforestry systems comes from work with *Pinus radiata*.

So what of the future for agroforestry? Within New Zealand, as elsewhere in the World, interest is swinging to the potential value of broad-leaved deciduous trees as being more appropriate for spaced-tree plantations, less competitive with the pasture under-storey for light in the winter time, and potentially more valuable than *Pinus radiata* for the enhancement of soil condition and nutrient status. Attention is therefore focussing on Poplar (*Populus* spp.) in particular, in part because they meet the above specifications and in part, also, because they are already present as spaced trees on many thousands of hectares as a result of their present value for soil stabilisation and land conservation on unstable soils of relatively shallow slope. In these situations poplar already provide the basis for agroforestry systems with substantial under-storey grazing, though there has been little attention as yet to the timber potential of the trees. Indeed, despite their widespread use as conservation species, there is very little objective information on the influence of poplars on soil water relations. Recent research has shown that spaced plants of broadleaf trees, such as poplar, does significantly reduce pasture growth and quality, influencing the economics of agroforestry systems which utilise trees for erosion control in grazed pastures on steep hill country.

Use of poplars for timber production would not be incompatible with their value for soil stabilisation, since they coppice easily from the base and do not lose root structure when felled. There are, however, reservations about the consequences to soil stability of unwise extraction procedures. However, there is a considerable source of untapped potential here which really needs detailed investigation. There is also scope for considering alternative deciduous species, some with substantial timber value.

This is not the place to speculate about alternative tree species and management systems. However, some of the issues are considered in the following paper which provides a balanced view of the available information. See what you think of it, and consider the value of the information it contains to the UNIT 3 assignment.

Table 8: **Tree growth at Tikitere (*Pinus radiata*). Age 22 years.**

Stocking rate (trees/ha)	Mean annual increment (m^3/ha/year)
50	7.2
100	14.5
200	22.6
400	36.0

Source: R.L. Knowles et al. (undated). Agroforestry Research at Tikitere. Mimeograph report.

Table 9: **Log grades at Tikitere. Age 19 years. (m^3 per grade)**

Stocking rate	Pruned	S Grade	L Grade	Pulp
50	59	2	17	26
100	113	2	41	64
200	156	21	61	101
400	167	191	68	147

The impact of widely spaced soil conservation trees on hill pastoral systems

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Abstract

An estimated 3.7 million ha or 33% of the North Island requires the application of significant soil conservation measures to be able to physically sustain pastoral enterprises. Traditionally, erosion control measures on hill farmland have centred on the planting of hardwood trees, such as poplars and willows, at wide spacings. Research and experience has confirmed that where hardwood trees are adequately planted and tended, they significantly reduce the magnitude of soil erosion and maintain soil stability. However, the effects that such erosion-control plantings have on pasture and animal production owing to changes in the farm microclimate, soil and water resources remains relatively unresearched in New Zealand.

Keywords: hardwood trees, physical sustainability, silvipastoral systems, soil conservation

Background

The development of North Island soft-rock hill terrain into pasture has increased the magnitude of hillside soil erosion 2- to 10-fold, even though the frequency of erosion events remains unaltered (Miller *et al.* 1996). This soil erosion reduces the productive capacities of pastoral hill farms (Blaschke *et al.* 1992). On-farm degradation can be seen as the physical removal of pasture by mass movement and fluvial erosion processes; depletion of fertile topsoil by accelerated gross or insidious soil loss; reduced soil water-holding capacity owing to shallower soils with poor physical structure and lower organic matter content; and damage to fixed structures such as farm tracks and fences (Clough & Hicks 1993; Hicks *et al.* 1993; Blaschke *et al.* 1992; Lambert *et al.* 1984). Pasture production on erosion scars takes about 20 to 40 years to reach levels equivalent to 70 to 80% of neighbouring uneroded sites, with little further recovery thereafter (Lambert *et al.* 1984; Douglas *et al.* 1986; DeRose *et al.* 1995). This indicates that on hillsides where mass movement erosion is severe and/or frequent, current production levels from pastoral regimes will increasingly become difficult to sustain (Trustrum *et al.* 1984). Eyles & Newsome (1992), using the New Zealand Land Resource Inventory database as well as other physical parameters, have estimated that 3.7 million ha or 33% of the North Island requires significant soil conservation measures in order to be able to physically sustain pastoral land uses.

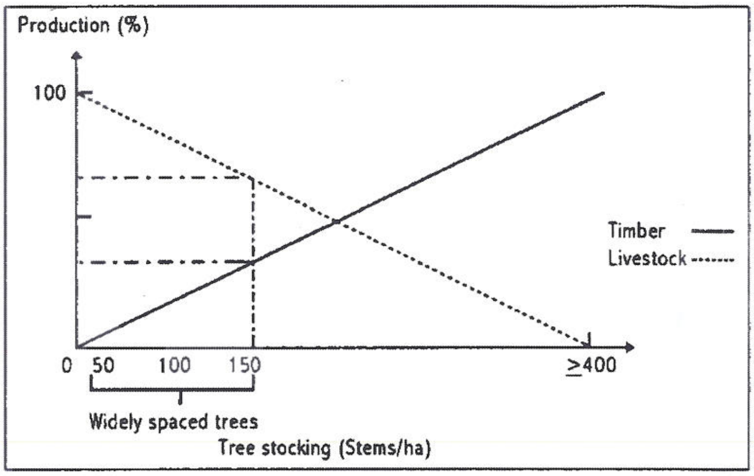
The tree species most commonly used for the stabilisation of easier sloped (<28°) North Island pastoral hill land are space-planted poplars and willows, and *Pinus radiata* forestry (Thompson & Luckman 1993). Where factors such as steep gradients, water stress, ongoing soil disturbance, and desiccating winds inhibit tree establishment and subsequent growth, alternative hardwood tree species, such as *Eucalyptus* and *Acacia* (wattles), are increasingly being planted (Van Kraayenoord & Hathaway 1986). Such inhibitory factors are common to eastern North Island regions.

The planting patterns and tree spacings used for pastoral hillside stabilisation are not usually uniform over entire paddocks. High tree stockings are used where erosion is severe or active, and spacings are progressively widened as trees extend into more stable ground (Van Kraayenoord & Hathaway 1986). The tree stockings used for soil conservation range between 25 to 150 stems/ha (Wilkinson 1995; Thompson & Luckman 1993), and though understorey pasture is present at these stockings its effectiveness for animal production has been little researched except for agroforestry trials with *Pinus radiata* (Maclaren 1988) (Figure 1).

Figure 1 schematically shows the continuum from tree–pasture systems to forestry systems, and illustrates the tree stockings that have potential for livestock grazing.

The development of whole-farm packages for the integration and management of silvipastoral systems using widely spaced hardwood soil conservation trees, that can be applied to a wide range of environments, requires a thorough understanding of how such trees utilise available farm resources and in turn affect existing pastoral systems. Information presently available is fragmented and incomplete. For this reason MAFpol contracted a review of research and practical experience, to identify the potential advantages and disadvantages that hardwood soil conservation trees may incur when incorporated into pastoral hill systems.

Figure 1 Schematic diagram showing the continuum from tree–pasture systems to forestry systems.



Approach

Because little has been published in New Zealand on spaced-planted hardwood conservation tree systems, most information obtained was from associated arable land shelter belts, *Pinus radiata* agroforestry, overseas silvipastoral studies, and from pasture and animal research which has relevance to tree–pasture systems. A large body of information exists as unpublished reports, technical bulletins and in the minds of practitioners. As part of the review, key researchers, soil conservators and farmers who have had a close association with hardwood conservation tree planting and management were consulted.

Tree effects on the hill farm microclimate

New Zealand research on microclimatic changes caused by trees is based mainly on *Pinus radiata* agroforestry and shelter belts. Changes to the radiation balance and surface wind flow are thought to be of particular importance when trees are introduced into pastoral systems, as they combine to regulate the energy balance of both understorey and overstorey. This in turn influences plant water use, temperature, and overall plant and animal productivity (Brenner 1996).

Light

New Zealand *Pinus radiata* tree stocking trials and overseas studies have demonstrated that the incidence of Photosynthetically Active Radiation (PAR) and the red-to-far-red ratio (R:FR) of light available to understorey pasture decreases under trees with larger, more dense canopies, and at higher tree stockings (Onyewotu *et al.* 1994; Eastham & Rose 1988; Anderson & Moore 1987; Ong *et al.* 1996). Lower PAR delays the rate of pasture development, but reductions in growth are partly offset by morphological changes in the plants resulting from a reduced R:FR caused by the filtering effect of tree foliage. A low R:FR ratio is an important signal used by plants to increase plant stem, internode, lamina or petiole lengths, in order to optimise PAR interception by pasture leaves (Mitchell & Woodward 1988). Indirectly the number of grass tillers and legume runners also decrease under shade (Ludlow *et al.* 1974), and so understorey pasture swards are less dense than open pastures (Percival *et al.* 1988). The soluble-carbohydrate content in ryegrass (*Lolium perenne* L.) roots and shoots decreases with lower light (Alberda 1965), reducing pasture regrowth and suppressing general plant growth and vigour (Eriksen & Whitney 1981; Wong & Wilson 1980). Thus, hard grazing (i.e., leaving low residual pasture cover) should be avoided, and the intervals between grazing should be extended in comparison to the grazing management of open pasture (Hawke & Percival 1992; Percival *et al.* 1988). However, the nature and actual extent of understorey pasture responses to shading, imposed by hardwood trees with different canopy structures and leaf display, planted at low stocking densities, and managed under different silvicultural regimes has not been measured in New Zealand.

Wind flow and wind speed

Measurements of the effects of trees on wind speed and air turbulence is limited to Pinus radiata agroforestry and shelter belt studies in New Zealand. Trees act as a barrier, influencing horizontal wind speed and air turbulence, as they absorb wind momentum and force air to flow around and over them (Brenner 1996). Open-structured shelter belts with high porosity such as widely spaced leafless poplar trees give relatively small, non-turbulent reductions in wind speed in comparison to more impermeable belts (Sturrock 1972). Turbulence is the main factor that affects the distance before normal wind velocity is regained (Gregory 1995). Standing trees in agroforestry systems have been shown to significantly reduce wind speed (Anderson 1991; Bird *et al.* 1992; Knowles 1991). Even at tree stockings of only 17 stems/ha, mature river red gums in western Victoria, Australia, reduced wind speed at 1.5 m above ground to 50–60% of that in adjacent open paddocks (Bird *et al.* 1992).

Soil water balance

Trees planted at high stockings are able to intercept large volumes of precipitation coming into a catchment and can remove large volumes of soil water by transpiration (Maclaren 1996; Fahey & Rowe 1992). In New Zealand, *Pinus radiata* within the Mangatu Forest lowered the soil water table by 2 m in comparison to areas where trees were felled and the land was revegetated in pasture (Treeby 1989). Australian investigations into the effectiveness of different planting strategies in reducing soil water, have shown that where trees were planted to cover 35% of lower slope and discharge zones, the water table was lowered by 2 m over a 9- to 10-year period. Widely spaced plantations also lowered the water table by 1.6 m over 10 years (Schofield 1991). It is evident that strategic plantings of trees can be used to lower water tables where drainage (surface or subsurface) is not feasible for technical or economic reasons, and in doing so can reduce the susceptibility of wet soils to stock treading damage. However, there is very limited information available on the effects of widely spaced hardwood trees on the soil water balance (Wallace 1996).

Tree effects on the soil resource

Trees can improve the physical and chemical properties of soils by providing organic matter from either litter and/or root decay. The effect that different tree species have on the surrounding micro-environment (soil water distribution, soil temperature and soil pH) and variation in the quantity and composition of tree organic matter also influences the biological properties of soils (Binkley 1995; Schroth 1995; Palm 1995). Canadian research has found that poplar stands have relatively high rates of nutrient cycling compared with most temperate forest species (Bernier 1984), and as well as supplying nitrogen via litter, root excretion and/or root decay, many tree species used for soil conservation (e.g., alders, acacias and robinias) are able to fix significant amounts of atmospheric nitrogen through symbiotic relationships (Maclaren 1996; Sheppard *et al.* 1984; Bulloch 1983).

Turnover of fine tree roots and associated mycorrhiza have been shown to contribute 2–4 times more nitrogen, and 6–10 times more phosphorus, than above-ground litter fall (Bowen 1984 cited by Palm 1995). A tree's ability to extend considerable distances laterally, especially at low tree stockings, means its roots influence the soil at distances far beyond the area affected by leaf fall (Schroth 1995).

Trees are highly efficient at utilising nutrients present in forest-soil or agroforestry systems. Several New Zealand investigations under *Pinus radiata* have shown low leaching losses of nitrates compared with the total nitrogen content in the system (Dyck *et al.* 1981; Knight & Will 1977).

Tree effects on pasture production

Changes to the microclimate, water balance and soil properties by trees in turn affect pasture production, but there have been very few studies on the effects of hardwood trees on the production of hill land pastures. Data that are available (Gilchrist *et al.* 1993; Miller *et al.* 1996) are based on point-in-time experiments of either single trees or trees at high stockings. The progressive impacts of widely spaced (25–150 stems/ha) hardwood trees on pasture production and quality, as the trees mature and their canopies develop, are unknown. Similarly the competitive interactions that hardwood trees have with hill pastures for available soil water and nutrients have not been measured.

Miller *et al.* 1996 observed at high tree stockings (400 stems/ha), 6- to 10-year-old willows formed a dense canopy which reduced annual pasture yields by 40% relative to that on stable open ground, but were similar to open pasture yields on unstable earthflows, and were higher than yields on recently disturbed ground. As found with other tree species such as *Pinus radiata*, under densely planted willows (400 stems/ha) the ryegrass and clover component of the pasture sward is lower than that of open pasture. Gilchrist *et al.* (1993) found that around single hardwood soil conservation trees pasture dry matter yields were similar to those of open pasture during winter, but in spring were significantly reduced closer to the trees. Through summer and autumn, reductions in pasture yields progressively became more uniform over entire paddocks.

Tree effects on animal production

New Zealand and Australian agroforestry research has shown general declines (lower ewe liveweights, lamb growth rates and wool weights) in animal productivity under *Pinus radiata* compared with that from open pasture (Anderson & Moore 1987; Bird *et al.* 1995; Percival *et al.* 1988; Knowles 1991). Animal production was lower at high tree stockings (>100 stems/ha) and under mature trees with greater crown dimensions (Table 1) (Hawke & Percival 1992). Factors attributed to the reduced animal production under *Pinus radiata* include: a reduction in annual pasture dry matter yields; a lower ryegrass and white clover component in the pasture sward; less dense pasture swards; an increased prevalence of gastro-intestinal parasites; and a greater proportion of low digestibility tree litter in the animal's diet (Anderson & Moore 1987; Percival & Hawke 1985; Percival *et al.* 1988; Bird *et al.* 1995).

Table 1 Wool production (expressed as a percentage of production achieved on open pasture) from a *Pinus radiata* agroforestry site (Bird *et al.* 1995).

Tree age (years)	60 stems/ha	200 stems/ha
9	99	94
10	93	73
11	89	68
12	87	59
13	89	42

Widely spaced hardwood soil conservation tree plantings may affect animal production differently from *Pinus radiata*. This is because trees are generally planted at low overall stockings (25 to 150 stems/ha); trees are planted close to final stocking ratios; poplar, willow, and eucalyptus trees generally have narrower, more open, canopies; the use of individually protected poplar and willow poles allows trees to be directly planted into erosion-susceptible areas of farms without having to exclude grazing livestock; and tree foliage from poplars and willows is nutritious and reasonably palatable to browsing livestock.

On land that is highly susceptible to erosion, any suppression of pastures by widely spaced trees is often counterbalanced by the utilisation of pasture on areas that otherwise would not have been available for grazing. The stabilisation of this land allows more efficient feed utilisation (Hicks 1995). Increases of approximately seven stock units/ha in annual stock carrying capacity have been recorded on spaced-planted, previously unstable ground on the East coast and the Wairarapa (Hicks 1995).

Tree effects on animal welfare

Animal welfare issues are attaining greater importance to New Zealand's primary export industries with the realisation of the potential market consequences if our standards of practice fall below those of our trading partners (Sutton 1990). Under the Animals Protection Act 1960, a code of recommendations and minimum standards has been set for all farm animals, including, freedom from discomfort and freedom from distress (Anon. 1994). In relation to these requirements, trees provide shade and shelter for grazing animals which reduces their exposure to direct ultra-violet radiation, temperature extremes, high wind speeds and driving rains (Bird *et al.* 1992; Gregory 1995). As a result trees also reduce energy required by animals to maintain a constant deep body temperature (Bird *et al.* 1992). However, under field conditions in New Zealand's temperate environment, the theoretical advantages of shelter have been difficult to prove as results have often been inconsistent (King & Sturrock 1984; Knowles 1991).

Trees can have positive effects on animal behaviour by reducing visual stimuli. This substantially reduces aggression in bulls and farmed red deer hinds (Chamove & Grimmer 1993; Whittington & Chamove 1995). Reduced stress, in a tree environment, is also attributed to increased calving percentages for sika and red deer (Crofskey 1988).

Additional benefits of trees

Certain soil conservation trees (e.g., poplars and willows) can be used as a source of fodder when there is a shortage of pasture during summer droughts (Hewson 1993; Hathaway 1986). Where carefully sited and managed, some poplar, acacia, robinia, alder, and eucalyptus species have timber values (Anon. 1995; van Kraayenoord 1987). The use of a variety of hardwood tree species also improves the amenity value of the farmers working environment and overall value of the farm (Lucas 1983).

Summary

Where hardwood soil conservation trees are adequately planted and tended they significantly reduce the magnitude of soil erosion, along with the associated detrimental impacts on pasture production and utilisation. Many of the hardwood tree species used in New Zealand for soil conservation also have positive effects on the soils of hill farms. This is owing to the addition of valuable organic matter to the soil, in some instances higher nitrogen fixation, and improved drainage of wet soils. However, even though relatively open-crowned and widely spaced hardwood trees have the potential to reduce the negative effects that *Pinus radiata* has on pasture and animals, as yet there is very limited numerical evidence to support such a hypothesis. Clearly, further research is required to demonstrate the value of silvipastoral systems utilising hardwood trees.

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7 COMPARING POPLARS AND PINES IN FARM FORESTRY SYSTEMS

A recent study in Northern Hawke's Bay funded by the Sustainable Farming Fund sought to compare livestock farming with forestry and agroforestry utilising spaced plantings of poplars. It compared profitability on a range of different land use categories and converted forestry performance to a $/livestock unit basis to allow easy comparison with pastoral farming. The environmental benefits of different systems are also compared. In particular, the benefits of trees for erosion control. An interesting feature of recent research into this area has found that spaced plants of poplar offer limited protection from slips because they fail to accumulate the minimum root biomass needed to provide protection, 30 tonnes of root biomass/ha. In contrast close plantings of pines reach this minimum by about 8 years. The results of this study (initial anyway) have been presented in the following Farm Forestry Newsletter. It comes up with some interesting conclusions, including that forestry may be more viable on easier parts of hill country farms due to lower harvest and transport costs.

Farm Forestry - the Green Solution

Newsletter

No. 1
November 2001

The New Zealand Farm Forestry Association, with support from the MAF Sustainable Farming Fund, is keen to discover if a careful application of farm forestry can at least match the medium to long term profitability of pastoral-based farming on our hill country, and at the same time meet long-term environmental values of reduced soil erosion and improved stream water quality. Three model farms, from Hawke's Bay, Wairarapa, and the South Island High Country, will be used as a basis for the study.

This newsletter presents interim results from the first of the three farms, which belongs to the Thomsen family, located at Patoka, northwest of Napier. The farm is typical of much of the summer-moist hill country stretching from Wairoa through to the western ranges of Hawke's Bay and the Wairarapa. This newsletter focuses on providing background on the role of trees in providing economic and environmental sustainability on hill country, and in developing simple methods for evaluating profitability and environmental protection of a wide range of options for radiata pine, and poplar, at the one-ha level.

The next newsletter will include an evaluation of the profitability of Douglas-fir, and results of investigations of the feasibility of some of the more promising one-ha options when applied on a larger scale. Subsequent newsletters will be produced as the study progresses over the next two years, and as more results come to hand.

Environmental impacts of trees

A large area of New Zealand's hill-country pasture is at risk from soil erosion. Nothing may happen for years or decades, and then a cyclone strikes, and the damage is catastrophic. When this occurs, it is not "bad luck"; it is predictable and can be avoided, at least in part. It is well known that mass soil erosion under trees (provided they are large and close together) is only one tenth as severe as under pasture. The effects of the erosion are not restricted to the farm where it occurs – the sediment enters rivers, and people downstream often suffer the worst effects. Some farmers on inland, hill country farms overlook this important point.

Even if soil erosion were not an issue, downstream inhabitants can bear the brunt of farming practices upstream. Some of the soluble nutrients (especially nitrogen and phosphorus) that are so beneficial to farming inevitably find their way into rivers. There they stimulate the growth of aquatic plants such as algae, which reduce the clarity of the water. When these plants die they deplete the water of oxygen, and often poison it with toxins, destroying the habitat of invertebrates and fish. Bacteria and other disease-causing pathogens from the faeces and urine of farm animals can also pollute the water for drinking and recreation.

The difference between various types of forestry (e.g., native bush versus plantations, pine trees versus hardwoods) is not nearly as pronounced as the difference between pasture and forestry. All types of forestry have similar effects on the

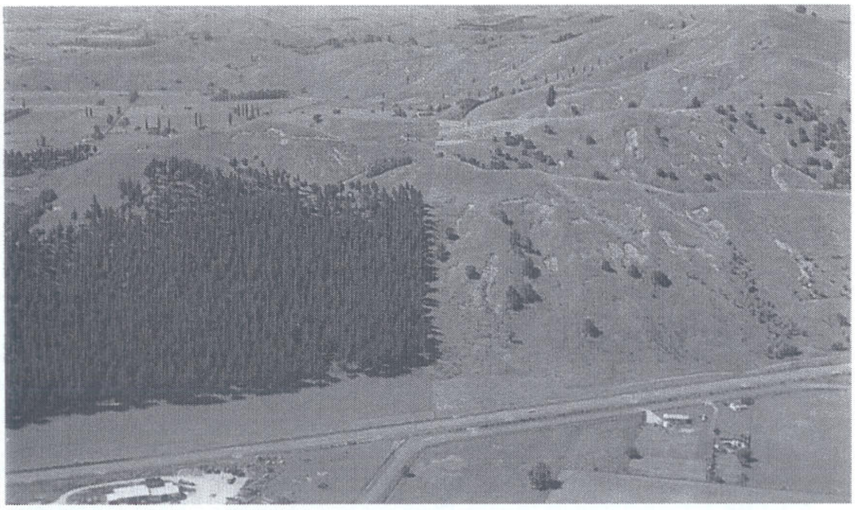

FIGURE 1: There is much evidence that a developed stand of trees offers much more protection against mass soil erosion than pasture, or even lightly scattered trees.

environment. So the important thing is to reintroduce trees – any sort of trees – onto those parts of a farm where environmental issues are critical, and where livestock production is unsustainable. An obvious example is the riparian zone; if the steep-sided slopes adjacent to waterways can be fenced off and planted in trees, this immediately reduces the impacts of farming on water quality, often with minimal effects on overall farming profitability.

In any realistic situation, environmental impacts of livestock-based grazing systems cannot be totally avoided. They can, however, be minimised. Tree-planting is a simple and easy option, and one which the New Zealand Farm Forestry Association has been advocating for many years.

FIGURE 2: Livestock can cause pugging, soil erosion and pollution of waterways. Careful tree planting, such as riparian strips, can greatly reduce these problems.

In addition to avoiding or mitigating environmental impacts of livestock-based farming systems, the objective of farm forestry is to create an interesting and pleasant farm, which is a mosaic of different land uses. Rather than "wall-to-wall" ryegrass or radiata pine, the goal is to choose the most appropriate use for every part of the property. Most farmers know that a single paddock can contain a wide variety of slopes and soils. There are parts that are highly productive for any crop, parts that will grow good trees but poor pasture, parts that will grow good pasture and poor trees, and parts that will grow neither well. The obvious first course of action is to retire the land that is not suitable for agriculture or forestry, concentrate trees on the land best suited for trees, pasture on the land best suited for pasture, and to agonise over the versatile land only when all that has been done. In many cases fences may need to be repositioned to more closely follow such land-use capability boundaries.

For this project, the Thomsens had a farm plan developed by the Hawke's Bay Regional Council, and then combined that information with their own farm business knowledge. They could then consider future scenarios for business growth, for succession planning, and for actioning environmental sustainability. It is critical that the above process is worked through to provide a framework from which to grow the farm business.

Knowledge gained during this study reinforces this decision making process.

FIGURE 3: Farm foresters like the Thomsens seek to achieve a blend of production, protection and amenity plantings.

The study farm

Like many New Zealand farms, the Thomsens' property of 1000 ha is highly variable, ranging from Land Use Capability Classes III to VIII. Because of deep gorges which have been retired from grazing, slightly less than three-quarters of the area is currently effective for pasture production. All of the farm is susceptible to various forms of erosion, but 21% (LUC classes V11e and V111e) is susceptible to severe levels of erosion, which under the current pastoral land use is unsustainable in the long term. The 761 ha of effective pasture on the pumice downlands and hill country are potentially capable of carrying 13 058 livestock units

The Thomsens' mission statement is "to increase productivity and profitability whilst maintaining financial and environmental sustainability". Among other approaches, they are seeking an intelligent tree-planting programme that achieves these multiple objectives.

This study

This study is designed to supplement the soil conservation plan completed by the Hawke's Bay Regional Council, which has made recommendations for land-use management, including production forestry and conservation plantings in selected areas. The current study focuses on the areas targeted for farm forestry and soil conservation planting, and analyses some poplar and radiata pine options, in terms of both profit and environmental goals. Subsequent reports will also examine additional tree species, and the effects of varying the scale and timing of afforestation, because if the 'at risk' areas are all planted at once there are bound to be problems of cash-flow and scarcity of other resources, such as labour.

As already mentioned, some land can easily and clearly be identified as most suitable for continued pasture or conversion to farm forestry. The problem arises at the borderline. Which land use should prevail in those areas where land will grow both good pasture and good trees? Should there be some combination, for example radiata pine agroforestry, or wide-spaced conservation plantings of poplar?

Our approach has been to first identify the type of farm forestry that is likely to be most profitable for the sites under consideration. This calculation was done with the aid of

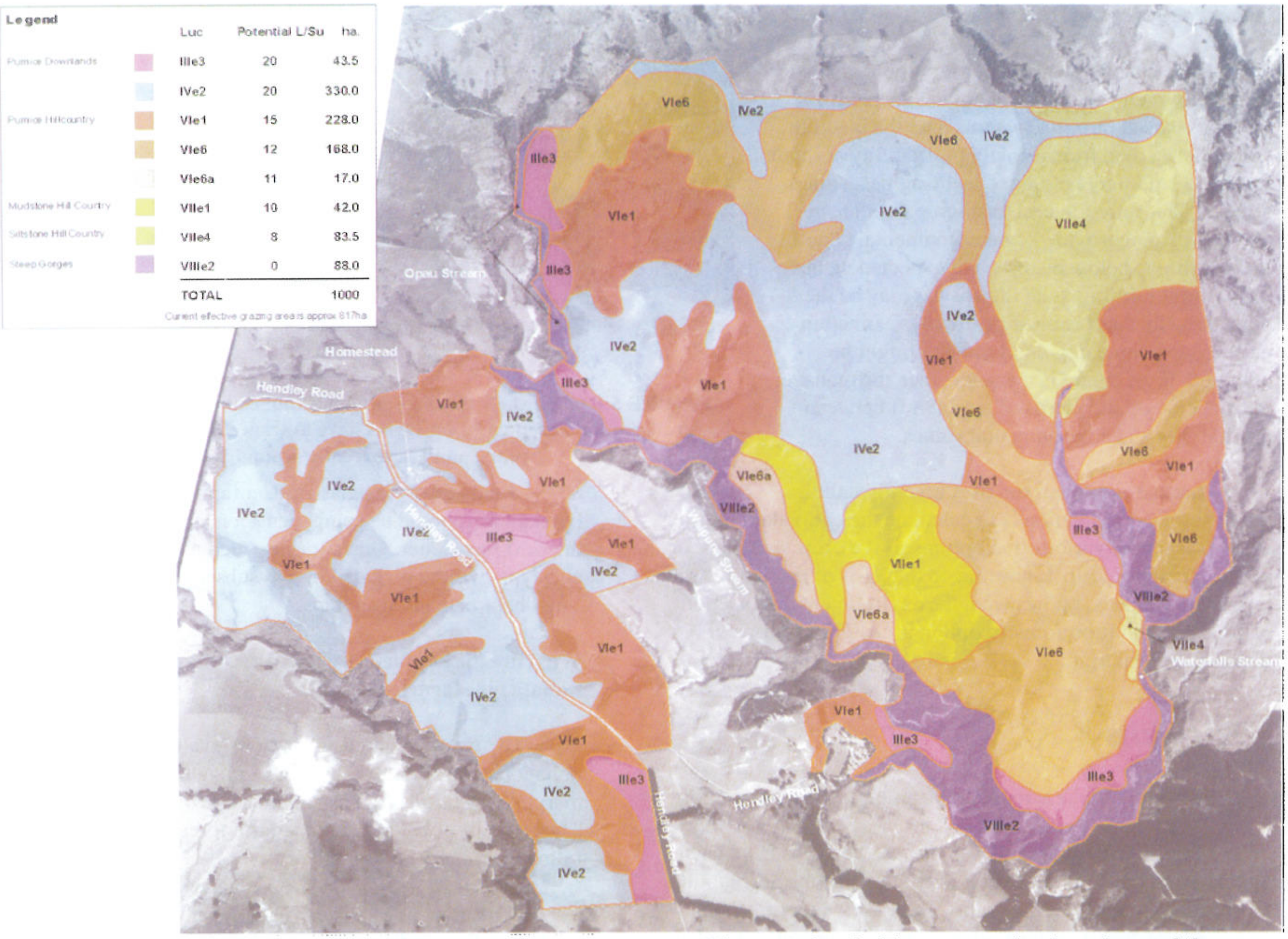

FIGURE 4: The Land Use Capability map for the Thomsen farm. This map helps the Thomsens to clearly understand the strengths and limitations of parts of their farm, indicated by the land use capability units, their potential livestock carrying capacity, and associated area.

specialised farm-forestry planning models, and a knowledge of prevailing costs and prices.

To evaluate the main environmental benefits, we have calculated root biomass. This is because root biomass is an indicator of the level of soil erosion control. After long periods of very heavy rainfall, soil is saturated and soil structure is compromised. In these major storm events that are responsible for the bulk of erosion damage, particularly on the North Island East Coast, the ability of trees to intercept rainfall and transpire groundwater becomes somewhat irrelevant. The quantity and strength of tree roots becomes all-important. We have discovered that tree species with weaker roots compensate by having more root biomass, and vice versa.

Having identified the most profitable type of farm forestry, and its contribution to erosion control, we then expressed this profitability in terms most farmers are familiar with. We have calculated this as " the gross margin per livestock unit that can produce the same return on capital as trees grown on that site". Gross margin is defined as the revenue per livestock unit, minus the variable costs. Examples of variable costs are shearing, fertiliser, animal health, freight, and feed. On-farm labour costs were treated as fixed, so were not subtracted. Return on capital is defined as the internal rate of return (IRR).

If the calculated gross margin figure is greater than that which can be reasonably expected from livestock-based farming systems over the medium to long term, then from a solely profitability point of view, the land may be judged as being best suited to trees. Trees are the best cash-crop for the site, and as well can provide key environmental benefits. If the figure is below historic and expected values for pastoral farming, then the answer may be the opposite – the land is most profitably retained in pasture, and some degree of erosion might be tolerated. If the figure is marginal, then the manager must decide on the merits of a trade-off between profitability and environmental values.

Another approach for sites urgently calling out for erosion protection is to calculate the equivalent farming gross margin for various tree options. If the estimate falls short of the existing livestock farming on the basis of profitability, the farmer now at least knows what the environmental protection offered by each farm forestry option is costing, in terms of farming gross margin.

The results

Which species of tree is most profitable?

Only radiata pine- and poplar-based options have been evaluated so far. This study certainly confirms the profitability of our main species, radiata pine. This result supports the thousands of forest owners who have independently decided to choose this species, so that it now accounts for 90% of the nation's timber resource. This is no accident.

Poplar has been shown in this report to be a poor species choice if profitability based on wood production is a criterion. The relatively high costs per tree of establishment, the low tree stockings usually employed, and low log values (even when pruned) result in this species being non-competitive when compared to current livestock-based systems, or other tree species. It must be remembered, however, that wood production is not usually the main reason why poplars are grown. The analysis described above can be used for evaluating poplar options in terms of farming gross margin just as it is for radiata pine.

Based on the many evaluations made to determine profitability, the average farming gross margin required for livestock systems to break even with poplar is only $28.18/lsu (livestock unit), and the average rate of return on capital (IRR) is just 2.7%. This compares with an average gross margin for sheep and cattle-based farming systems on Hawke's Bay summer moist hill country such as Patoka of $40.35/lsu , over the past four years, and current returns (2001-2002) of around $60/lsu. The traditional role of focused planting of poplar in maintaining profitability of livestock-based farming systems on landscapes that have erosion potential may very well be justified – but their advocacy for widespread planting for profitable timber production is not supported by this study.

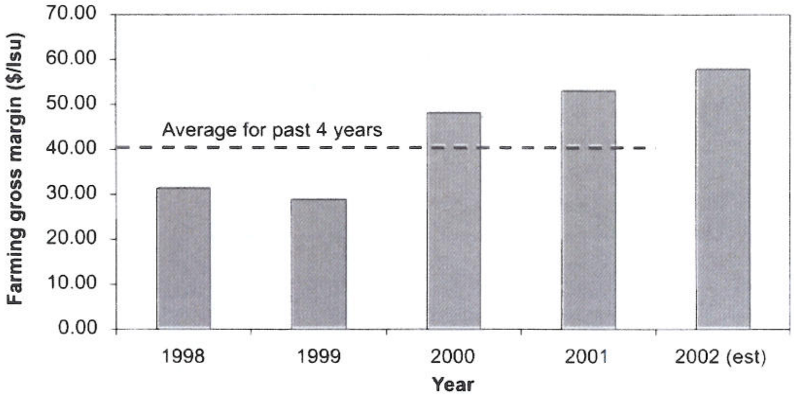

FIGURE 5: On Hawke's Bay summer moist hill country, gross margins per livestock unit on sheep and beef farms have averaged $40.35 over the last four years, and are currently around $60.

Analysis of Douglas-fir as a farm forestry option on the Patoka farm should be completed soon, and will be reported in the next newsletter. Other species such as the cypresses and eucalypts will be included in two subsequent studies, involving a model farm in the Wairarapa.

What are the key factors which affect the profitability of radiata pine farm forestry?

The many hundreds of options evaluated showed that radiata pine produced an average equivalent farming gross margin of $41.50/lsu, and an internal rate of return (IRR) of 7.5%. The profitability of radiata pine farm forestry depends on the following, in order of importance:

1. *Livestock carrying capacity.* At carrying capacities above 11-12 lsu/ha, livestock can usually out-compete trees. Depending on the contour, and therefore the logging cost, trees can often be shown to be more profitable than livestock at carrying capacities under 11 lsu/ha. This

doesn't mean that trees should not be planted on erosion-prone land carrying more than 11-12 lsu/ha – it simply means that the environmental benefits may have to used to justify any financial shortfall. Livestock carrying capacities of 4 lsu/ha to 14 lsu/ha were evaluated.

2. *Tree productivity*. Farm sites typically grow more wood per hectare than conventional forest sites, provided that the stands are not grown at less than 200 stems/ha. At Patoka, a pruned final crop of 300 stems/ha on a rotation of 30 years is expected to produce a mean annual increment (MAI) of 28.2 m^3/ha. This compares to an average MAI of around 30 m^3/ha for pruned stands on farm sites throughout New Zealand, at that stocking. A typical forest site would be expected to produce an MAI of around 24 m^3/ha at 300 stems/ha. We have analysed the effects of varying the range of such '300 index' values between 20 and 36, which is the range exhibited by over 560 sample plots in the national permanent sample plot data base. Actual rotation ages of 28 years only were evaluated.
3. *Harvesting system (skidder or hauler), and trucking distance.* Skidder logging is cheaper, but can be employed only on the easier country. Combined logging and trucking costs can easily vary by up to ± $10/ m^3, or around ± $8000/ha, depending on the harvesting system, and trucking distance. We analysed combined logging and trucking costs of $30/$m^3$ to $50/$m^3$.
4. *Land and livestock capital values*. As land and livestock capital values increase, farm forestry becomes more competitive. To many readers this may seem a surprising and counter-intuitive result. We suspect it arises because these items represent a smaller proportion of the total cash flows in a farm forestry enterprise, relative to their proportion in a solely farming enterprise. Land values between $200 to $400/lsu, ($800-$5600/ha) and livestock capital values between $0 and $100/lsu were evaluated.
5. *Understorey grazing*. Although such grazing is of poorer quality and inferior to that grown in open conditions, it is important because it brings in revenue early in the rotation of a tree crop. This money could be earning interest or paying off debt. In many of the options evaluated, it is almost as important as the cost of labour. The benefits of understorey grazing accrue more to the lower tree stockings (200-250 stems /ha) than to the higher stockings of 350-400 stems/ha, offsetting somewhat the lower overall wood yields of the former.
6. *Source of labour.* If on-farm labour is available, considerable savings can be made. Otherwise, contract labour at full market rates was assumed.
7. *Minor influences*. Two factors, final crop stocking (within the range of 200-400 stems/ha, in all cases pruned to 6.3m), and conversion of total yield to merchantable yield (from 82% to 88%), have only a small influence on profitability.

What this means is that there are many situations on a hill country farm where radiata pine can carry the cost of establishment and management, or at least come close to it, and can offer environmental protection as well. Most poplar options fall well short if the same objective criteria are used.

An example evaluation

To illustrate the sensitivity of the results to variations in the input values, a 'standard' regime for radiata pine was run, with a few key variations. Two basic scenarios were compared, easy and steep contour.

On easy contour, logging costs based on a skidder operation were set at $32.50/$m^3$. Land value was set at $400/lsu, and livestock carrying capacities of the land from 4 lsu/ha to 14 lsu/ha were analysed. Livestock capital values of $70/lsu were used. A '300 index' of 28.2 m^3 reflected the local sample plot data. A conversion of total yield to merchantable yield of 82% was assumed. A final crop stocking of 250 stems/ha was used, together with 'standard' log prices. Butt log prices were related to the pruned log index for a 28 year rotation, and unpruned logs were priced according to the most recently published MAF 12 quarter domestic log sales price list. The results were compared for with and without understorey grazing, and contract labour was compared to using (free) on-farm labour.

On the steep contour land, a logging cost of $39/$m^3$, and a land value of $200/lsu were used. All other assumptions were kept the same as those used on the easy contour land.

- **On hauler country (steep contour) and using a farming gross margin of $40-45/lsu as a benchmark, farm forestry would be more profitable than pastoral farming on land that supports less than 8 livestock units per hectare. With understorey grazing, and using farm labour, farm forestry gives similar returns to agriculture at less than 10 lsu/ha. If the benchmark farming gross margin is raised to $50/lsu, then based solely on profitability farm forestry could only be justified on land carrying less than 6 lsu/ha.**
- **On skidder country (easy contour),and using a farming gross margin of $40-45/lsu as a benchmark, even land which carries 12 lsu/ha may be better off in trees. If understorey grazing and using farm labour is a possibility, then land may need to carry more than 14 lsu/ha to justify retention in pastoral farming. If the farming gross margin benchmark is raised to $50/lsu, based solely on profitability, such farm forestry may only be justified on land carrying 10 lsu/ha, or less.**

These results are shown in Table 1.

TABLE 1: Gross Margins ($/lsu) necessary to equal profitability of radiata pine farm forestry (250 stems/ha, pruned to 6.3 m)

Livestock Carrying capacity (LSU/ha)	Easy (skidder) contour		Steep (hauler) contour	
	Without understorey grazing	With understorey grazing	Without understorey grazing	With understorey grazing
4	71 (76)	74 (80)	61 (66)	63 (69)
6	57 (61)	60 (65)	47 (51)	48 (54)
8	49 (53)	52 (57)	39 (43)	41 (46)
10	45 (48)	48 (52)	34 (38)	36 (40)
12	42 (45)	45 (49)	30 (34)	32 (37)
14	39 (42)	42 (46)	28 (31)	29 (33)

The first figure assumes contract labour for all farm forestry operations. Figures in brackets show results using on-farm labour.

A comparison of these results with the recommendations of the soil conservation plan for the Patoka farm is given in Table 2.

TABLE 2: Comparison of soil conservation plan recommendations, and this study

Land Use Capability Unit	Area (ha)	Potential Livestock Carrying Capacity	Site Index (forestry)	Recommended Land Use	
				Soil Conservation Plan	This study
IIIe3	43.5	20	28-33	Pasture	Pasture
IVe2	330	20	28-33	Pasture	Pasture
VI e1	228	13-15	30-33	Spaced poplars	Pasture or pines
VI e6, VI e6a	185	10-12	30-33	Spaced poplars	Mostly pines
VIIe1	42	10	27-31	Spaced poplars or pines	Pines
VIIe4	83.5	8	27-31	Pines	Pines
VIIIe2	88	Nil	Nil	Retirement	Retirement
TOTAL	1000				

It can be seen that most recommendations of the soil conservation plan are supported by this study. Some areas are undeniably better off in pasture, others in pines. Some are not worth attempting to manage in either land use. The contrast between the two studies occurs in the marginal situations, where there is productive pasture but there is also a risk of erosion. One solution followed by the soil conservation plan is to plant these areas in widely spaced poplars, which confer some soil stability while retaining some grazing in, under and around the trees. Another, arising from this study, is to fence off erosion-prone areas at the lower end of the range of carrying capacity, and to progressively plant them out in a series of productive and profitable radiata pine woodlots.

As previously mentioned, trees provide most of their benefit through the ability of roots to bind the soil. Poplar roots have 2.2 times the tensile strength of radiata pine, and Douglas-fir roots have 1.5 times the tensile strength of radiata pine. But poplar trees do not have a great root mass for the same sized tree when compared with pines and Douglas-fir. One discovery was that the "soil holding ability" of individual trees, which is root mass times tensile strength, is remarkably constant between these species, provided the trees are of equal size.

Another important point is the number of trees per hectare. The more trees, the more mass of roots, the greater the potential for erosion prevention. Poplar is traditionally planted and managed at very low stockings compared with radiata pine, and pine is planted at lower stocking than Douglas-fir. Unfortunately, the latter is relatively slow growing, so the site is not fully occupied by roots for a longer period after initial establishment. However, the slower decay of Douglas-fir root systems following harvest becomes an eventual asset.

There is evidence that rather conservatively managed stands of radiata pine on farm sites become effective in preventing about 90% of mass soil erosion once they have reached about 8 years of age. We estimate that this coincides with the production of around 30 tonnes of root biomass per ha. What this may mean is that many radiata pine and Douglas-fir options are running 'surplus to requirements' as far as environmental protection is concerned. In a serious storm such as Bola, this may not be a bad thing.

After compensating for the different root tensile strengths, and root decay rates following harvest, we have calculated the ability of a typical regime of radiata pine, Douglas-fir, and two final crop stockings of poplar, to hold the soil. Over a rotation, and following the initial establishment phase, Douglas-fir meets this critical level of '30 tonnes of radiata pine equivalent root biomass' for 91% of the time; radiata pine exceeds it for 66%; Poplar at 100 stems /ha exceeds it for only 23% of the time. Poplar at 50 stems/ha never reaches this threshold. Once established in perpetuity, because of its slow rate of root decay Douglas fir never falls below 26 tonnes/ha. Similar minimum values are 10 tonnes/ha for pine, and 0.5 tonnes/ha or less for the poplar options (see Figure 6)

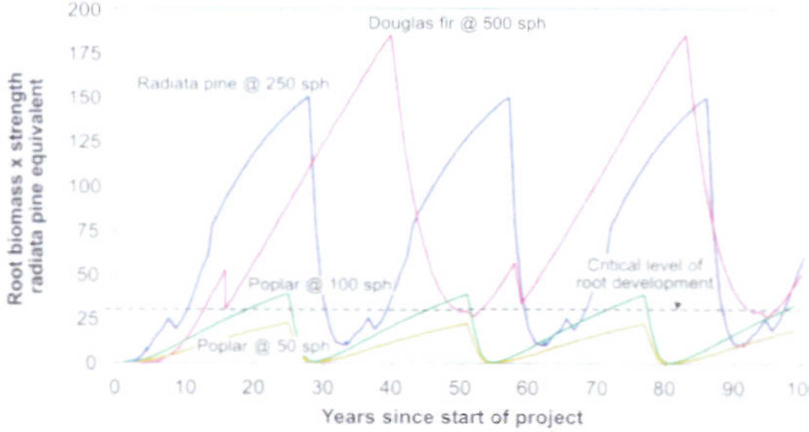

FIGURE 6: The ability to hold soil, and thereby prevent erosion, rests on a combination of root-mass, root tensile strength, root decay rates following harvest, tree stocking, and relative growth rate. We need to take all these factors into account to compare the soil holding ability of different tree species over long time frames.

So widely spaced poplars are better than nothing, but in many applications may be a long way from being ideal as far as serious erosion prevention is concerned. Their use is most probably justified for local erosion prevention, on a micro-site rather than as a broad hectare application, and when planted at an effective stocking on the 'at risk' areas approaching 100 stems/ha, rather than at 20 or 50 stems/ha.

The obvious disadvantage of the pines is the reduction in livestock carrying capacity, even allowing some understorey grazing. Land is temporarily removed from full production, and this affects cash-flow. An 'estate-level' analysis can determine if there are likely to be bottlenecks of cash-flow, labour or other resources. There are a number of ways of dealing with such constraints, such as varying the proportion of the farm being planted, and the rate at which planting takes place. These are aspects of 'feasibility' rather than profitability, and will be examined in detail in a following newsletter.

Getting started

The key is to plant the *first* 5-10 hectares of trees on a *good* site! A "good" site means that growing and harvesting costs are low, and growth rate is good. Most farms can spare this quantity of land, even if it is fairly productive in terms of pasture, but the revenue that is generated (typically $30 000-$40 000 a hectare for radiata pine) is usually sufficient to create a comfort margin to absorb subsequent costs. A farmer new to farm forestry should also learn about what is involved in growing a high value, profitable tree crop on a modest scale on a handy site, rather than embarking on a large scale afforestation programme in a difficult gully at the back of the farm.

Evaluating your own situation

One objective of this study was to build an easy-to-use tool, so farmers and their advisors can work out for themselves the profitability of farm forestry in terms of Internal Rate of Return and the equivalent Farming Gross Margin per livestock unit produced by the tree crop. It is intended to make this available on the NZ Farm Forestry Association web site. The model will allow the user to estimate the effects of varying the:

- Livestock carrying capacity of the land
- Land value
- Logging cost (logging, roading, loading, cartage)
- Capital value of livestock
- Index for wood production
- % of wood which is merchantable
- Number of trees per hectare at harvest
- Relative log price
- Understorey grazing (with or without)
- Labour (own or contract)

The poplar model followed the same template, except it assumed all options would have understorey grazing. This model also differed in that pruning/no pruning is given as an option. Wood yields for poplar, and understorey relationships, were based on nationwide 'MARVL' inventories and measurements of canopy closure by *Forest Research* in a wide range of mature and semi-mature stands, some of which were coincidentally in proximity to the Patoka farm.

For radiata pine, the yield of timber was derived with the '300 Index' calculator. This is a recent development of the Forest and Farm Plantation Management Research Cooperative, and is based on analysis of data from a large number of long-term replicated trials throughout New Zealand, on both farm and forest sites. It can be calibrated using local data from sample plots on a particular farm, or in the neighbourhood. At Patoka data were available from 16 sample plots in semi-mature farm stands within a 10km radius, from which measurements had been made over many years, and which matched the management system preferred by the Thomsens (pruned sawlogs, thinned early to final crop). Calculating the final yield at the equivalent of 300 stems, and subsequently at stockings from 200 stems/ha to 400 stems/ha, for clearfelling at age 28 years, was a simple matter using the '300 index calculator'. The model STANDPAK was used to estimate the 'pruned log index', to allocate the harvestable volume into MAF standard domestic log-grades, and to estimate the level of understorey grazing.

The Agroforestry Estate model (AEM) was then used to take account of all the costs and revenues involved, to estimate the equivalent farming gross margin produced by the farm forestry option, at the point where the IRR for the farm forestry option and livestock farming were the same. But the user does not need to know the nuts-and-bolts of the models! We have done many hundred computer runs and have boiled down the results into a quick-and-easy spreadsheet-based calculator, which effectively produces results for hundreds, or even thousands of unique combinations of the above factors, with acceptable precision (see Figure 7).

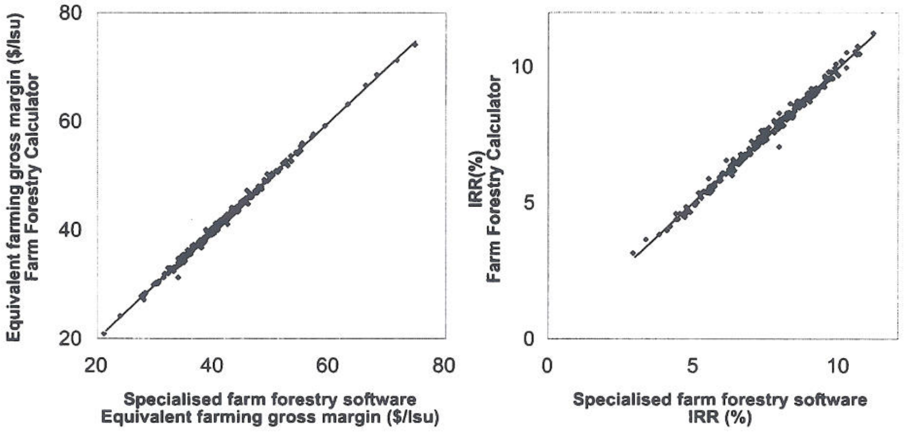

FIGURE 7: A comparison of the results for radiata pine in terms of a) Farming Gross Margin, and b) IRR obtained by the use of the specialist farm forestry modelling systems, and the resultant spreadsheet-based farm forestry profitability calculator.

Although the mechanisms are based on a large database, complex mathematics, and a close understanding of farm forestry, we believe we have provided what a typical user wants – a simple, easy-to-use and reliable method for evaluating the profitability and environmental protection attributes of a wide range of farm forestry options.

Conclusions

Research, under the Sustainable Farming Fund, has shown that on summer moist Hawke's Bay Class VIe and VIIe land, radiata pine-based farm forestry can provide financial and environmental sustainability. If the land can support no more than 8-12 lsu/ha, then radiata pine-based farm forestry may match or even exceed current pastoral systems for profitability. Poplar has been shown to fall short of this in terms of profitability, so would need to be justified in terms of soil conservation and other benefits, and planted at the required densities.

Cash-flow bottlenecks can be managed by planning the scale and timing of the farm forestry project. These issues will be explored in a following newsletter.

As part of this project, easy-to-use models of profitability (equivalent farming gross margin produced by the tree crop) and internal rate of return were constructed for poplar and radiata pine at the one-hectare scale. These will be placed on the NZ Farm Forestry Association website, so users can adjust inputs to quickly evaluate their own particular situation.

Further studies in this series will assess farm forestry options on a 'summer-dry' farm in the Wairarapa, and on high country in the South Island. A wider range of tree species will be included in the evaluations, and issues of feasibility as well as profitability will be addressed.

Acknowledgements

This newsletter reports work to date on the MAF Sustainable Farming Fund grant "Farm Forestry for Economic and Environmental Sustainability" FRST contracts CO4X0004 and CO4X0010 contributed to the research on tree growth and yield.

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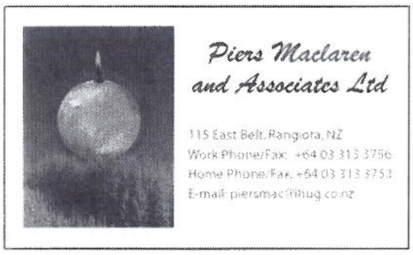

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REFERENCES/FURTHER READING

Most of the detailed information shown in Tables and Figures in this UNIT come from unpublished material in the Proceedings of the Agroforestry Research Collaborative, and is therefore difficult for readers to access.

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Refer also to articles in the New Zealand Tree Grower.