Balancing pastoral and plantation forestry options in New Zealand and the role of agroforestry

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Abstract. Pastoral agriculture and forestry enterprises are key features of New Zealand's landscape and are very important economically. They are competing landuses, particularly on moderate to steep hill country. Agroforestry involving spaced trees of *Pinus radiata* on pasture was developed in the 1970s to provide dual incomes from livestock enterprises and the later tree crop. In contrast, wide-spaced trees of predominantly *Populus* and *Salix* spp. are planted mainly for erosion control. Characteristics of pastoralism and plantation forestry are reviewed, including trends in conversions between these landuses. Roles, challenges and opportunities with wide-spaced trees are presented, together with current and future research initiatives. Pastoralism and forestry will continue to compete strongly for hill country sites and at present there is an increasing trend of converting previously forested areas to pasture, particularly in the central North Island. Agroforestry involving *Pinus radiata* has virtually ceased because of adverse effects on wood quality, pasture production and animal performance. There are millions of wide-spaced trees of *Populus* and *Salix* spp. on hill country and their planting is expected to continue unabated because they are the most practical and efficient means of enabling pastoralism on erodible slopes and they provide multiple ecosystem services. The species have significant advantages compared to other woody species but many older trees have grown very large because they have received negligible or no silviculture. This is an increasing problem, requiring development and implementation of appropriate management strategies. There is growing interest by landowners in the environmental outcomes of spaced-tree plantings.

Keywords: Soil conservation, Salicaceae, tree-pasture systems, silvopastoralism

Introduction

New Zealand is a hilly and mountainous country with a total land area of 26.8M ha. Over 20% of its land surface exceeds 1,000 m elevation and at least 40% comprises steep, non-arable hill country below 1,000 m elevation (Blaschke *et al.* 1992). At least 1,000 years ago, all of the North Island and most of the South Island were forested (Cameron 1962; White 1999). With habitation by Maori people within the last 800 years, and in particular European settlers within the last 200 years, large tracts of indigenous mixed broadleaved, podocarp and coniferous forests have been cleared for the growing of food crops, energy supply, building materials, and the establishment of a range of pastoral grazing enterprises. Commercial plantation forestry involving exotic tree species commenced in the late 1800s/early 1900s, often in areas that were considered uneconomic or unsuitable for agriculture. Today, low to highly productive grassland covers about 11.0M ha (41%) of the country's land area (Beef + Lamb New Zealand 2012) and plantation forestry comprises 1.75M ha (7%) (Hedley *et al.* 2009, Anon 2012). Both sectors contribute significantly to New Zealand's gross domestic product (Ministry of Agriculture and Forestry 2011).

Plantation forests are distributed widely throughout New Zealand but most of the area (70.3%) occurs in the North Island, almost half of which is in the central regions (New Zealand Forest Owners Association 2011). Most of the forests are grown on moderate to steep hill country (Nagashima *et al.* 2001; Quinn *et al.* 2007; Raymond 2012) with slope angles often exceeding 20^{o}. These areas are unsuitable for arable use and achievement of long-term sustainable productivity can be compromised because of factors such as moderate to severe mass movement erosion, shallow soils with increasing steepness, low soil organic matter status and poor water holding capacity, soil nutrient deficiencies and scrub weed reversion (Gillingham *et al.* 1998; Matthews *et al.* 1999; Dodd *et al.* 2008; De Rose 2012).

The New Zealand landscape has been classified on the basis of its land use capability (LUC) into classes 1 to 8 according to its capacity for long-term sustained production (NWASCO 1979, Lynn *et al.* 2009). As class number increases, there are increasing limitations to use of the land and a corresponding decrease in its versatility of use. Limitations may include unfavourable climate, erosion risk, shallow soils, low soil water holding capacity, stoniness, and excessive wetness. About 7.5M ha (28%) of New Zealand has been mapped as LUC Class 6, most of which is stable productive hill country with moderate erosion potential. LUC Class 7 comprises 5.7M ha (21%) of the country and has limitations similar to those for Class 6 land, but they are more severe. LUC Class 6 land is suitable for both pastoralism and forestry whereas Class 7 land is more suitable for forestry in many instances (Lynn *et al.* 2009). However with the implementation of significant soil conservation measures, Class 7 land can be suitable for pastoralism. Most plantation forestry occurs on LUC Classes 6 and 7, rather than the more versatile Classes 1-5. LUC Class 8 land is unsuitable for pastoralism or forestry enterprises because of very severe to extreme limitations, often extreme actual or potential erosion (Lynn *et al.* 2009), and is used mainly for conservation of flora and fauna, erosion control and water management.

Pastoral enterprises and plantation forestry have been competing landuses on moderate to steep hill country (LUC Classes 6 and 7) for many decades. The temporal and spatial mosaic of these landuses on these landscapes has been governed by numerous factors including capital outlay and economic returns over various timeframes, environmental effects, political and regulatory initiatives, and social and cultural considerations (Ross *et al.* 2002, Hawke 2004, Douglas *et al.* 2006a, Elliott and Hawke 2007, Lee 2007, Hedley *et al.* 2009). Competition between these landuses occurs mostly at the individual farm level but can occur at other scales (*e.g.* district) and have quite far-reaching effects such as on water quality at the catchment scale, and the well-being of local communities. The development of agroforestry in the 1970s aimed for both livestock production from pastures, and timber production from wide-spaced trees, usually *Pinus radiata*, on the same land unit (Hawke 1991, Knowles 1991, Hawke and Wedderburn 1994). The term agroforestry may include additional systems such as forests/woodlots and shelterbelts, but is confined here to wide-spaced tree plantings. Other tree-pasture systems, usually based on *Populus* or *Salix* spp., are established on large tracts of erodible hill country to enable the continuation of pastoralism (Wilkinson 1999; Benavides *et al.* 2009). However in these systems, tree spacing is often highly variable and targeted to areas deemed of greatest erosion risk. Furthermore, the trees are planted mainly for soil conservation rather than timber production, and consequently they have usually received negligible or no silviculture (Cameron 2003).

The objectives of this paper are to outline key features of pastoralism and forestry in New Zealand hill country, trends in conversions between these landuses, background to agroforestry and the extent of its current use, and the role of wide-spaced trees. Finally, we describe current and planned research initiatives with tree-pasture systems.

Pastoralism

Developed livestock grazing systems in New Zealand hill country are based on year-round grazing of predominantly temperate, introduced grasses, legumes and herbs (Kemp *et al.* 1999, Charlton and Stewart 2006). *Lolium perenne* and *Trifolium repens* are components of nearly all seed mixtures but a range of other species may be included (Scott *et al.* 1985; Kemp *et al.* 1999). Hill country pastures are farmed in development states ranging from low (unimproved) to high depending on aspects including fertiliser strategies, extent of species introduction and general oversowing practices, stocking rate and pasture utilisation, and effectiveness of weed and animal pest control programmes. Annual utilisable pasture production in North and South Island hill country is mostly in the range 5-10 t dry matter (DM)/ha, although 20-25 t DM/ha/yr can be achieved on livestock camps in moist areas (Chapman and Macfarlane 1985).

Livestock on hill country farms are predominantly sheep and beef cattle, with farms in the South Island carrying a greater ratio of sheep:cattle compared with North Island farms (Matthews *et al.* 1999). Deer are also farmed in some hill country enterprises for venison and antlers/velvet. Environmental challenges and consequences of pastoral farming of hill country include: loss of nutrients originating from grazing animals and fertiliser applications through overland flow and leaching; contamination of water bodies with sediment and nutrients; contributions to greenhouse gas (GHG) emissions; changes to soil invertebrate populations; and potential damage to soil structure and other soil physical characteristics (Betteridge *et al.* 1999, Russell *et al.* 2001, Schon *et al.* 2011, Mackay *et al.* 2012b). There can also be total loss of soil profile following extreme erosion events. Pastoral hill country is up to 20-times more susceptible to mass movement erosion than similar areas with woody vegetation (Hicks 1991, Marden and Rowan 1993, Dymond *et al.* 2006), depending mainly on lithology, slope, and rainfall.

Plantation forestry

The predominant tree species grown in New Zealand is *Pinus radiata*, comprising approximately 90% of the area of the national estate (New Zealand Forest Owners Association 2011). The species is hardy, fast-growing, adapted to a variety of environmental conditions, productivity often exceeds 25 m^3/ha/yr in many parts of the country and trees are ready to harvest in 25-30 years (Kimberley *et al.* 2005; Kirschbaum *et al.* 2012; Woollons and Manley 2012). Other species grown include *Pseudotsuga menziesii*, *Cupressus macrocarpa*, *Acacia melanoxylon* and *Eucalyptus* spp.

In addition to their production of wood for a range of products and purposes, hill slopes with established forests have lower susceptibility to erosion than with any other ground cover, and this appears largely independent of species (Phillips *et al.* 1990; Brown 1991; Cairns *et al.* 2001; Dymond *et al.* 2006). The presence of forests enhances other ecosystem services such as flood mitigation, carbon storage in wood and soil, filtering of nutrients, and even cultural services such as recreation. Erosion management in tree plantations is critical at establishment and harvesting, where vegetation removal and mechanical earthworks temporarily increase soil movement and the risk of significant soil loss (Marden *et al.* 2005, 2006). Extensive guidelines (Vaughan 1984; Spiers 1987) and a code of practice (New Zealand Forest Owners Association 2007) have been developed to guide operational planning and maintain soil and water values through mitigation of erosion and sedimentation.

The role of exotic forests in sequestering carbon to reduce atmospheric GHG concentrations has received increasing attention, both in terms of environmental management and revenue generation (Hollinger *et al.* 1993; Robertson *et al.* 2004; Adams and Turner 2012). In a recent study of *Pinus radiata* at 140 sites, it was concluded that mainly untended trees could be grown on a rotation length of 60+ years to enable a longer period of carbon sequestration than from contemporary rotation lengths (Woollons and Manley 2012). Such an approach requires appraisal in the context of factors including carbon market price, tree stand area, and projected returns as trees age.

Conversions between pastoralism and forestry

During the 1990s, 20,000-90,000 ha of pastoral land was converted to plantation forestry annually, and concomitant research determined the impacts of this land use change, predominantly with respect to soil chemistry (Alfredsson *et al.* 1998; Ross *et al.* 1999; Parfitt and Ross 2011), but also other soil attributes including soil bacteria, bulk density and hydrophobicity (Singh *et al.* 2007; Paripovic 2011). Since the mid-1990s, there was a significant reduction in new plantings mainly because of reduced numbers of new conversions from pasture, with the lowest area of 1,900 ha planted in 2008 (Ministry for Primary Industries 2012). In the mid-2000s, there was also an increase in the practice of not replanting forests after harvest and in a few cases, forests were converted to pasture before they reached maturity (Ministry for the Environment 2007). Recently, the area of new plantings has increased, partly because of grants for afforestation as part of the government's Emissions Trading Scheme (http://www.climatechange.govt.nz/emissions-trading-scheme/about/basics-.html), with an estimated 12,000 ha of new plantings in 2011 and a provisional estimate of 18,500 ha in 2012 (Ministry for Primary Industries 2012).

In the last decade, deforestation of exotic forests and conversion to pastoralism has been an increasing trend, mainly in the central North Island for dairy production (Hawke 2004; Elliott and Hawke 2007; Hedley *et al.* 2009; Paripovic 2011). A perennial pasture was established successfully on an ex-forest site with addition of lime (4 t/ha) and phosphorus (40 kg/ha) to provide an appropriate pH and Olsen P status for grass and legume growth (Hawke 2004). In the region, Brodnax (2007) estimated that the total conversion may be as high as 60,000 ha, and will have a number of environmental consequences for local and regional water systems, principally because of the significant dung and urine excretions from the introduced livestock. Hydrology of the catchment will also be modified because of increased runoff (lack of flood mitigation service).

Agroforestry

Agroforestry systems in New Zealand have been evaluated since the 1970s with respect to the tree component, pasture understorey, soils, animal performance, and their interactions, continuing through the 1990s (Hawke 1991; Knowles 1991; Hawke *et al.* 1993; Hawke and Wedderburn 1994; Hawke 1997; Knowles *et al.* 1999; Maclaren and Knowles 1999a; Perrott *et al.* 1999) and into this century (Amatya *et al.* 2002; Peri *et al.* 2002; Chang and Mead 2003; Benavides *et al.* 2009). The Tikitere project in the central North Island was a major source of knowledge on the impacts of tree density (tree stocking rate) (50, 100, 200 and 400 stems per hectare (sph)) on the system components. For example, trees at lower densities had considerably larger diameter growth, greater stem and branch size, and were shorter than those at higher densities (Hawke 2011). When the trees were harvested at 25 years, total volume ranged from 213 m^3/ha at 50 sph to 935 m^3/ha at 400 sph. Canopy closure occurred earlier at high than low tree densities with high densities causing the greatest reduction in pasture understorey production and change in botanical composition. Hawke (2011) reported that increasing tree density and age resulted in reduced animal performance. Despite much experience with agroforestry in New Zealand, there has been negligible recent reporting of economic aspects (Maclaren and Knowles 1999b, Hawke 2011).

Current interest in agroforestry has waned considerably and we are unaware of any new blocks being established on farms. A recent harvest of *Pinus radiata* at 155 sph concluded that there was a lack of volume of logs from such a system compared with trees grown in plantation at 320 sph and that "you cannot, it seems, have it both ways" (Jones and Cullen 2008). This was reinforced by the findings from the Tikitere project where it was concluded that agroforestry adversely affected wood quality, pasture production and animal performance (Hawke 2011). There does not appear to be a future for agroforestry involving *Pinus radiata* but there may be opportunities with high-value timber species such as some belonging to the genera *Cupressus*, *Eucalyptus*, *Quercus* and *Sequoia*, and species that are deciduous, with less impact on pasture understorey growth.

Wide-spaced trees to support pastoralism on hill country

There are millions of wide-spaced plantings of *Populus* and *Salix* spp. on erodible pastoral hill country, particularly where erosion arises from surplus soil water (Thompson and Luckman 1993; Wilkinson 1999). Key advantages of these species include: an ability to establish in the presence of grazing livestock (sheep and sometimes young cattle) using vegetative cuttings with plastic sleeve protectors; deciduous growth habit; extensive and rapidly developing root systems (McIvor *et al.* 2008; McIvor *et al.* 2009; Douglas *et al.* 2010); and effectiveness in reducing a range of erosion processes (Thompson and Luckman 1993; Douglas *et al.* 2013). They also provide shade and shelter for grazing livestock, valuable supplementary fodder during times of soil water deficit, vista enhancement, potential for gaining carbon credits, flood mitigation by intercepting rainfall and increasing drainage, and biodiversity (McGregor *et al.* 1999; Kemp *et al.* 2001; Kemp *et al.* 2003; Betteridge *et al.* 2012; McIvor and Douglas 2012). Numerous clones are available, varying in attributes including growth form, leaf retention, tolerance to wind, and pest and disease resistance (National Poplar and Willow Users Group 2007). On seasonally drought-prone sites, such as those on north-facing upper slopes, where *Populus* spp. and *Salix* spp. may fail to establish or survive, *Acacia* spp. and *Eucalyptus* spp. are options (Sheppard and Bulloch 1986; Bulloch 1991; Millner and Kemp 2012).

Trees on slopes should be spaced to provide effective soil stabilisation and enable adequate light transmission for understorey pasture growth. Interlocking of roots from neighbouring trees, analogous to overlaying a steel reinforcing mesh across a planted slope, is critical for enhancing soil strength and resistance to failure. Wilkinson (1999) advocated hillslope plantings of *Populus* and *Salix* at densities of 25 to 100 sph, equivalent to spacings of 20 m and 10 m, respectively. On the East Coast of the North Island, individual trees of *Populus* x *euramericana* aged 14-17 years and spaced 20 m apart, on average, saved 8.4 m^2 of ground from shallow landsliding following a severe storm (Hawley and Dymond 1988). Across all trees in their study, the area of landslide scar was reduced by 13.8% compared with similar sites without trees, and modelling suggested that at a tree spacing of 10 m, the reduction would have been at least 70%. In the lower North Island on slopes averaging 27^o, established trees at 32-65 sph (18-12 m spacing), mostly *Populus* spp., reduced shallow landslide occurrence by 95% compared to paired pasture control sites (Douglas *et al.* 2013). Excavations of entire root systems indicated that trees need to be older than 5 years to make worthwhile contributions to slope reinforcement through lateral and vertical root development (McIvor *et al.* 2008, McIvor *et al.* 2009). It is recommended to plant *Populus* spp. at 8-15 m centres depending on the severity of erosion (National Poplar and Willow Users Group 2007), with thinning to achieve wider spacing possible as trees mature.

The impact of wide-spaced trees on understorey pasture yield and quality has received considerable attention for more than a decade, mainly in relation to *Populus* spp. (Guevara-Escobar *et al.* 1997; Douglas *et al.* 2001; Douglas *et al.* 2006b; Wall 2006; Wall *et al.* 2006; Guevara-Escobar *et al.* 2007; Benavides *et al.* 2009; Wall *et al.* 2010), but also beneath and beyond trees of *Acacia*, *Alnus*, *Eucalyptus* and *Salix* spp. (Gilchrist *et al.* 1993; Power *et al.* 1999, 2001; Devkota *et al.* 2009). Under mature, unpruned *Populus deltoides* (mean diameter at breast height (DBH) = 70 cm) at a spacing averaging 16.4 m (37.2 sph), providing essentially 100% canopy closure during foliation, annual pasture accumulation was reduced by 40% compared with nearby areas without trees (Guevara-Escobar *et al.* 2007). Accumulation beneath younger trees was similar beneath and beyond 5-year-old trees (Guevara-Escobar *et al.* 2007), 7 or 11% less beneath trees aged 7 years than beyond (McIvor and Douglas 2012), and 23% less beneath trees aged 8-11 years than beyond (Douglas *et al.* 2006b). Modelling indicated that pasture yield during summer beneath *Populus* x *euramericana* trees aged 16-19 years was 12.5-21% less than on areas without trees (Gilchrist *et al.* 1993). There has been a burgeoning development and understanding of canopy closure models and impacts (McElwee and Knowles 2000; Guevara-Escobar *et al.* 2005; Wall *et al.* 2006; Wall *et al.* 2010), reflecting the major influence of radiation interception on understorey responses (Dodd *et al.* 2005). These will prove useful for evaluating tree spacing scenarios and their likely implications.

Populus and *Salix* species are important and widely used sources of timber and other products internationally (Turley *et al.* 2006; Spinelli *et al.* 2011) but the potential of wide-spaced plantings in New Zealand has not been realised, despite various attempts (McGregor *et al.* 1999). The general lack of silviculture in any form, and no harvesting, has resulted in many of the older plantings developing into very large trees *e.g.* DBH > 60 cm, which significantly shade understorey pasture and are a liability to farm infrastructure, livestock and humans through potential limb breakage and toppling. Few options exist for dealing with large trees which has deterred some current farmers from commencing or continuing planting programmes. Apart from removal by professional logging contractors, large trees can be poisoned by injecting the trunk with herbicide, which results in death and decay but without certainty of the timing of these events. Glyphosate and metsulfuron-methyl were more effective in killing old *Populus* trees (DBH = 70-101 cm) when injected between October and February during their active growth, than when injected in April when growth had slowed (National Poplar and Willow Users Group 2007), though all trees died eventually.

Pollarding, involving complete removal of the tree canopy, particularly at young and intermediate tree ages, is practised by some farmers for limiting tree size and reducing shading of pasture (National Poplar and Willow Users Group 2007). Unpublished results from a study determining the effect of pollarding trees of *Populus deltoides* x *P. nigra* clone 'Veronese' (mean DBH = 21 cm) found that 4 years after pollarding, the increase in DBH of pollarded trees (3.3 cm) was 66% less than for unpollarded trees (9.8 cm), and coarse root (> 2 mm diameter) mass and length were about 60% less for pollarded compared with unpollarded trees. These findings have important implications for slope stabilisation because they suggest that pollarded trees need to be spaced closer together than unpollarded trees to achieve similar levels of effectiveness.

There have been very few economic analyses of wide-spaced trees in pastoral systems (Parminter *et al.* 2001; Orsborn *et al.* 2003). A cost-benefit analysis of planting *Populus* spp. on erosion-prone hill country under three scenarios, varying mainly in erosion severity, gross margin per stock unit, and fodder value, found that the on-site profitability of planting for erosion control alone was marginal at best (Parminter *et al.* 2001). It was suggested that factors such as likely reduced lamb losses, reduced off-site effects, vista enhancement and reduced insurance payouts from storm damage, were added incentives for planting programmes. On a hill country farm, modelling predicted a financial advantage from feeding ewes *Populus* and *Salix* foliage as a supplement to pasture during dry conditions in summer/early autumn (Orsborn *et al.* 2003).

Current and new research initiatives for wide-spaced trees

Following an extensive literature review, ten aspects were deemed important for future understanding and knowledge of the complexities and functions of tree-pasture systems (Benavides *et al.* 2009). These were effectiveness of trees for controlling erosion, their root distribution, controlling tree size, modelling system impacts on erosion processes, effect of canopy shape on pasture understorey growth and links with root distribution and water use, alternative tree species, carbon sequestration, spaced-tree effects on water, nutrient and sediment patterns, animal welfare, and economic analyses.

Some of these aspects have been addressed recently including the effectiveness of wide-spaced trees in reducing the occurrence of shallow landslides on steep slopes (Douglas *et al.* 2013), increased understanding of root distribution (McIvor *et al.* 2009; Douglas *et al.* 2010), and the effect of spaced trees on grazing behaviour and physiology of beef cattle (Betteridge *et al.* 2012). New or on-going initiatives include those determining the impact of pollarding trees of *Populus* and *Salix* spp. on understorey pasture production, water use patterns, and root development (McIvor *et al.* 2011), linking vegetation management on-farm, including spaced-tree conservation plantings, with reducing the risk of erosion and sediment loss to waterways (Mackay *et al.* 2012a), and the effect of *Populus* and *Alnus* spp. at different densities (60-1,200 sph) on soil carbon stocks to 1 m depth. Environmental outcomes of tree-pasture systems on hill country will be of increasing interest.

Conclusion

Strong competition between landuses of forestry and pastoralism on moderate to steep hill country is on-going and the balance between them is governed by a wide range of socio-economic and other factors. The momentum gained in the 1970s-1990s in blending the two landuses on the same land unit in the form of agroforestry with *Pinus radiata*, has waned considerably, to the extent that few, if any, new examples exist on farms. Other tree species may be considered in future agroforestry initiatives. There has and continues to be active planting of wide-spaced trees of *Populus* and *Salix* spp., primarily for erosion control, but also for a range of other functions. Research is addressing some key aspects of these ecosystems.

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