

# Factors determining shrub abundance on uncultivable hill country

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## Abstract

Development of mānuka (*Leptospermum scoparium*) and gorse (*Ulex europaeus*) is a widespread problem on pastoral hill country and is associated with reduced fertiliser inputs and grazing pressures. Using mānuka as a source for specialty products offers a potentially new, profitable enterprise alongside livestock and forestry. However, there is a lack of quantitative information on the optimum soil nutrient status and associated fertiliser programme to encourage presence and growth of this species. In a survey across 324 grazed sites, mānuka had greatest presence on steep slopes (>25°) and soils with Olsen P <10 µg/ml. Mānuka presence was three times greater on steep than medium slopes (13–25°) and 12 times greater than on low slopes (<13°). Annual fertiliser inputs did not appear to change this outcome provided Olsen P remained low. Mānuka was virtually absent where Olsen P approached 50 µg/ml. At other grazed sites, mānuka and gorse were most likely to occur where Olsen P was <15 µg/ml. This study provided insights to underpin a set of nutrient guidelines for mānuka under grazing conditions to maximise its establishment and growth. It remains to be determined what the optimum Olsen P level is for this plant when managed in regimes without grazing and treading pressure.

**Keywords:** mānuka, gorse, soil fertility, hill country

## Introduction

Evergreen shrubs such as mānuka (*Leptospermum scoparium* J.R.Forst et G.Forst. var. *scoparium*) and gorse (*Ulex europaeus* L.) are common features on steep pastoral hill country, usually where livestock grazing pressures are low. This is often associated with low fertiliser inputs and/or low levels of subdivision. Mānuka is a native pioneer species which is often one of the first species to establish following site disturbance and it is an effective nurse plant for slower-establishing native shrub and tree species. Mānuka has wide tolerance of site conditions and establishes and grows on inhospitable sites including those of low soil nutrient status (Porteous 1993). Gorse was introduced from Europe in the early 1800s as an attractive species for hedges and for providing shelter for livestock. It has developed into one of New Zealand's most invasive weeds (Isern 2007), particularly on the Chatham Islands.

Gorse is a nitrogen (N)-fixing species and is similar to mānuka in its propensity for high seed production and dispersal, effectiveness in erosion control, and role as a nurse species for establishment of more desirable native species (Sullivan *et al.* 2007).

Clearance of mānuka and gorse to increase pastoral areas on farmed hill country has been an on-going objective for a number of decades (Grant 1967; Rolston *et al.* 1981), with the extent of clearance at any time subject to a mix of economic, environmental and cultural drivers. While controlling gorse is likely to continue in the foreseeable future, there has been a rethink of the “value” of mānuka in hill country with the emergence of specialty products, such as essential oils and honey from this plant (Stephens *et al.* 2005). The potential exists for a mānuka-based industry to develop, offering a profitable enterprise option on some landscapes, alongside livestock and forestry. Profitability would be very dependent on the genetic makeup of the mānuka populations, particularly in relation to essential oil yield and effectiveness. The transformation of mānuka from a costly weed, or at best a soil conservation plant option on eroding hill country, to the basis of a new, profitable enterprise, shifts strategic management of this plant resource from one of preventing establishment and active eradication through cutting and spraying, and intensive grazing, to practices that encourage establishment, growth and prolific flowering of this species. Stands of related kānuka (*Kunzea robusta* de Lang et Toelken) may also be the basis for honey production enterprises on steep hill country.

The role of soil fertility in survival, establishment and growth of mānuka has received little attention and there is a perception that the species is ideally suited to low fertility sites, and responds poorly to fertiliser application. There are in fact few published studies on the effect of soil nutrient status on mānuka growth in predominantly pastoral hill country under either grazing or no defoliation. Short-term (<1 year) responses of mānuka to fertiliser application have been reported in studies conducted on peat (Schipper *et al.* 2002) and forest soils (Ledgard & Davis 2004). Responses of mānuka to addition of fertiliser can be confounded with those of associated herbaceous species, principally exotic grasses, which flourish and often out-compete other vegetation. Furthermore, as

land is intensified through fertiliser and other practices, there are coinciding increases in pasture production and livestock numbers, which increase the likelihood of young mānuka plants being grazed repeatedly, damaged by treading and killed. The primary objective of this study was to determine the effect of soil nutrient status on mānuka abundance and growth. A secondary objective was to determine the influence of topography and soil nutrients on the probability of occurrence of shrubs compared with grassland cover.

## Materials and Methods

### Sites

Studies were based at two locations in the southern North Island, at AgResearch's Ballantrae Hill Country Research Station near Woodville (henceforth referred to as Ballantrae), and across four commercial sheep and beef farms in the Whanganui District (Whanganui).

**Ballantrae:** Four adjacent, unreplicated farmlets of approximately 10 ha each, which varied in soil nutrient status following different fertiliser application histories at various times since 1975 were used (Mackay & Lambert 2011). The four farmlets were: Low fertility-no fertiliser (LFNF); Low fertility-low fertiliser (LFLF), receiving 125 kg/ha/yr superphosphate; High fertility-no fertiliser (HFNF), and High fertility-high fertiliser (HFHF), receiving 375 kg/ha/yr superphosphate. In the LFNF and HFNF farmlets, topdressing ceased in 1981. Soils in the farmlets were Ngamoko silt loam and Mangamahu steepland soil (Lambert *et al.* 1990), and across the farmlets, slopes of 1–12°, 13–25° and >26° comprised 28%, 43% and 29%, respectively, of land surface area (Lambert *et al.* 1983). The farmlets were grazed continuously by breeding ewes and replacements at stocking rates ranging from about 7 stock units (SU)/ha on the LFNF farmlet to 16 SU/ha on the HFHF farmlet, depending on available forage supply. From 1996 to 1998, treatments of a high rate of N fertiliser (400 kg/ha/yr) and differential stocking rates were applied to four paddocks within each of three of the farmlets (LFNF, LFLF, HFHF) in a N response trial (Lambert *et al.* 2003). In 2003, the LFNF and LFLF farmlets had Olsen phosphate (Olsen P) levels averaging <10 µg/ml whereas the HFHF farmlet had Olsen P levels approaching 50 µg/ml (Mackay & Lambert 2011); results for the HFNF farmlet were not reported. Olsen P levels varied between slopes within farmlets and soil depth. For example, at 0–7.5 cm soil depth, Olsen P for all slope classes was <5 µg/ml in the LFNF and <10 µg/ml in the LFLF farmlets, whereas in the HFHF farmlet, it was 70, 45 and 30 µg/ml for low, medium and high slopes, respectively (Figure 3 in Mackay & Lambert 2011). There was negligible variation between the farmlets in soil pH (average 5.3)

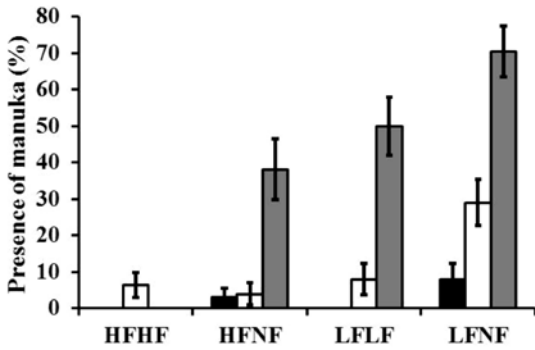
and sulphate-sulfur (SO<sub>4</sub>-S) at 0–15 cm depth (<15 ppm).

**Whanganui:** The four farms, collectively comprising about 3500 ha of moderate to steep hill country north of Whanganui City, were selected as part of a larger study (Douglas *et al.* 2006). All farms included fragments of native bush. Soils across the farms were of sedimentary and volcanic origin, including Egmont black silt loam, Westmere hill country soils, and Pohangina and Taihape steepland soils.

### Measurements

**Ballantrae:** A total of 324 measurement sites were selected randomly across the four farmlets (78–85 sites per farmlet) and their locations recorded in a GIS database. All locations were identified on aerial photographs at scales ranging from 1:3000 to 1:350. Each site was a circle of 3 m radius and was assessed in October 2005 for overall slope (henceforth SLOPES) and number of mānuka plants. Where mānuka plants occurred at a site, 1–13 plants were selected for measurement of slope at the base of the plants (SLOPEM; °), plant height (HEIGHT; cm), root collar diameter (DIAMETER; mm), and number of branches per plant from the base (BRANCHNO). SLOPES was assessed as low (<13°), medium (13–25°), or steep (>25°). About 100 mānuka plants across 36 sites were cut accidentally by contractors, which limited measurements, principally of HEIGHT and BRANCHNO. DIAMETER of the cut plants, and SLOPEM, could often be measured because plant bases frequently remained. Soil testing was not conducted because recent data (2003) for the three slope classes in the LFNF, LFLF and HFHF farmlets were available (Mackay & Lambert 2011).

**Whanganui:** Across the four farms, 29 plots, each a square of 1 ha, were identified on aerial photographs taken in 2001. Each plot was classified manually by majority vegetation cover into classes of grass and shrub. Shrub species were almost exclusively mānuka and gorse (>95% of shrub cover) but their respective covers were not estimated. In August 2005, each plot was assessed for biophysical features (e.g. vegetation (grass, shrub), slope (°) using a spirit level (up to 20 measurements /plot depending on accessibility), Land Use Capability (LUC) class aided by farm maps, risk of erosion (subjective assessment of 0, slight, moderate, severe)), and five randomly selected soil cores sampled to 75 mm depth. Soil samples were bulked and analysed for pH (1:2.1 v/v water slurry), Olsen P, SO<sub>4</sub>-S (involving phosphate extraction), and potassium (K; "Quick test" involving ammonium acetate extraction). Livestock defecation and urination had the potential to



**Figure 1** Effect of slope on presence (% of sites with at least one plant) of mānuka in farmlets varying in long-term fertiliser application history. HFHF=high fertility-high fertiliser, HFNF=high fertility-no fertiliser, LFLF=low fertility-low fertiliser, LFNF=low fertility-no fertiliser. Slopes are low (black column), medium (white), and steep (grey). Vertical bars represent standard errors.

modify soil chemistry because all areas in which plots were located had been grazed by sheep or cattle, or both, at various times.

### Statistical analyses

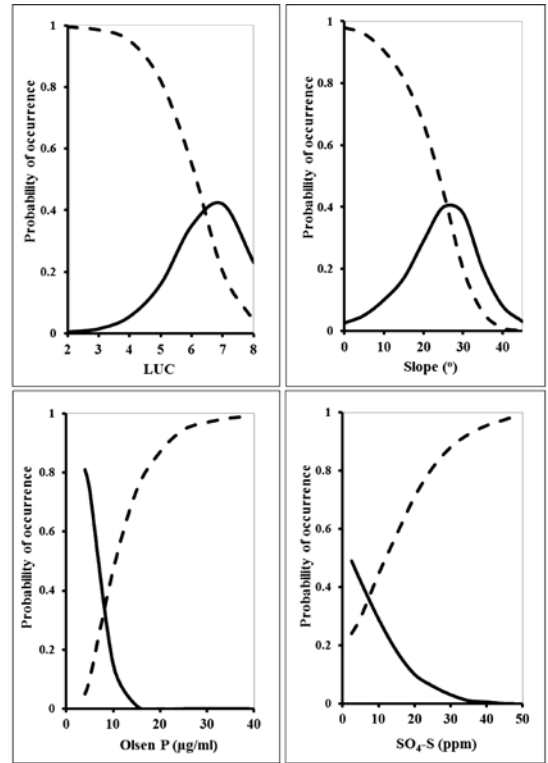
**Ballantrae:** Presence/absence of mānuka plants at sites was analysed using logistic regression with sources of variation of farmlet, SLOPES and farmlet  $\times$  SLOPES. Depending on plant attribute (e.g. height, diameter), 67–89% of data on mānuka plants were collected on steep slopes and therefore analyses were confined to this slope class on all farmlets except HFHF, where no plants were found. HEIGHT, DIAMETER and BRANCHNO (no data for HFNF) were analysed using mixed effects models (REML). All analyses were performed using GenStat 17th edition (VSN International 2014).

**Whanganui:** The data were analysed using a log-linear model to determine the probability of a plot being covered by grass or shrub, based on slope, LUC class, Olsen P, and  $SO_4$ -S. Other continuous variables were analysed e.g. soil pH, but they had no significant effect on vegetation cover (data not presented). The absence of separate cover data for mānuka and gorse precluded determining probability response curves for each species.

### Results

#### Ballantrae

The greatest number of sites with mānuka occurred in the LFNF farmlet with presence averaging 34% compared with 18% in LFLF, 14% in HFNF and 2% in HFHF farmlets ( $P<0.001$ ). At least three times more sites on steep slopes had mānuka (39%) than



**Figure 2** Probability of occurrence of vegetation covers of grass (- - -) and shrub (—) in relation to Land Use Capability (LUC) class, slope, Olsen P and sulphate sulfur, estimated from data from 29 plots on farms in Whanganui District.

on medium slopes (12%) and 12 times more than on low slopes (3%) ( $P<0.001$ ). There was an interaction between farmlet and SLOPES ( $P=0.011$ ), mainly because mānuka was found at 4–12-times more sites on steep slopes than on low and medium slopes in all farmlets except HFHF (Figure 1).

Plant attributes did not vary significantly between farmlets. Across farmlets, mean HEIGHT was 56.9 cm ( $n=49$ ;  $s.e.=10.5$  cm; range=20–320 cm), mean DIAMETER was 44 mm ( $n=145$ ;  $s.e.=3$  mm; range=1–160), and mean BRANCHNO was 3.9 ( $n=33$ ;  $s.e.=0.4$ ; range=1–9). SLOPEM averaged  $47^\circ$  ( $n=145$ ;  $s.e.=1^\circ$ ) and ranged from  $15^\circ$  to  $90^\circ$ .

#### Whanganui

The probability of occurrence of a particular vegetation cover depended on the physical attributes of the landscape including slope ( $P<0.001$ ) and LUC class ( $P<0.001$ ) (Figure 2), but not on risk of erosion (data not presented). Of the soil properties influenced by farm management decisions, the probability of occurrence of a particular vegetation cover depended on Olsen P ( $P<0.001$ ) and  $SO_4$ -S ( $P=0.036$ ) (Figure 2), whereas

there was no influence of soil pH (range 5.2–7.6) or soil K status (data not presented). Twelve of the 29 plots had shrubs, seven with gorse, and five with both mānuka and gorse.

The highest probability of shrub cover occurred on LUC Classes 6 and 7 ( $P=0.4$ ) and slope of 25–30° ( $P=0.4$ ) (Figure 2). Shrubs were only likely to be found on land with Olsen P of  $<15 \mu\text{g/ml}$  and  $\text{SO}_4\text{-S}$  of  $<30$  ppm. The highest probability of shrub cover occurred at Olsen P of  $<10 \mu\text{g/ml}$  and  $\text{SO}_4\text{-S}$  of  $<10$  ppm. The category grass had a probability of 0.5 or higher of occurring on land with LUC Classes of 2 to 6, slope of 0–25°, Olsen P of  $>11 \mu\text{g/ml}$ , and  $\text{SO}_4\text{-S}$  of  $>12$  ppm.

## Discussion

This study highlighted the predominance of mānuka on steep slopes with negligible or no long-term or recent fertiliser topdressing history. The findings at Ballantrae and those of soil test results obtained in 2003 (Mackay & Lambert 2011) suggest that mānuka is most abundant on soils with Olsen P levels  $<10 \mu\text{g/ml}$ . Results from the Whanganui study supported this. The very low mānuka plant presence in the HFHF farmlet at Ballantrae and the zero probability of any shrub cover in Whanganui in soils with Olsen P  $>20 \mu\text{g/ml}$ , suggest that mānuka cannot compete with exotic grassland species, or tolerate the increased livestock grazing, soil N status and treading pressures. Possible reasons for greater mānuka presence on the lower fertility, steeper slopes at Ballantrae include fewer impacts from grazing livestock, greater tolerance than forage species of soil water deficits, lower nutrient requirements than forage plants, and less competition through reduced herbage accumulation by forage plants (López *et al.* 2003). Livestock grazing of the Ballantrae trial areas was exclusively by sheep but wild goats and possums were present at various times, which may have affected results because of their different behaviours and diet preferences compared with sheep. Anecdotal evidence from observation of kānuka stands in Central Otago appears to support these findings, that is, greater incidence on lower fertility soils and steeper slopes, although aspect (higher population recruitment initially on shaded faces) and exposure to frost also influence establishment there too.

The lack of differences in size of mānuka plants in farmlets receiving low inputs (LFLF) or that had previously received high inputs before cessation (HFNF) (Mackay & Lambert 2011), indicates that underlying soil P fertility is a key determinant of the amount of mānuka that establishes successfully and grows, rather than the input of a P fertiliser. This was because there was little difference in total P input between these two farmlets between 1975 and 2003, despite markedly different application rates (Mackay & Lambert 2011).

The probability curves in the Whanganui study were developed from data collected from only 29 plots and from a process that did not involve a formal experimental protocol to determine the relationship between vegetation cover and soil nutrient status. Consequently the data should be treated with caution. They suggest that shrubs (mānuka, gorse) are most likely to occur on soils with Olsen P  $<15 \mu\text{g/ml}$ . The explanation also aligns with qualitative observations relating to reduced shrub establishment potential and increases in grazing pressure with higher fertility. The owner of one of the case study farms planned to raise Olsen P to  $17 \mu\text{g/ml}$  on moderate sloping hill country, which suggests a future low likelihood of shrub presence because of reduced seedling establishment. In the absence of land use information, the probability curves could be used as a preliminary guide to possible changes in landuse.

In Whanganui, field inspections of plots found that cover of gorse often seemed greater than for mānuka, and that the two species frequently developed as distinct vegetation communities, perhaps because of different soil fertility tolerances and plant growth habits, and gorse being a N-fixing species. This indicated that reversion from previously developed pasture to shrub cover was frequently dominated by gorse. Where gorse occurs, it can reduce or preclude livestock grazing of an area, which may encourage mānuka regeneration if a seed source is available. Gorse has potential to facilitate development of other vegetation assemblages over time (Sullivan *et al.* 2007) but until gorse stands mature and open up, seedling recruitment would probably be constrained.

## Conclusions

Mānuka was most abundant on slopes  $>25^\circ$  and on soils with Olsen P  $<10 \mu\text{g/ml}$ . Results suggested that underlying Olsen P status is a key determinant of mānuka presence under grazing. Mānuka and gorse are more likely to occur where Olsen P is  $<15 \mu\text{g/ml}$  and  $\text{SO}_4\text{-S}$  is  $<30$  ppm.

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