REVEGETATION OF RECENT SOIL SLIPS IN MANAWATU

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN APPLIED SCIENCE AT MASSEY UNIVERSITY

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Abstract

Trifolium repens, Lotus pedunculatus and *Holcus lanatus* were oversown on two recent soil slip surfaces at AgResearch's Ballantrae pastoral hill-country farm near Woodville. The two slip surfaces were located on (Manamahu steepland soil) sedimentary mudstone. One slip had a north aspect and the other had a south aspect. Both slips were located on a land class 6 with slope 28-33^0.

The pasture species were oversown during early spring and the percentage seedling emergence and early establishment from viable seeds oversown was analysed at early spring (Day 15), late spring (Day 45), early summer (Day 90), and late summer (Day 120). The slip surfaces showed micro-climatic extremes in terms of both soil moisture and surface temperatures during the summer period. Significant differences ($P < 0.05$) were found in soil moisture between north and south facing slip surfaces. Higher soil moisture and lower soil mean temperature were recorded on the south aspect slip surface.

Significant differences ($P < 0.05$) were found between the three pasture species in terms of seedling emergence and early establishment. Significant differences ($P < 0.05$) were also found with aspect. The south aspect slip surface had a higher percentage of seedling emergence and earlier establishment for all the species. Interaction between species by aspect became significantly different ($P < 0.05$) at Day 90 and Day 120. The main effects of time and species were also significantly different ($P < 0.05$) illustrating seedling emergence and establishment as a race against time.

Trifolium repens was a more successful pasture specie, than *L. pedunculatus* and *H. lanatus* due to its higher consistency on both north and south slip surfaces. *Oversowing T. repens* during early spring is a viable option for rehabilitation of recent soil slips in Manawatu.

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Kamal Prasad

The green Earth is the meadow we graze in. the ground we are shaped from.

The daily bread, that keeps body and soul together.

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Chapter 1 Introduction

Soil slip erosion is a common feature of pastoral hill country farms in New Zealand, particularly where forests have been removed and replaced by pasture (Lambert, Trustrum, & Costall, 1984; DeRose, Trustrum, Thomson, & Roberts, 1995). The majority of soil slips occur after high intensity rainfall events, on sloping pasture lands (Brooks, Crozier, Preston, & Anderson, 2002; Xie, Esaki, & Cai, 2004). The resulting damage from soil slips can have a wide range of consequences, affecting not only the lives of local farm communities, transportation systems and farm infrastructure and lowland farmers but also the environment (Glade, 1998). For example, the February 2004 storm event degraded 8000 $km^{2\ of}$ hill country farmlands alone (Hancox & Wright, 2005) and cyclone Bola, in March 1988, degraded approximately 18,000 ha of farmland, via soil slippage in the Gisborne/East Cape region (Quilter, Korth, & Smith, 1993).

'Soil quality and management support our productive industries – 17% of New Zealand's GDP depends on the top 15 cm of our soil. Soil is at the heart of New Zealand's clean green image – it underpins how the world views us and how we view ourselves. Failure to sustain our soil and water resources will put $2.16 billion of our total GDP at risk' (Horizons Regional Council, 2009).

Lambert *et al*., (1993) highlighted that pasture productivity on recent soil slips takes at least two decades to reach 80% of the production of pasture on soil slip surfaces, when compared with adjacent uneroded surfaces. In terms of revegetation of soil slip surfaces, Baisden *et al*. (2002) highlighted soil fertility as one of the key limiting factors affecting the slow recovery rate of soil slips. DeRose *et al.,* (1995) highlight that soil slips undergo climatic extremes. Nevertheless, the topography also makes mechanical pasture conservation impossible.

Two recent steep-hill country soil slip scar surfaces were selected for the revegetation trial, one facing north and the other facing south. Both the slip surfaces were on recent Pliocene mudstone and they were located on Land Use Capability class 6, with slope 28-33^{o}. The soil chemical and physical properties of the soil slip surfaces may partly explain why some species are successful colonisers on soil slip surfaces (Lambert, *et al.*, 1993). Evidence is provided of the status of the soil fertility, together with details relating to micro-climatic factors, such as soil temperature and soil moisture regimes on these slip surfaces and their effect on seedling emergence and the early establishment of selected pasture species used in this experiment. Also, data from the Ballantrae farm meteorological station provided supplementary knowledge relating to the slips micro-climatic factors.

The experiment was conducted from September 2008 to February 2009 in an open sheep grazing system of 10.4 su/ha. Considering the limitation of space on typical soil slips (Trangmar, Basher, & Lawton, 2003), three pasture species were oversown. The three pasture species used in this experiment were *Trifolium repens, Holcus lanatus* and *Lotus pedunculatus*. Upon oversowing during early spring, visible seedlings were repeatedly counted at four different stages on designated areas: early spring (Day 15); late spring (Day 45); early summer (Day 90); and late summer (Day 120).

Seedling emergence and the early establishment of these species, at these time-intervals, were analysed, via SAS (9.2). The data were transformed by dividing the number of emerged seedlings by the estimated number of viable seeds, which had been over-sown within a measured area. The analysis was conducted using Univariate Procedure or Repeated Measures and Analysis of Variance. Pearson's correlation coefficient between oversown herbs, weeds, total cover and species cover, provided additional insight after 120 days from establishment, respectively.

The objectives of the present experiment were to compare seedling emergence and the early establishment of three herbage species on two recent soil slips, at AgResearch's Ballantrae hill country farm near Woodville. Secondly, the role of aspect and species by aspect interaction, are compared, on seedling emergence and early establishment. The effects of time on herbage species are also discussed. Soil fertility, soil moisture and soil surface temperature regimes on the two aspects provide details relating to the success or failure of the oversown species.

Photographs taken during the revegetation process, from Day 15 (early spring), are used as evidence to predict soil slip cover after 120 days (late summer) and the dominant herbage species, which can be used to rehabilitate the soil slip surfaces, are identified. New strategies are highlighted and the documentation of unforeseeable limitations is also discussed.

Chapter 2 Literature Review

The focus in this review is the revegetation of soil slips in pastoral hill country farms. The review is based on literature which explains the reasons for soil slips; soil properties on soil slip surfaces; previously conducted research on revegetation of soil slips; examples of the pasture species that were tested; the role of soil temperature and moisture on seedling emergence; the role of aspect; 'seed under microscope'; and detailed discussions on the pasture species used in this experiment.

2.0 History and importance of soil slip scar revegetation.

In the past century, rural environments in most parts of the world, have undergone massive transformations. The growing need to supply more food for the world's population has led to the conversion of marginal land into agricultural land. Subsequently, the degradation of this type of land has been perceived to be largely caused by poor farming practices (Petty & Shah, 1997; Dymond, Jessen, & Lovell, 1999).

In New Zealand, land degradation via soil slippage on marginal hill-country is a consequence of clearing and converting native forest to pasture lands (Horizons Regional Council, 2005). Three quarters of New Zealand's landmass is geologically young, comprising either crushed and shattered rocks or uplifted and poorly consolidated young sedimentary rocks (Krausse, *et al.*, 2005).

Figure 2.1. Both shallow and deeper seated slipping in Mudstone (Mm) in Mangawhero hill country after 2004 storm event (Hancox & Wright, 2005).

Subsequently, high intensity rainfall events on sloping pasture lands, on highly erodible sites, have created slippage (Glade, 2002). The February 2004 storm alone, over the southern North Island, caused extensive shallow land-sliding of over 8000 km² of Manawatu-Wanganui hill country (Hancox & Wright, 2005). Cyclone Bola, in March 1988, degraded approximately 18,000 ha, via soil slip erosion in the Gisborne/ East Cape region alone (Quilter *et al*., 1993).

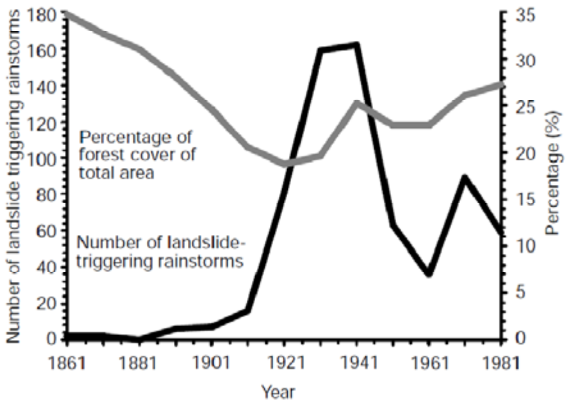

Figure 2.2. Relationship of forest cover to recorded number of landslide-triggering rainstorm events between 1861 and 1981 in New Zealand (Glade, 1998).

Today, almost all farming areas in the North Island hill country are still prone to soil slippage, involving translational displacement of regolith (Brown, 1991). Soil slips and debris avalanches, with linear scars and debris tails are noticeable on hill country slopes in weakly consolidated Tertiary siltstones and mudstones (Trotter, *et al*., 1989). The outcrops of these rocks are extensive in Taranaki and Wanganui and the East Coast region of the North Island, from East Cape to Wairarapa (Brown, 1991). Soil slippage is common on moderate or even gentle slopes in the same lithologies (Trotter, *et al*., 1989).

Pasture is New Zealand's predominant vegetation class, covering 53% of the total land area. It has been estimated that only 31% of New Zealand's land can sustain pastoral farming, without significant erosion controls (Eyles, *et al.,* 1991). Pastoral industries provide 64% of New Zealand's export income and their contribution to the Gross Domestic Product has risen from 13.5% in 1990 to 17% in 2006. This increase is partly because of marked agricultural intensification or productivity increases (MAF, 2006).

Soil slips are higher in number in pastoral farms, than in forested areas and thus there is a larger volume of soil loss (Glade, 1998). The resulting soil loss rates, through soil slip erosion reduces the potential productivity of the farms (Wilmshurst, 1997). This creates implications for the sustainable management of national soils, especially on pastoral hill country farms in New Zealand (Krausse, *et al.*, 2005).

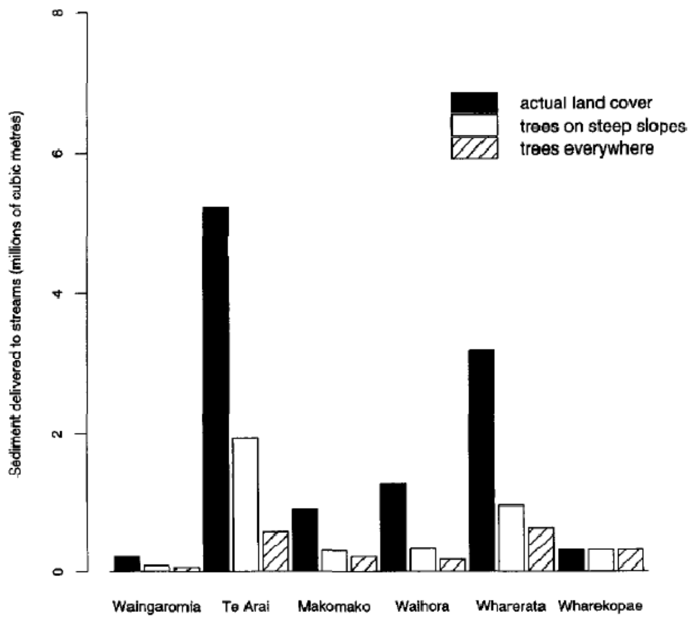

Figure 2.3. Bar plot of sediment delivered to stream resulting from a storm with 600 mm of rain, in each of the landslide prone systems, as a result of three different land cover scenarios: actual land cover (pasture), trees on steep slopes only (none in Wharekopae), trees everywhere (except Wharekopae) (Dymond *et al.*, 1999).

Figure 2.3 illustrates the estimated amount of sediment delivered to streams at different localities, under pastoral based farming systems. The shallow landslides frequency was higher in actual land or pasture cover. Hillsides steeper than 20^0, which are underlain by mudstone and sandstone, are more susceptible to landslides and these comprise more than 10% of the North Island (Dymond, *et al.*, 1999). Finding a means to quickly revegetate these scars will result in decreased sediment losses to streams/rivers and faster rehabilitation of recent soil slips.

2.1 Characteristics of soil slips

In this section, the processes of soil slip erosion, soil slip characteristics and its ecological implications and the major factors that are responsible for slippage, are discussed.

Soil slips are rapid flow movements of unconsolidated wet soil materials and thus soil movement occurs due to the shearing of saturated soil above a well-defined failure surface (Trangmar *et al.*, 2003). The failure surface is usually a zone of low permeability within the soil, or at the soil–bedrock interface, exposing a slip surface approximately parallel to the slope.

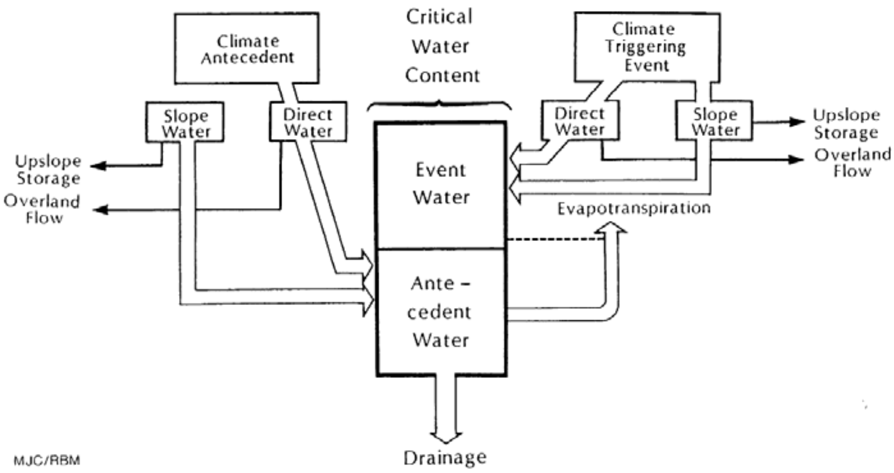

Figure 2.4. Conceptual hydro-climatic landslide triggering model (Crozier, 1999).

Figure 2.4 explains the impact of a typical rainstorm event and its effect on soils that are prone to slippage. The critical slip surface has one of three possible slip surfaces: the wetting front; the groundwater table; and the interface of the soil and rockbed *(*Xie *et al.*, 2004). Failure occurs when increases in soil moisture content raise pore-water pressures and thus shearing forces within the soil above the shear strength, act along the failure surface (Brooks *et al.*, 2002). Subsequently, saturation results in reduced cohesion and friction between soil particles, thus decreasing shear strength and increasing shear stress. This results in slippage through increased soil weight (Hick & Anthony 2001; Trangmar *et al.*, 2003). Occasionally, there can be some rotational movement during the slippage period, followed by a debris-tail, which often settles in waterways (Crozier, 1999; Hick & Anthony 2001).

Secondary implications are blockages of farm drainage systems, which eventually supplement sediment travelling to streams and rivers, which hold economic and ecological significance for the local hill country farm communities (Crozier, 1986).

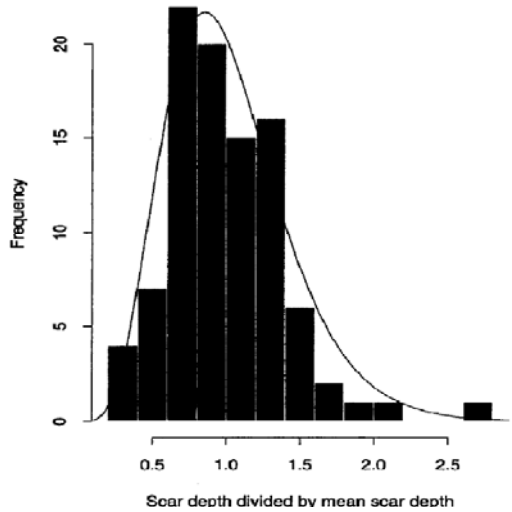

Figure 2.5. Histogram of normalised scar depths (Dymond, et al., 1999).

Figure 2.5 illustrates the high frequency of shallow landslides (0.5m to 1.5m in depth) on pastoral based farms (Dymond *et al.*, 1999). Grassland areas are generally affected by soil slippage, with the ratio on hill country pastoral areas ranging between 30-50%, compared with only approximately 8% for areas in native forest, scrub and pine forest in a major storm event (Hancox & Wright, 2005).

DeRose *et al.*, (1993) stated that the depth of pre-existing regolith on post-deforestation landslide sites is estimated from a regression of regolith depth on slope angle, for undisturbed (non-landslide) profile segments. Regolith depletion on landslide sites is in turn estimated by subtracting the depth of regolith on landslide sites from the estimate of pre-existing regolith depth. 'For hillslopes steeper than 28°, where all post-deforestation landslides occur, average surface lowering is 0·20 ± 0·05 m, and the regolith depletion rate is 24·0 ± 6 mm yr^{-1}. The average surface lowering is greatest at 0·23 ± 0·07 m, on hillslopes steeper than 32°, where most post-deforestation landslides occur. Here, the regolith depletion rate is 2·7 ± 0·8 mm yr^{-1}'.

Other literatures also highlight that soil slips are the major contributors to sedimentation in water ways, since they occur often, even during regular seasonal rainfalls (DeRose, Trustrum, & Blaschke, 1993; Dymond *et al.*, 2006; Glade, 1998, 2002; Page, Trustrum, & DeRose, 1994).

Table 2.1. Sediment budget of an erosion-inducing rainstorm (Cyclone Bola, 8th-11th of March, 1988) in Lake Tutira catchment, Hawke Bay (Glade, 2002).

Budget component	Location	Process	Sediment flux (%)	Total (%)
Input	Hillslopes	Landslide	89	
		Sheet erosion	7	
		Tunnel gully	2	
	Valley floors	Channel	2	100
Storage	Hillslopes	Deposition	21	
	Valley floors	Deposition	22	
Output	Lake bed	Sedimentation	51	
	Lake outlet	Stream/channel transport	6	100

Hill slopes are the major contributors of sedimentation, through landslides and sedimentation travelling to rivers and lake beds (Table 2.1). Trangmar *et al.* (2003) stated that soils on shady aspects (E, SE, S, and SW) have consistently higher moisture content and they recharge to a critical moisture content faster than those soils on sunny aspects, during rainfall events. Concave sites concentrate water during rainfall events and they reach failure moisture content more rapidly than moisture-shedding or convex slopes (Crozier, 1999). Failure may occur at these sites, even during low-intensity rainfall events, if antecedent soil moisture levels are sufficiently high, after periods when rainfall has exceeded evapotranspiration (Brooks *et al.*, 2002). Sites exposed to the prevailing, rain-bearing, south-westerly winds also show a high incidence of failure (Hicks & Anthony 2001). Soil moisture loss is either through drainage or evapotranspiration (Roderick & Farquhar, 2005).

Potential failure planes are typically found between 1.0 and 2.0 m depth, at the contact surface area between regolith and unweathered parent material (Cammeraat, van Beek, & Kooijman, 2005). These failure surfaces usually coincide with changes in texture, bulk density, porosity and permeability (DeRose *et al.*, 1995). Soil physical properties on slip surfaces can provide in-depth knowledge relating to revegetation. Newly vegetated cover on slip surfaces can ultimately decrease further losses, by providing a significant shear strength contribution to these soils. This increases landslide-initiation thresholds, by changing the location of the critical shear plane, through evapotranspiration (Ekanayake & Phillips, 2002). However, evapotranspiration rate decreases due to lower amount of solar energy received during winter in New Zealand (Scotter & Heng, 2003).

2.2 Soil properties on soil slip surfaces

In this section, the soil properties of soil slips are discussed, which may partly explain the constraints to faster revegetation.

Table 2.2. Soil bulk density, particle density and porosity for different erosion classes, and deposition and wooded control sites (Ebeid, Lal, Hall, & Miller, 1995). (LSD - Least significant difference).

Erosion class	Bulk density (mg/m^3)	Particle density (mg/m^3)	Porosity (%) F
A. 0-10 cm depth			
Slight	1.41	2.66	41.2
Moderate	1.49	2.61	42.8
Severe	1.45	2.58	43.3
Deposition	1.44	2.65	45.6
Wooded control	1.2	2.46	51
LSD (0.05)	0.06	0.17	1.4
B. 10-20 cm depth			
Slight	1.45	2.61	45.6
Moderate	1.59	2.61	40.5
Severe	1.55	2.66	41.7
Deposition	1.5	2.61	43.6
Wooded control	1.34	2.66	49.6
LSD (0.05)	0.07	0.19	2

A study conducted in central Ohio states that bulk density increases with an increase in regolith stripping and it is also generally higher, due to the high compactability of the subsoils (Table 2.2). Both bulk density and particle density increase with soil depth (Ebeid *et al.*, 1995) and thus it can be interpreted that there are changes in other soil physical properties at different soil depths, such as soil texture and structure and hydraulic conductivity on the exposed subsoil surfaces. Consequently, as a result, changes in soil chemical properties, on the exposed subsoil surfaces, could also be evident.

Soil core samples, from the interface of the soil slips indicated that 23-37 year-old soil slips recover 50-72% soil Carbon (C) stocks in comparison with the core samples from uneroded sites, on similar sites and aspects in Wairarapa. The reduction in soil C can range from 36 -90 Mg C/ha, in subsoils adjacent to uneroded soil surfaces (Baisden, Parfitt, & Trustrum, 2002).

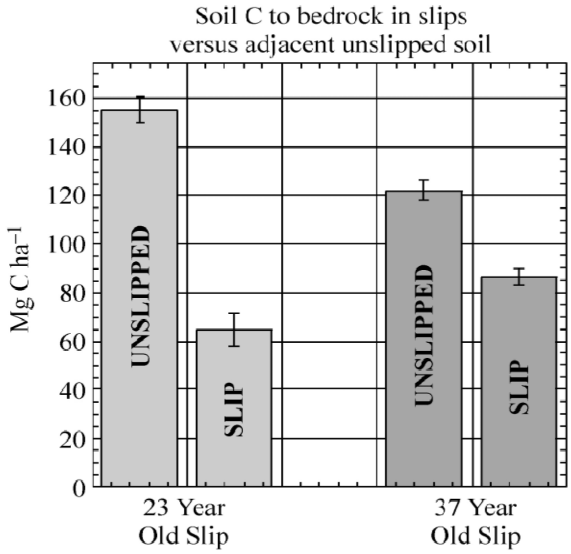

Figure 2.6. Soil organic Carbon in replicate soil cores taken to the bedrock interface in landslide scars and adjacent unslipped soil (Baisden *et al*., 2002).

Identification of pasture species, which can germinate and establish early in these low fertility soil slip environments, can ultimately reduce the recovery time (Figure 2.6 & 2.7). Soil shear strength in relation to rooting, indicated that pasture roots contributed to soil strength, but only in the upper 0.4 m of the soil (Baisden *et al*., 2002; Luckman, Gibson, & Derose, 1999). Hence, decreasing the soil moisture below the exposed surface will reduce the risk of further failure and sedimentation losses.

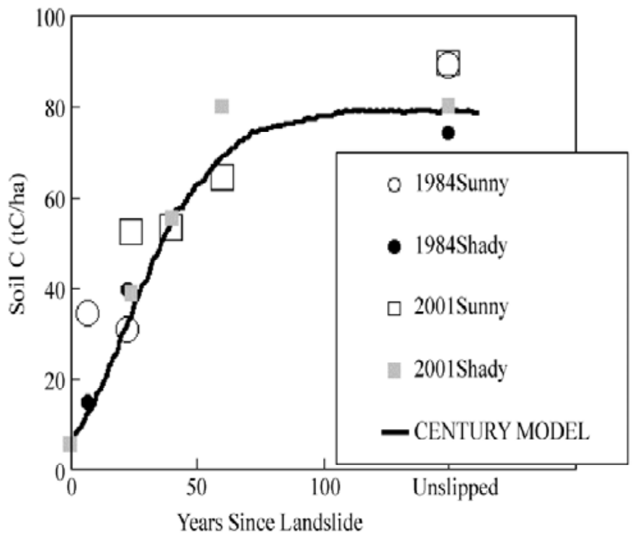

Figure 2.7. Soil C in the upper 20 cm of the soil profile measured in landslide scars and in un-slipped areas. The solid line shows a simulation of recovery on a fresh scar using the CENTURY model (Baisden *et al.*, 2002). Sampling was conducted on adjacent aspects – North for sunny and south for shady. (Exact sampling dates were not mentioned).

Soil organic matter (SOM) acts as a reservoir for majority of the important nutrients (McLaren & Cameron, 1996). Pallic or Brown soils often have adequate supply of soil potassium (During, 1984). The recovery pattern of SOM on landslide scars has indicated soil phosphorus (P) and nitrogen (N) as nutrients which limit vegetative cover due to slow soil C accumulation (Baisden *et al.*, 2002). In general, on extremely dry soils or if the soil temperature exceeds 15^0C, volatilisation losses can also occur (Hedley, 2005). In addition, increased vegetative cover considerably reduces the recovery period (Baisden *et al.*, 2002).

Soil properties on hill slope pastures, at three different localities within eastern Taranaki were measured over four years. The measurement sites were either on uneroded soils, representing top, middle and bottom slope positions, or on landslide scars, with ages ranging from 12 to 80 years.

Table 2.3. Mean soil fertility (1983-87), water contents (WC) and phosphate rock (PR%) for uneroded and eroded sites at different localities in New Zealand (DeRose *et al.*, 1995).

	Uneroded			Eroded		
	Makahu	Tututawa	Pohokura	Makahu	Tututawa	Pohokura
pH	5.7[a]	5.7[a]	5.5	5.4[b]	5.4[b]	5.2
Ca^{2+} (ppm)	4.9[a]	4.9[a]	3.1[b]	5.0[a]	4.1	3.3[b]
Mg^{2+} (ppm)	19[bc]	23[b]	15[c]	31[a]	46	33[a]
K^+ (ppm)	6.6	9.5	5.4	4.1[a]	6.0	3.9[a]
Olsen P (ppm)	10.6	8.2[a]	5.9[c]	17.5	6.6[bc]	7.6[ab]
PR (%)	86[a]	79[a]	85[a]	45[b]	35[b]	44[b]
$S0_4^-$ (ppm)	16[a]	15[a]	15[a]	14[a]	14[a]	14[a]
WC (%W/W)	74	60	66	52	39	46

Figures followed by the same letter do not differ at ($P<0.05$) level of significance.

Table 2.3 indicates that eroded sites resemble subsoil environment, which has lower soil nutrients, than uneroded remnant soils under pasture (DeRose *et al.*, 1995). A similar study, in east Shropshire, UK (Fullen & Brandsma, 1995), also confirmed that there were changes in the textural and chemical composition, due to erosion on loamy sand, which was due to runoffs. Soil properties were measured using an array of ten 25 m^2 runoff plots at the experimental site, over six years. There were positive associations between the erosion rate and the soil's textural change and also SOM decreased from a mean of 2.54% to 0.5%, after soil erosion. Both soil macronutrient (K, Ca and P) and micronutrient (Fe and Cu) were significantly ($P < 0.05$) lower after erosion. Exposure of bare soil caused the mean soil pH to fall from 5.55 to 5.05. These measurements suggest that erosion also regularly reoccurs in northern Europe and thus there were serious long-term implications on soil fertility (Fullen & Brandsma, 1995). Similarly, reduced soil fertility will have a negative impact on seedling emergence.

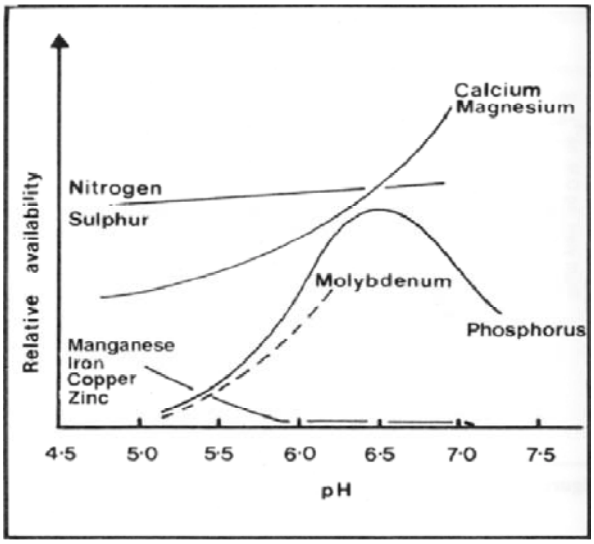

Figure 2.8. Availability of essential soil nutrients with differences in soil pH (McLaren & Cameron, 1996, p. 181).

Lower pH restricts the availability of many nutrients and thus, it may also have an influence on seedling emergence and the early establishment of the oversown pasture (Figure 2.8). A pH range of 5.7-6.3 creates a desirable soil environment that adequately releases soil nitrogen and phosphorus (Sparling & Schipper, 2004). Slipped soil surfaces create difficult conditions for the establishment of most pastures species.

Existing soils have very little regolith left after slippage. Bulk densities are usually high (1.4- 1.6 cm^3) and soil porosity is generally low, when compared to adjacent remnant pasture surfaces. The soil C, N, Olsen P and cation exchange capacity (CEC) are also generally low and thus this can be challenging for early plant establishment.

Table 2.4 Target soil test ranges for near maximum production on recent Pallic and Brown soils (source: Overseer Nutrient Budgets) (Hedley, 2005).

NZ soil name	Pallic and Brown
Soil Test	
Olsen P	20-30
Olsen P high *	30-40
Soil test K	5-8
Sulphate-S	10-12
Organic-S	15-20
Soil test Mg	pasture 8-10 animal 25-30
pH	5.8-6.0

* target ranges for high producing dairy farms (current milk solids production/ha is in the top 25% for the supply area).

Alternatively, average or near maximum pasture production is achieved at Olsen P 20 µgP/g, for Pallic and Brown soils. The soil slips in this study are on Tertiary sedimentary mudstone and the existing plant nutrients come from weathered parent material. These soils can have a low percentage of P retention (anion sorption capacity), but they can also have adequate supplies of potassium (During, 1984). There is no useful soil test readout for soil N, since soils do not have the ability to hold nitrate and thus it is easily lost, as water drains through the soil. Soil nitrate levels decrease after each rainfall and drainage event (Hedley, 2005).

The subsoil is deficient in the majority of essential nutrients and thus revegetation of these scars normally takes decades, before it returns to the same fertility state as un-slipped soils (Sparling *et al.*, 2003). Increasing the soil C accumulation will improve the retention of other essential nutrients (McLaren & Cameron, 1996). Pasture species, which can persist, will increase the SOM accumulation and thus ultimately shorten the recovery time.

Any improvement in the soil's physical and chemical properties will ultimately support more plant growth and thus result in rapid stabilisation of soil slips. Identification of pasture species, which show vigorous growth and early persistence, will enhance SOM accumulation on these slip scars.

2.3 Previously tested pasture species to revegetate slips

In this section, different pasture species (used in previous revegetation trials) and their performance to persist on soil erosion slip surfaces are discussed.

Quilter *et al.* (1993) conducted an experiment after Cyclone Bola to identify plants suitable for low cost revegetation of soil slips scars. Eight species of grasses, three species of herbs and thirteen species of legumes were oversown on soil slips, without any additional fertiliser application. Moreover, the performance of these pasture species was evaluated for three years, under normal pastoral hill country farming conditions. The experiment suggested that 20-40% of viable legume and 15-46% of viable grass/herb seeds had produced seedlings. Total grass cover on the soil slips was negligible, indicating N supply as the key limiting factor. Use of leguminous pasture species will inject the needed soil nitrogen (N), which is one of the key nutrients for plant growth and establishment (Kristensen & Thorup-Kristensen, 2007).

Lambert *et al*. (1993) conducted an experiment at Te Whanga Station, 15 km east of Masterton on Kourarau steepland soils, which are derivatives from fossiliferous siltstone and they have a moderate to severe erosion limitation. In this study, two recent erosion slips were selected on different slope aspects: one facing north and the other facing south. Several pasture species were used for this trial and their establishment was evaluated on both soil slips (Table 2.5). The study separated the pasture species into 'slow establishing' and 'fast establishing' seed mixtures.

Significant differences ($P < 0.05$) were found between fenced and unfenced plots after 2.5 years of research in Wairarapa (Lambert *et al.*, 1993). In reality, it is highly unlikely that farmers will fence the numerous slip scars on their farms, in order to assist faster rehabilitation. Red clover was fast establishing on these slips, but eventually it declined over 2.5 years and became just a minor sward component. Hence, red clover is a short-lived pasture species and thus it is unsuitable for longer term revegetation of slips. Farmers should over sow Maku lotus and red clover on slips for revegetation under open grazing (Lambert *et al*., 1993).

Table 2.5. Slow and fast establishing seed mixtures were differentiated after seeding on a pastoral hill country farm in Wairarapa (Lambert *et al*. 1993).

Slow establishing seed mixture (slew seed treatment)	**Fast establishing seed mixture (Fast seed treatment)**
Cocksfoot (Grasslands Wana)	Perennial ryegrass (Grasslands Nui)
Phalaris (Grasslands Maru)	Prairie grass (Grasslands Matua)
Smooth brome grass (Grasslands selection)	Yorkshire fog (Grasslands selection)
Crested dogstail (Grasslands selection)	White clover (Grasslands Tahora)
Browntop (Grasslands selection)	Red clover (Grasslands Pawera)
Red fescue (Grasslands selection)	Subterranean clover (Mt. Barker)
Tall fescue (Grasslands Roa)	Chicory (Grasslands selection)
Red clover (Grasslands Pawera)	
Suckling clover (commercial line)	
Crown vetch (Grasslands selection)	
Lotus (Grasslands Maku)	

Pasture production on erosion scars took 20 years to reach a level of 70-80%, in comparison with that of adjacent uneroded sites and eventually it reached 80-85%, in an extended time frame (Lambert *et al*., 1984). This illustrates that revegetation (or recovery of soil slips) takes more than two decades to reach maximum potential and thus further research is required to identify and reduce this recovery period (Lambert *et al.*, 1993). More importantly, it suggests that productivity of slips never attains that of adjacent uneroded ground.

A few literatures have highlighted the poor performance of perennial ryegrass on eroded steep hill country soils (Lambert *et al.*, 1984; DeRose *et al.*, 1995 Prasad *et al.*, 1998) and thus it was not selected as a pasture species in this experiment.

Douglas and Foote (1994) wrote that several grasses, legumes and herbs are being used to revegetate soil slips, Two of several important attributes of herbaceous species desired for revegetation are their ability to establish well from seed in the field and thus provide rapid ground cover. They also highlighted that seeding in the field is more likely to germinate and establish, rather than using containerised planting stock.

Perennial species, which were investigated for revegetation in New Zealand, include birdsfoot trefoil, the canary clovers, cicer milkvetch, perennial lupin, sheep's burnet, the wheat grasses and numerous other grass species. In addition, most of these species are suitable for low fertility soils and they are also tolerant to prolonged moisture deficits (Douglas & Foote, 1994). Nevertheless, greater birdsfoot trefoil *(L. pedunculatus)* was one of three selected pasture species used in this revegetation trial. A detailed explanation is provided in Section 2.8.

An experiment was conducted on natural vegetation successions on shallow landslide scars in Tertiary hill country in the East Cape region of New Zealand. This experiment focused on the primary successions of landslide scars and the relationship between soil depth and landslide age (5-72ys). Seventy-five vascular plants were recorded in the plots, of which one-third were adventitious and commonly widespread throughout the region. Nearly two thirds were 'accidentals', occurring in only one or two plots. Ferns constituted the bulk of the native species, in addition to an abundance of dicotyledonous herbs and adventitious grasses (Smale, McLeod, & Smale, 1997). The initial vegetation succession, which grew before five years, was not recorded.

Figure 2.9. Pori Station farm in Wairarapa. Note the vegetative succession of legumes grasses, ferns and weeds on old soil slip scars.

Oversowing and top dressing helps to restore production on freshly eroded slip scars. It raises pasture growth on slips from less than 20%, and up to more than 50% of the level on adjacent stable ground, within one to two years (MAF, 2002).

Conversely, a field experiment presented evidence that plant species diversity does not have an effect on hill country pastures that have been established from sowing. Apart from soil fertility and slope angle, the strongest influences on establishment were the locality and site characteristics (Dodd *et al.*, 2004).

2.4 The effects of soil temperature and moisture on seedling emergence

The importance of soil temperature and moisture on seedling emergence are presented. Secondly, the wilting point and field capacity of clay soils are also discussed. The subsoil environment of the slip surface can have a higher degree of compactness and thus can be more comparable to clayey soils than, silty or sandy soils.

Temperature is one of the most important ecological factors that may affect the natural distribution of plants and their satisfactory germination, growth and proper seasonal adjustment for agricultural cultivation (Campbell *et al.*, 1999). Temperature is also directly related to light, as both light and temperature are a measure of the same energy (Murphy *et al.*, 2004). Oversown seeds under satisfactory environmental conditions require adequate temperature to initiate radicle and plumule development and thus attain successful germination (Grljusic *et al.*, 2008). However, soil slip surfaces undergo climatic extremes and also extreme soil physical conditions (DeRose *et al.*, 1995).

Temperature regulates the rate of metabolic processes, many of which are increased by approximately two-fold for every 10^0C increase in temperature (Fulkerson & Slack, 1996). Pasture production is higher with higher soil temperatures, either during spring, summer, winter, or autumn (Wedderburn *et al.*, 1996). There are also differences in pasture production between different pasture species during winter, reflecting their different responses to temperature (Nicol, 1987). The ideal temperature for sowing is when the soil reaches at least 10^0C. However, the surface temperature is usually 5^0C lower than the temperature at 10 cm depth (White & Hodgson, 1999). Pasture cover reflects about 24% of the incident solar radiation, whilst forests emit less (Scotter & Kelliher, 2004). Hence, a lack of vegetative cover on recent soil surface slips in particular, may emit higher values, than ground covered with remnant pasture.

Rainfall and evaporation, between the time the roots emerge from seeds and enter the soil, are the most critical factors for establishment (Bradford, 1995). Death of the radicle tip can occur due to water deficit, even after it has entered the soil (Linhart, 1976). A greater chance of seedling establishment can be achieved via oversowing, when the soil surface is continually wet by rain, dew or frost (Campbell, 1967). Alternatively, low surface moisture can be caused by wind and thus it can hinder radicle entry into the soil (Awan *et al.*, 1996).

Germination is slower when temperatures are low and thus it takes more rain, over a longer period, to germinate seeds sown in colder months (Edwards *et al.*, 2005). This ensures that seeds wait for a few centimetres or more of rain before germination thus ensuring continued wet soil conditions after germination. Germination has been observed after only a few centimetres of rain in hotter months: However, the soil surface rapidly dries after this insignificant rainfall and the radicle tip is killed (Campbell, 1967).

In New Zealand, evapotranspiration is usually the second largest factor, in terms of soil water balance (Scotter & Kelliher, 2004). It has been estimated that soils under pasture cover, in the areas surrounding Palmerston North, have an average of 1000 mm rainfall per year and typically approximately 700 mm is lost through the evapotranspiration process (Scotter & Heng, 2003). Evapotranspiration outstrips the replacement water from rainfall for at least three months of the year in almost all the main agricultural regions of New Zealand (Nicol, 1987). Variation in rainfall, between September and February, accounts for at least 60% of the annual variation in pasture production. This variation may have been due to high radiation, which reduces the effectiveness of the rainfall (Nicol, 1987). Pasture productivity on erosion scars is depressed in summer, probably because of low soil water holding capacity on poorly structured shallow soils with low SOM (Lambert *et al.*, 1984).

Pasture species respond differently to moisture stress and thus species with deep root systems can extract water to a greater depth than shallow rooting species thus increasing their persistence (Skinner, 2005). As the soil progressively dries, the availability of the essential plant nutrients declines and pasture growth is restricted by both low nutrients and moisture availability (Nicol, 1987).

Marshall *et al.,* (1999) found that with 47% clay composition, soil water content reaches saturation point at 0.6, field capacity at 0.41 and permanent wilting point at 0.20 by ratio (Table 2.7). This is relevant since subsoil slip surfaces in this study are on Tertiary mudstone lithology in Mangamahu steepland soil (Dodd *et al*., 2004).

Table 2.6. Water content as a volume fraction of the surface clay dominated soils at three soil water conditions. Adopted from (Marshall *et al.*, 1999, p. 11).

	Clay (%)	Saturated	Field capacity	Permanent wilting point
Clay	47	0.6	0.41	0.20
Loam	22	05	0.29	0.05
Sand	3	0.4	0.06	0.02

Furthermore, they highlighted that after continuous drying and wetting, it has been seen that, after any reversal of direction, the drying soil has a higher water content than the wetting soil, at the same suction (Marshall *et al.*, 1999). However, this difference is usually negligible but any higher soil moisture percentage can be advantageous for seedling establishment during the dry summer months since growth of certain species is halted (Dodd & Orr, 1995).

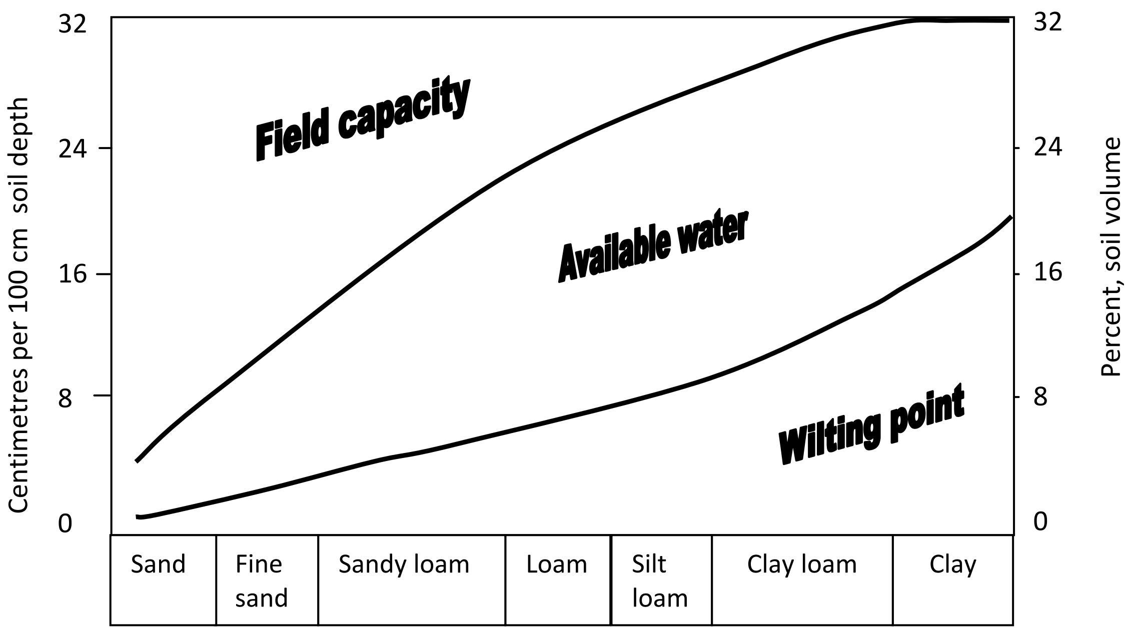

Figure 2.10. Relationships of soil texture to available water-holding capacity of soils. The differences between the water content at field capacity and the water content at permanent wilting point is the water available (Adopted from Foth, 1990).

Similarly, Figure 2.10 illustrates that for silt-loam soils, the percentage of water to reach field capacity has to be approximately 32% of soil by volume (Foth, 1990). However, clay composition varies from soil to soil (Gibbs, 1980).

Lin *et al.*, (1996) conducted research using a combination of tension infiltrometers and dye tracers to investigate the extent and nature of water movement at low tensions through the well-structured subsoil of Ships clay (very fine, mixed, thermic, Chromic Hapluderts). 'Under flow, at 0-cm tension, macropores greater than or equal to 0.5 mm and mesopores from 0.06 to 0.5 mm contributed about 89% and 10% of the total water flux, respectively. Micropores <0.06 mm contributed the remaining 1% of the total water flux, but constituted about 95% of the total soil porosity'. This can provide further knowledge on the effect of soil moisture slip surfaces and thus evaluating soil porosity of the slip surfaces.

Adequate soil moisture and temperature on the slip surface will have a direct impact on seedling emergence and early establishment. In terms of oversowing, soil water content should be between the available water and field capacity (Foth, 1990,). The soil temperature should reach at least 10^0C during oversowing (White & Hodgson, 1999). However, the mean surface temperature is usually lower (approximately 2-5^0C) than the soil temperature at 10 cm depth (Marshall *et al.*, 1999).

2.5 Effect of slope gradient and role of aspect

In this section, the steepness of the slope and the effect of land class on soil slippages are discussed. The slope gradient for steep hill country is greater than 25^0 and hill country slopes have a slope range of 15^0 to 25^0 (Lynn *et al.*, 2009). Lynn *et al*. (2009) also distinguished that a slope range of $26\text{-}35^0$ is termed as steeplands. There are many moderate slopes between 10^0 and 20^0 in Manawatu–Wanganui hill country and their landsliding probability is almost one third of that for slopes greater than 30^0 (Dymond *et al.*, 2006).

Slope is the major limitation for potential productivity of hillsides, since it increases the surface/map area ratio by 30% on a 35^0 slope (Grant *et al.*, 1973). Slope gradient has a direct impact on the extent of shallow soil slippage (Hancox & Wright, 2005) and thus the effect of the slope classes can be seen at Agresearch's Ballantrae Hill Country Research Station farm, Woodville (the site selected for this experiment) which belongs to Land Use Capability class 6. There are numerous soil slip scars at this site and both old and new scars are visible. Similarly, the majority of soils between a slope gradient of $25\text{-}40^0$ are susceptible to slippage under pastoral farming in New Zealand (Sparling *et al.*, 2003).

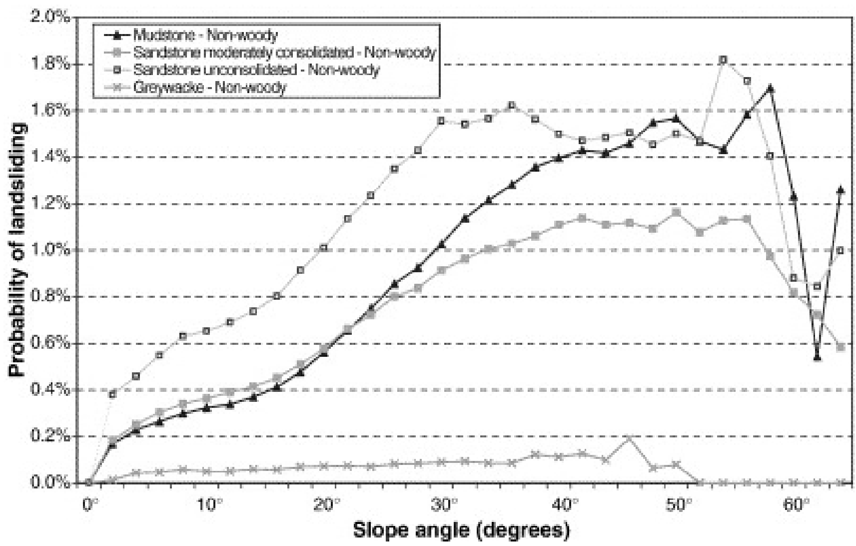

Figure 2.11. Landslide probability under non-woody vegetation versus slope angle for the four main rock types in Manawatu–Wanganui hill country. Landslide probability is calculated as the proportion of land in erosion scar (Dymond *et al.*, 2006).

Figure 2.11 shows the different probabilities of land-sliding on pasture lands and slope angle for the four common rock types in Manawatu–Wanganui hill country farms. Between 0^0 and 40^0 land-sliding probability generally increases linearly with increasing slope: It stays constant until 55^0 and then declines slightly. The gradual and linear rise of land-sliding probability contravenes the concept that a threshold slope above 20^0 has a higher probability of landsliding. These results also suggest that sandstone and mudstone on pastoral hill country, even below 20^0, are susceptible to land-sliding. Land cover affects the probability of land-sliding for each of the rock types (Dymond *et al.*, 2006).

Table 2.7. Slope thresholds for rock types in the Manawatu- Wanganui region during extreme rainstorm if the vegetation cover is not woody (Dymond *et al.*, 2006).

Rock/regolith type	Slope threshold (degrees)
Loess	26
Tephra	26
Mudstone	24
Crushed mudstone/argillite	24
Sandstone/limestone	28
Greywake/argillite	28
Volcanic rocks	28

Other literatures cited offer similar discussions on the steepness of the slope and erosion. They highlight that soil slippage increases, as slope gradient increases (Begueria, 2006; Brooks *et al.*, 2002; Crozier, 1986; Hancox & Wright, 2005; Jankauskas & Fullen, 2002; Luckman *et al.*, 1999).

There are a few reports on the effects of aspect on pasture productivity in New Zealand. Aspect affects the hydrology, because southern facing slopes are generally wetter, with lower evapotranspiration rates, than north facing aspects (Hancox & Wright, 2005).

Two experiments, which examined the effect of artificial shade on net pasture herbage accumulation, botanical composition and soil characteristics, were conducted between 1994 and 1999, at Whatawhata Research Centre near Hamilton. This study highlighted that the most influential factor was the level of shade, which accounted for 68% of the variation and it reduced net herbage accumulation by 20-80%, compared to open pasture. The second most influential factor was shade duration, which accounted for only 6% of the variation (Dodd *et al.*, 2005).

A study was conducted for three years on slope gradients of 20^0-30^0 from Marlborough to North Otago. The south facing aspects produced on average 14% more dry matter than the north facing aspects. Both aspects had spring and autumn growth peaks and a summer depression, which was greater on the north facing aspect (Radcliffe *et al.*, 1977). Gillingham (1984) found similar results with higher soil moisture on south facing aspects than north facing aspects at all times of the year.

Table 2.8. Effect of slope and aspect on *Trifolium repens* flower head appearance per m^2 on rotationally grazed pasture at Ballantrae AgResearch farm. The main effect of aspect, and the slope aspect interaction, were significant at P < 0.001 (Chapman & Anderson, 1987), (Numbers represent flowerhead appearance per m^{-1}).

	Aspect		
Slope	South-west	North-west	Mean
Flat	95	97	96
Steep	112	74	93
Mean	104	86	

Table 2.8 illustrates that the south west facing aspect had higher flower-head density, indicating higher plant density. Alternatively, the north west facing site also had seedling emergence, but this was less than the south west facing steep slopes (Chapman & Anderson, 1987). In this experiment, there could be a high possibility of high seedling emergence on the south facing aspect. This would generally be due to higher soil moisture and shade influencing a higher emergence rate on the south aspect slip surface. Nevertheless, both sites were open for livestock and hence seedlings may have been affected by livestock defoliation.

2.6 Influence of defoliation and revegetation

Grazing is thought to be safe until stem elongation commences, because young seedheads are below grazing height and thus there is little chance of their removal by grazing (Rowarth, 1990). Grazing can have a wide influence on the persistence of different pasture species, since livestock selectively defoliate, via preferential grazing on different pastures (Nicol, 1987).

Natural reseeding plays a role in pasture persistence and composition in hill country (Rattray, 2005). Seed production from the established pasture species may influence the latter’s chances of survival and active colonisation (Rowarth, 1990).

2.7 Seeds, oversowing and seedling emergence

Tosun *et al.* (2003) stated that if sufficient nutritive materials are not stored in small or shrivelled kernels, then the seeds usually die — even if they germinate. Coffman (1961) stated that a seed is a living organism and must be dealt with as such, if good results are to be expected, under favourable conditions for germination. Germination of seeds results from physiological and biological processes and thus a dormant seed is one that fails to germinate, when it is rehydrated in an environment that supports normal germination (Bewley, 1997).

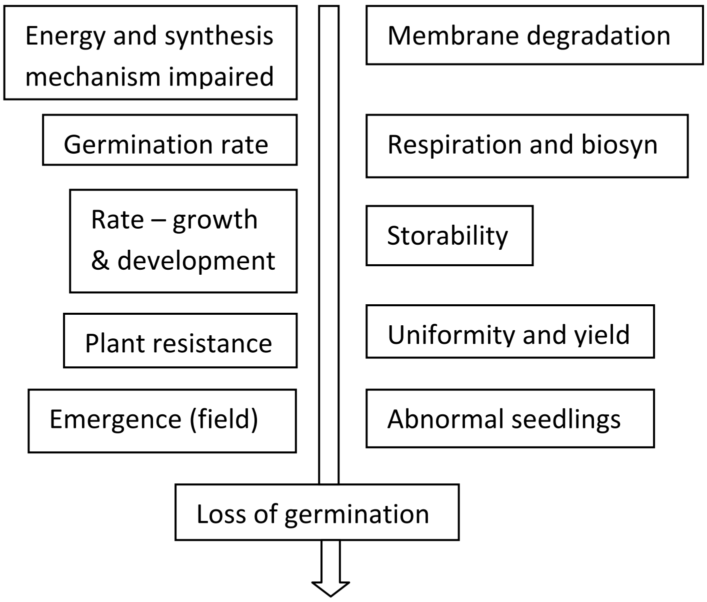

Figure 2.12. Variability associated with differences in seed vigour that affects the germination processes of seeds (McWilliams *et al.*, 1970).

McWilliams *et al.* (1970) stated that during seedling emergence, many factors have to be favourable, in order for the seed to germinate (Figure 2.12). Seeds that perform well are termed 'high vigour seeds', whilst those that perform poorly are called 'low vigour seeds'. Seedling vigour involves the rate of extension of both the root and shoot, which is often correlated with a germination rate (McWilliams *et al.*, 1970). In particular, the rapid elongation of the seedling root is considered to be a pre-requisite for successful establishment in hill country (Simpson, 2001).

In terms of pasture establishment, hill country always poses a challenge for farmers, due to steepness of the slopes. Oversowing is the most desirable method, since mechanical sowing is impossible. This is a method of dispensing seeds that creates even spacing between the seedlings (Pottinger *et al.*, 1993). The soil surface is often extremely patchy, when viewed at the scale of a seed or seedling. This spatial heterogeneity in the seedbed micro-environment is a major factor that determines whether a germinating seed will survive to emergence (Bellotti & Moore, 1994; Kutilek & Nielsen, 1994). The smaller the seed, the greater the relative heterogeneity it will meet. Larger seeds may obtain dominance over smaller seeds and thus have a greater chance of survival (Fenner, 1983). A seed lying free on a hard soil surface may be unable to effect root penetration (Harper *et al.*, 1970). Establishment is a race against time, in which seedlings change in physiological resistance and thus develop an escape or avoidance mechanism, through morphological development (Torssell, 1976). Ultimately, this will result in survival of the oversown pasture species.

Numerous investigations have disclosed that favourable conditions alone are sometimes insufficient for obtaining satisfactory germination of viable seeds and thus, it has been shown that delayed germination has occurred (Coffman, 1961). Oversown seeds stand a lesser chance of survival than sown seeds, at particular soil depth, since germination needs optimum temperature, moisture (Cook & Ratcliff, 1984) and also growing media.

Two of the major components of seed crops are the weight of each seed and the number of seeds a plant produces (Chapman & Anderson, 1987). The latter depends upon the number of fertilised flowers in the spikelet and on the ear, in addition to the number of ears on the tiller and the number of reproductive tillers in the plant (Rowarth, 1990). Malnourished plants will not be able to produce large numbers of viable seeds (Wedderburn *et al.*, 2005). Hence, higher seed rates may increase the possibility of survival and thus supplement wider colonisation of these bare slip surfaces. The three pasture species selected for this trial are well established species in New Zealand.

2.8 Pasture species selected for revegetation

The three pasture species selected for this revegetation trial are commonly used in pastoral hill country farms in New Zealand and hence, these seeds are readily available throughout New Zealand. Numerous studies have highlighted the success of *Trifolium repens* on hill country farms (Rattray, 2005; White & Hodgson, 1999). *Holcus lanatus* has been also regarded as a successful pasture species to colonise numerous soil types in New Zealand (Smale *et al.*, 1997; White & Hodgson, 1999). Nevertheless, *Lotus pedunculatus* is also regarded as the pioneer legume to revegetate in a low soil fertility environment (Douglas & Foote, 1994; Lambert *et al*. 1993; Wedderburn *et al.*, 1996).

2.8.1 White clover

White clover *(Trifolium repens)* is New Zealand's most important forage plant. It is a perennial legume with higher growth rates during spring, summer and autumn (Warren, 2001). It fixes nitrogen in pastures and provides high quality herbage feed. *Trifolium repens L.* cv. 'Grasslands Tahora' has been bred for its persistence on hill country farmland (Clark *et al.*, 1984) and it can contribute to the revegetation of soil erosion slip scars (Lambert *et al.*, 2000), by increasing soil nitrogen in the exposed subsoil slipped surfaces (McLaren & Cameron, 1996). Hence, strong clover growth is essential for hill country.

2.8.2 Morphological features

This is a prostate legume with stolons initially radiating from the buds in the axils of the rosette of leaves. The leaves are trifoliate with oval leaflets (White & Hodgson, 1999). The first stage of growth is a taprooted plant, but this later forms a network of stolons, forming new plants at the node, as the original taprooted plant dies (Rattray, 2005). The main structural component of the plant is the stolon, which consists of nodes and internodes. Each node produces one trifoliate leaf, a lateral bud and two nodal root buds. These root buds will grow, if they come into contact with moist soil shortly after they emerge (Marriott *et al.,* 1997). The average seed size is 1 mm in diameter and an average of 1000 seeds are produced per plant (Roy *et al.*, 2004). *Trifolium repens* seed yields have been recorded at an average of 300kg/ha (Rowarth, 1998).

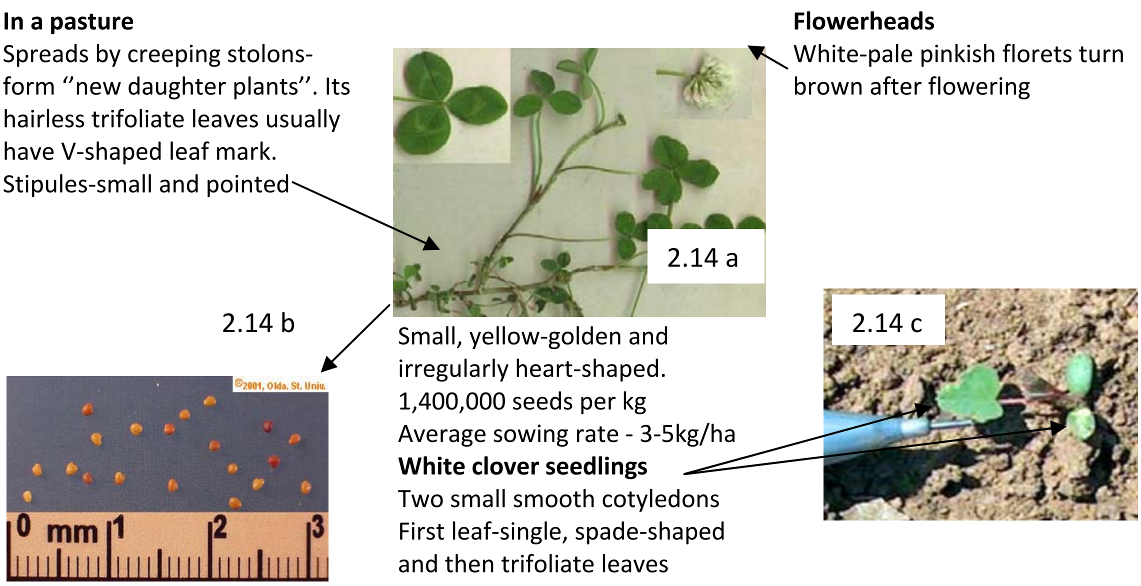

Figure 2.13 Morphological features of white clover. Adopted from Stewart & Charlton, (2006); Caddel, (2008).

2.8.3 Seasonal persistence

Caradus & Dunn (2000) highlighted that the medium to small leaf typed *T. repens* breeding lines and cultivars, which achieved high growth at AgResearch's Ballantrae station over three years trials, had New Zealand parentage. Persistence is highest in *T. repens* cultivars that produce the highest density of stolons (Marriott *et al.*, 1997). Eventually the parent plant dies after a few years and thus the plant must develop roots from the stolons, in order to persist (Brink *et al*., 1999). The plant may also flower and produce viable seeds, particularly under lax grazing (Garay *et al.*, 1997). This allows regeneration from seeds, a method that can be important under summer-dry conditions (Stewart & Charlton, 2006). Furthermore, during summer, the stolons in between the new plants tend to die and senescence, thus leaving a large number of small plants, not all of which survive (Vipond *et al.*, 1997).

Grasslands Tahora, a small-leaf type, is low growing, with many small and thin leaves. This makes it extremely difficult for grazing animals to remove them and thus it gives the plants an excellent tolerance to severe defoliation (Warren, 2001). They are best used under close, continuous grazing, particularly with sheep (MAF, 2009; Stewart & Charlton, 2006). In one study, the emergence of Grasslands Tahora averaged 60% of oversown seed. However, this was oversown on existing sward cover, in order to improve the botanical composition and they were subjected to treading before oversowing (Hume & Chapman, 1993).

T. repens produces an average of 1000 seeds/plant (Hugo *et al.*, 1991). However, the viable seeds from this yield may be generally low, due to a lower fertility environment (Wedderburn *et al*., 2005) of soil slip surface.

Alternatively, mean tiller numbers per plant, at the final harvest in the lowest photosynthetically active radiation (14% ambient), were higher for *T. repens* than in the unshaded treatment (Devkota, Kemp & Hodgson, 1997). A lesser amount of solar radiation interception on the south aspect slip surface (Chapman & Anderson, 1987), may have had a favourable effect on seedling emergence and early establishment.

Clover seed germination is sensitive to soil temperature, with 5.8^{0}C being close to the minimum for germination (Rattray, 2005). The ideal soil temperature for seedling emergence for *T. repens* is $15\text{-}10^{0}$C (Hill & Luck, 1991). The ideal soil temperature for optimum growth of *T. repens* is between $20\text{-}24^{0}$C (Karsten & MacAdam, 2001).

Furthermore, both *T. repens* and birdsfoot trefoil exhibited a reduction in their rate of germination and increases in the time needed for germination, at the two lowest soil temperatures, 12-6 and 8-2°C, respectively. This shows that, in terms of germination, *T. repens* is susceptible to low winter temperatures.

Water stress severely restricts the growth of white clover and phalaris but then, after rainfall, the growth rate is higher for white clover (Liu & Kemp, 1992). In terms of survival, clover sheds its leaves and conserves a larger proportion of carbohydrates in the stolons, in order to overcome drought (Karsten & MacAdam, 2001). After a 30 day drought and 10 day recovery period with soil moisture, the carbohydrate storage concentrations in droughted plants, relative to irrigated controls, were higher in *T. repens* than other pasture species. *T. repens* shows higher levels of persistence than perennial ryegrass and tall fescue, in terms of water stress (Karsten & MacAdam, 2001).

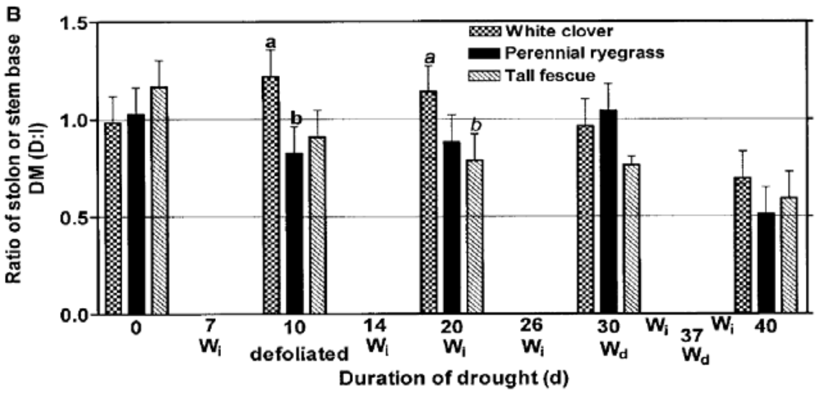

Figure 2.14. (A) Total leaf dry mass per pot; (B) Ratio of leaf dry mass; droughted: irrigated plants. Wi indicates when irrigated plants (controls) were watered. Wd indicates when droughted plants were watered. Bars represent 1 + S.E. Different bold letters (a, b, and c) indicate species means that were significantly different ($P < 0.05$) within each harvest date. Different italicized letters (a and b) indicate species means that were significantly different ($P < 0.1$) within each harvest date (Karsten & MacAdam, 2001).

T. repens can be a useful pasture species for revegetation work, due to its ability to fix nitrogen (Barratt *et al.*, 1995). The proportion of atmospherically derived N in a pure stand of white clover amounted to 60–80% of the total N content, equivalent to 109, 110, 103 and 90 kg N ha^{-1} for the treatments of 3, 24, 48 and 72 kg N ha^{-1}, respectively (Høgh-Jensen & Schjoerring, 1997). Hence, any survival would be beneficial to the revegetation process, in terms of increased fertility. McNeill *et al.* (1997) also predicted the average amount of soil N (mg) that can be fixed per clover plant at different dates after sowing (Figure 2.16).

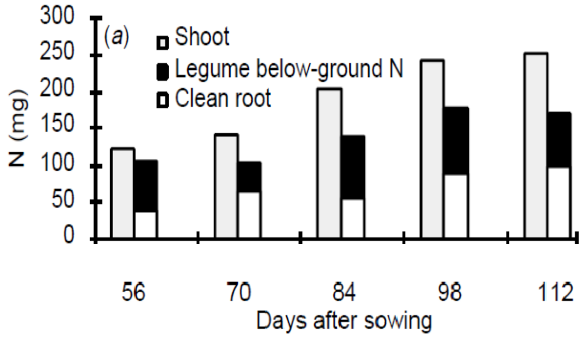

Figure 2.15. Measured shoot and clean root nitrogen and estimated legume derived nitrogen in other fractions below ground (mg) for subterranean clover (McNeill *et al.*, 1997).

Similarly, an experiment in the mountainous region of Azad Jammu and Kashmir, Pakistan, highlighted that *T. repens* had an average of 20 nodules per plant with a potential to fix N_2 and thus it can fix an average of 77 kg N/ha, which is a very encouraging figure, even under low moisture conditions (Abbasi & Khan, 2004). By increasing soil pH from 4.71 to only 4.99 and an increase in Olsen P in soils, a positive response was seen with nodulation and rihzobial population in *T. repens* (Staley, 2003). Numerous studies have highlighted that net herbage production increases with fertiliser inputs or in soil with fertility (Beare & Tregurtha, 2004; Minson *et al.*, 1993; Warren, 2000; Woodman *et al.*, 1998). However, lower soil N may enhance better root nodulation, as studies also suggest that higher soil N restricts root nodulation (Hedley, 2005). *T. repens* may have a competitive edge over grasses in low fertility soils.

2.8.4 Yorkshire fog

Yorkshire fog *(Holcus lanatus)* is a traditional pasture species, which has been widely used for its growth performance and persistence on low fertility soils in New Zealand. *H. lanatus* belongs to the Gramineae family and it attains to a maximum height of around one metre. *H. lanatus'* average seed yield is 200-300kg/ha. Lower soil fertility may decrease the seed yield and it may also produce large numbers of non-viable seeds.

2.8.5 Morphological features

H. lanatus is a perennial grass, which is recognised by its velvety surface (soft, hairy) on both sides of the leaves and its distinctive greyish seed heads. The stems with rhizomes grow outwards along the ground (White & Hodgson, 1999).

In pasture, its leaves look flat and dull and soft and downy. It is usually very densely tufted and often dewy (Chaves *et al.*, 2006). It has green, striped foliage, and its tiller bases are often pinkish/purplish in colour. Its leaf has a conspicuous white ligule, where the leaf blade meets the leaf sheath. The leaf blades are velvety and pointed and the flower-heads are 100-200 mm long (Stewart & Charlton, 2006).

2.8.6 Seasonal persistence

It is tolerant to frosts, wind and water logged soils and it also grows throughout the year, irrespective of the climatic constraints, but it establishes well during early-spring (Chaves Chaves *et al.*, 2006). This species flourishes well with adequate moisture content (Shiferaw *et al.*, 1992) or in damp, wet, infertile situations (Chaves *et al*., 2006). The limitations of this species can be drought impact during late summer, when the Manawatu-Wanganui region has low rainfall.

A study was conducted at AgResearch, Whatawhata, on the botanical composition and genetic structure of North Island hill country pastures after oversowing different pasture species at low and high soil fertility site. After 16 months *H. Lanatus and Agrostis capillaris,* were ranked as the dominant species of different grasses. However, delayed germination occurred at the first two dates of data collection (Wedderburn *et al*., 1996).

Table 2.9. The macronutrient composition (dry-matter %) of pasture and weed species from organic dairy pastures (Harrington *et al.*, 2006).

	N	**P**	**K**	**S**	**Ca**	**Mg**	**Na**
Perennial ryegrass	3.37	0.480	1.97	0.530	1.77	0.253	0.618
White clover	3.77	0.370	3.80	0.347	0.42	0.173	0.182
Chicory	4.56	0.347	2.83	0.213	1.19	0.237	0.205
Narrow-leaved plantain	4.35	0.663	3.80	0.627	1.18	0.393	0.591
Yorkshire fog	2.70	0.400	3.20	0.260	0.36	0.173	0.175
LSD (P<0.05)	0.84	0.071	1.06	0.148	0.473	0.074	0.161

Table 2.9 explains the importance of soil fertility and the performance of *H. lanatus,* in comparison with other pasture species. *H. lanatus* nutrient composition was the least compared to other pasture species. Other literatures also refer to *H. lanatus* as a low fertility grass (White & Hodgson, 1999).

A study was conducted on *H. lanatus* seedling performance, under different levels of pH. Mean root and shoot elongation was higher at pH of 5.6 but it decreased with increasing acidity (Kidd & Proctor, 2001). *H. lanatus* was more productive than perennial ryegrass at fertiliser application rates of 0 kg N and 120 kg N, but not at higher N rates. This infers that *H. lanatus* can perform well in soils deficient in soil N (Frame, 1991).

As slip surfaces resemble a low fertility subsoil environment, the possibility of *H. lanatus* achieving higher emergence and persistence than *T. repens* is worth investigation. Furthermore, mean tiller numbers per plant at the final harvest in the lowest photosynthetically active radiation (14% ambient), were significantly higher ($P < 0.0001$) for *H. lanatus* than for the other grass species (Devkota, *et al.*, 1997). Hence, it can be assumed that the south facing aspect slip surface may have higher seedling emergences than the north facing slip surface.

2.8.7 Lotus pedunculatus

This pasture legume is also referred to as 'Greater Birdsfoot Trefoil', 'Maku Lotus' or 'Greater Lotus'. *Lotus pedunculatus* has been used widely in New Zealand to develop improved pastures out of poor grasslands. It is usually considered a pioneer legume for land development and early revegetation of eroded areas (Hugo *et al.,* 1991).

2.8.8 Morphological features

L. pedunculatus is a perennial legume with a long tap-root that develops a crop of upright stems during the growing season. It is a scrambling stoloniferous plant with a stem that grows up to 1m long, or it scrambles to 2m in length (Roy *et al*., 2004). *L. pedunculatus'* average seed yield is 50-200 kg/ha (Rowarth, 1998) and thus it can regenerate via natural seeding. It also spreads through rhizomes, with adventitious roots at their nodes. The leaves are trifoliate but the stipules look very much like leaflets, with the appearance of a compound leaf with five leaflets. The flowers are yellow (White & Hodgson, 1999).

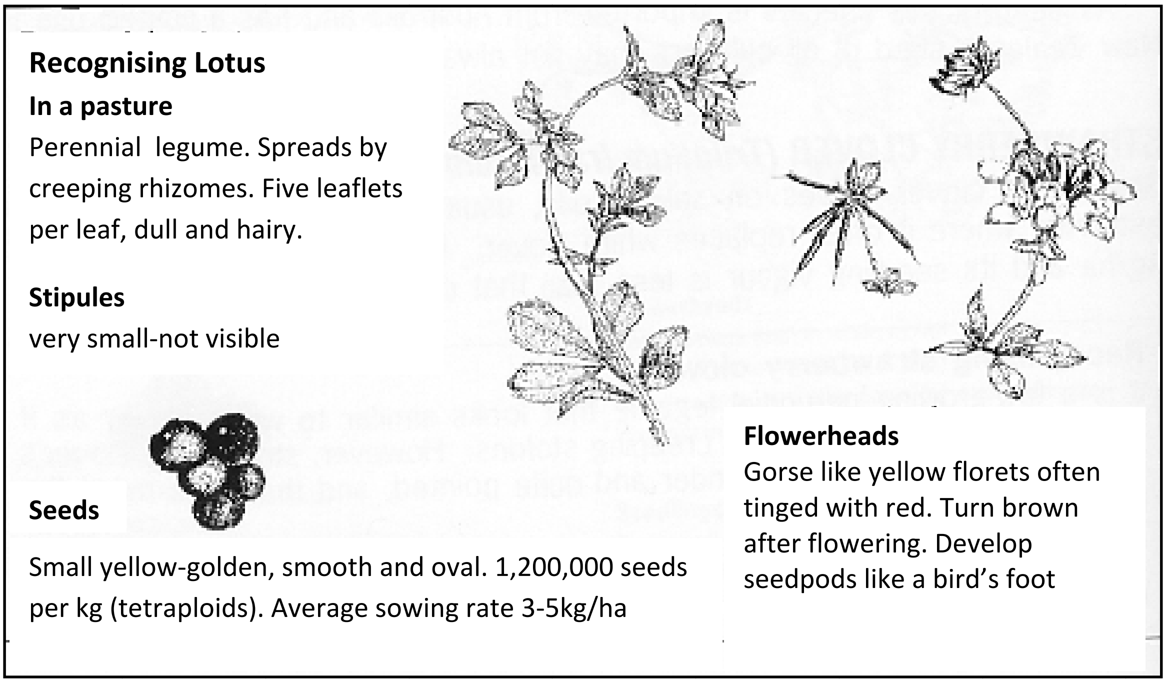

Figure 2.16. Morphological features of *L. pedunculatus.* Adopted from Stewart & Charlton, (2006).

2.8.9 Seasonal persistence

Grazing should be lenient and more than for white clover. Legume establishment is successful on back slopes, because of less competition from grass (Guretzky *et al.*, 2004). Main growth is during spring and summer and thus it is recommended for sowing in late winter to early spring, or late summer to early autumn (Warren, 2001). *L. pedunculatus* shoots in autumn can spread well over a 1m and it roots at intervals and become rhizomatous. This ensures that *L. pedunculatus* persists and spreads from year to year (Hugo *et al.*, 1991). *L. pedunculatus* produces the highest yields in areas with mild summers and heavy dews. Sowing rates are 2-5kg/ha, with higher rates used for tetraploid cultivars, because of their seed size (White & Hodgson, 1999). The tetraploid seeds result in more vigorous seedlings that establish faster than diploid cultivars. The sowing seed rate for *L. pedunculatus* is between 3-5kg/ha (Stewart & Charlton, 2006). *L. pedunculatus* seeds are an average of 1.2 mm in diameter and there is an average of 600-900 seeds per plant (Clark *et al.*, 1984; Kelman & Forrester, 1999).

Establishment is slow (especially at low temperatures) and the plant is not very competitive at the early stages of growth, in comparison with other legumes (Hugo, *et al.*, 1991; Langer, 1994). The optimum temperature for shoot growth is between 18-22^{0}C (Blumental & Harris, 1998) and the minimum temperature requirement for seedling emergence is 5^0C (Kelman & Forrester, 1999). In terms of seedling emergence, *L. pedunculatus* grew better at 24-20^0C than *T. repens* (Hill & Luck, 1991).

It shows a higher tolerance to water logging and thus it performs well under wet conditions (Fulkerson & Slack, 1996; Shiferaw *et al.*, 1992). The growth rates of Grasslands Maku was measured as soil moisture changed from field capacity (FC) to 20% and FC to FC again, in three regrowth cycles. As moisture stress was induced by increasing the temperature, proportionately larger reductions in growth rates were seen in *L. pedunculatus* (Anuraga *et al.*, 1993). Hence, *L. pedunculatus* can survive at 20% soil moisture in the field.

Particularly at low levels of fertility and in moderate drought, *L. pedunculatus* may out-yield *T. repens* in grazed pasture (Hugo *et al*., 1991). *L. pedunculatus* is a forage legume suitable for infertile and acidic soils (White & Hodgson, 1999). It is also more tolerant to soil acidity, low phosphate and excesses of manganese and aluminium, than white clover (Clarkson, Mears, Lowe, & Lloyd, 1991; White & Hodgson, 1999).

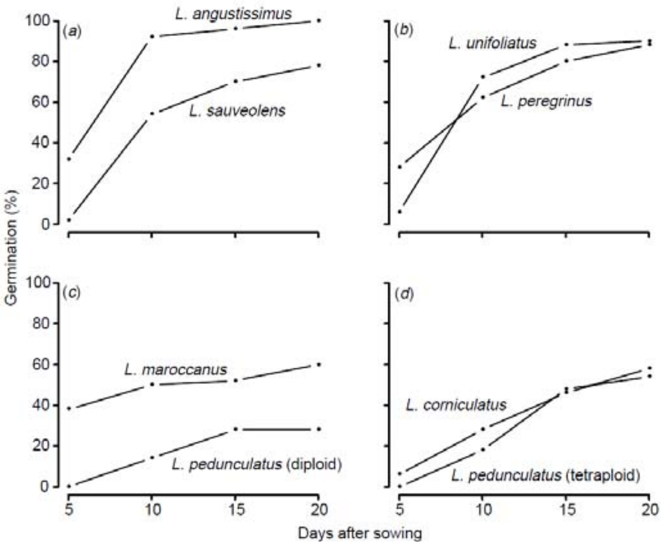

Figure 2.17. Percent germination over 20 days at 5^0C of lotus species categorised by life cycle and seed size: *(a)* annual, small seeded; *(b)* annual large seeded; *(c)* perennial, small seeded; and *(d)* perennial large seeded (Kelman & Forrester , 1999).

Figure 2.17 illustrates the germination of *L. pedunculatus* under controlled conditions in NSW, Australia. The seed production and abnormal seedling growth of *L. pedunculatus* and other lotus cultivars are not unexpected (Kelman & R. Forrester, 1999; McKersie & Tomes, 1982) but abnormal seeds also germinate (Kondo, 1993). Some specific conditions during seed development may have influenced seed quality. Nevertheless, larger seeds (tetraploid) perform better than the lotus species with smaller seeds. The larger seeds perform better above 5^0C (Kelman & Forrester, 1999).

A study also highlighted that a higher seed rate for *L. pedunculatus* is needed for better establishment and it performs better in low fertility and high rainfall areas (>1000mm/yr) (Kemp *et al.*, 1998). Seedling emergence of *L. pedunculatus* showed significant response to fertiliser N and superphosphate placement. However, seedling numbers declined in all treatments over summer and 32 weeks after oversowing (Woodman *et al.*, 1998). In contrast, the recent slip surface environment will have negligible botanical competition but may be subjected to extreme climatic conditions for survival. Nevertheless, a plant population of no more than 20-30 plants per m^2, is sufficient (Langer, 1994).

The current literature provides necessary evidence that the three species — *T. repens*, *H. lanatus* and *L. pedunculatus* — are dominant pasture species, which may have the ability for early establishment and thus this may lead to stabilisation of slips by a reduction in the length of the recovery period. Benefits will include a reduction of sedimentation losses to streams and rivers, whilst improving productivity over time.

The current literature provides evidence that *T. repens, H. lanatus* and *L. pedunculatus* are suitable pasture species which can be tested for revegetation work, via oversowing on recent slip surfaces. The results may provide in-depth knowledge, through the measurement of seedling emergence and early establishment, in field-based conditions.

Chapter 3 Methodology

3.0 Introduction

Three species namely *Trifolium repens*, *Holcus lanatus* and *Lotus pedunculatus,* were oversown on two recent soil slip faces on north and south facing aspects at AgResearch's Ballantrae Hill Country Research Station, Woodville. Both slips were located on Land Use Capability Class 6 (28-33^0). The effects of soil temperature and moisture on seedling emergence and summer persistence were recorded during the trial period. Soil properties on the two trial sites were tested and analysed according to methods in Blakemore *et. al*., (1987). The data were analysed by a univariate procedure and repeated measures analysis of variance in order to determine the performance of the three pastures species in terms of seedling emergence and early establishment on recent soil slips.

3.1 Location of the Ballantrae Agresearch farm

AgResearch's Ballantrae pastoral farm is situated in North Island hill country (15- 25^0) and steep land (> 25^0) near Woodville (Appendix 11) and is about 35 km east of Palmerston North, on the eastern side of the Ruahine Ranges. The long term average rainfall is 1200 mm/year and the property rises to 350 m above sea level. At Ballantrae, the rainfall variability is historically high and thus wet and dry periods occur. Rainfall is more variable in summer and thus it can have a marked effect on seedling emergence and persistence. The station winters 1,180 breeding ewes and hoggets and 340 cattle. During this experiment, the average stocking rate was 10.4 su/ha. The farm covers 485 ha of summer-moist, moderate to steep hill country, of which 330 ha is pasture. The topography makes mechanical pasture conservation impossible.

3.2 Description of study sites at Ballantrae.

The two research sites were located within the sheep grazing area. Both soil slips occurred during the winter of 2008 (Appendix 10). The slips were large enough to accommodate four treatments and four replicates. The altitude of both slips was within the range of 10 m and thus the precise altitude difference was negligible. One slip was selected on a north facing aspect (slip 1; S 40°38.5322' E 175°53.7207') and the other had a south facing aspect (slip 2: S 40°38.5122' E 175°53.7187'). The slips were situated on tertiary-marine sedimentary mudstone/siltstone lithology and Mangamahu silt loam. Both of the sites were not rotationally grazed and, therefore, they were accessible to sheep during the entire trial period. Soil slips are where regolith has been to some extent stripped out and, hence, the slipped area resembles the subsoil environment.

A trial area of 4 m x 5 m was selected from each of the slip faces (Figure 3.1). The debris tail area was excluded. These slips had not been subjected to any over-sowing, nor any fertiliser application, since the slippage events. During the entire trial period, only minimal seepage was witnessed but the runoff marginally affected two replicates on the north facing aspect (Figure 3.2).

Figure 3.1. The two soil slips at the beginning of the revegetation trial. The left picture is the north facing slip face and the right picture is the south facing slip face.

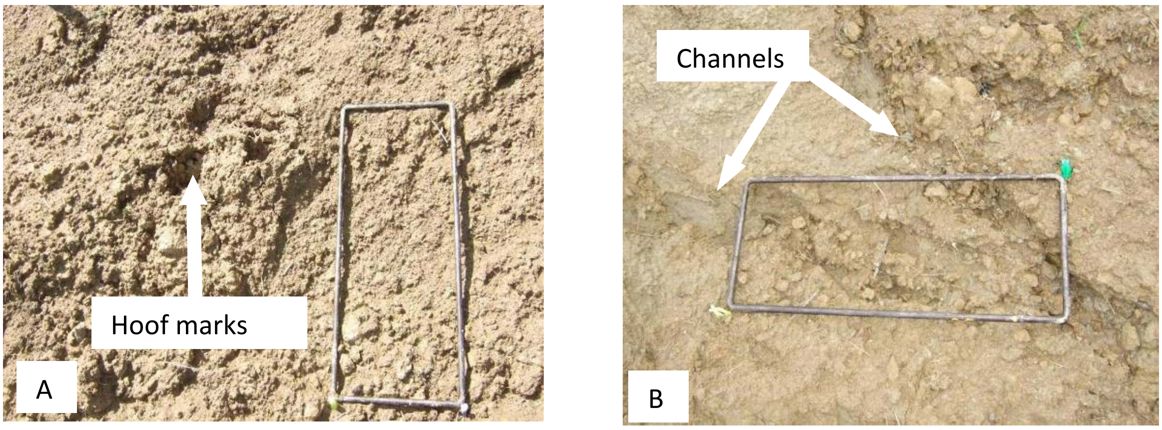

Figure 3.2. Pictures showing recent hoof marks (A) on south facing slip and the effect of runoff on one of the north facing replicates. Some seeds may have washed away through these channels (B) but others survived.

3.3 Experimental design

The revegetation trial was conducted under a randomised plot design, comprising four treatments and four replicates. Each plot size was measured and pegged at 1 m^2 and different treatments were randomly distributed across the entire trial area. Between the second and third replicates, 1 m was used as a work area, during seedling counts. This work area provided easier access to the individual plots, during seedling counts.

Slip 1 North facing steep hill country Slope angle 33^0				
R1	**T4**	**T2**	**T3**	**T1**
R2	**T2**	**T4**	**T1**	**T3**
1 m work area				
R3	**T1**	**T3**	**T4**	**T2**
R4	**T2**	**T3**	**T1**	**T4**

Slip 2 South facing steep hill country Slope angle 32^0				
R1	**T2**	**T3**	**T4**	**T1**
R2	**T2**	**T1**	**T3**	**T4**
1 m work area				
R3	**T1**	**T2**	**T3**	**T4**
R4	**T4**	**T3**	**T1**	**T2**

Figure 3.3. Distribution of individual treatments (T) and replicates (R) under randomised block design at the two slip sites.

Table 3.1 illustrates the seed rates of *T. repens* (Grasslands Tahora), *H. lanatus (*Massey Basyn), and *L. pedunculatus* (Grasslands Maku), per hectare*.* It also provides information on the seed rate per m^2. Notably, all species had the same seed rate.

3.4 Field materials for revegetation trial

1. 4 mm rope
2. 100 g pasture seeds (T. Ripens, Holcus lanatus, L. pedunculatus)
3. 40 pegs
4. Button probe thermometer
5. 0.1 m^2 quadrat
6. Clinometer (Field slope & aspect check).
7. Digital camera

Table 3.1. Description of the treatments, seed rates, and plot rates.

Treatments	Pasture species	Seed rate (kg/ha)	Plot rate (g/m^2)
1	*Holcus lanatus* (Massey Basyn)	6	0.6
2	*Trifolium repens (Grasslands Tahora)*	6	0.6
3	*Lotus pedunculatus (Grasslands Maku)*	6	0.6
4	Control		_

3.5 Soil moisture

At both research sites the gravimetric water content (W%) percentage was recorded at intervals of two weeks, from 0-5 cm depth. Four samples were taken separately from both trial sites. Gravimetric water content (%) was also converted to volumetric water content (%). The following formula was used for this calculation i.e. $\theta = GWC * P_b$

The Ballantrae meteorological station is located on one of the hilltops and it was approximately 500 m from both trial sites. Rainfall data and soil moisture, at 10 cm, was also recorded, during the entire trial period.

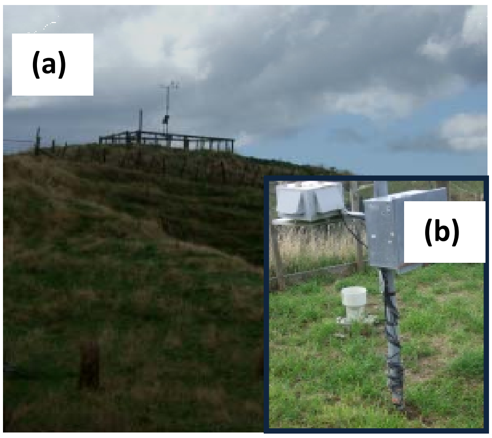

Figure 3.4. Location of the meteorological station at AgResearch's Ballantrae farm near Woodville.

Soil moisture (VWC %) was also recorded during the trial period at the meteorological station. However, this was not a good prediction for bare soil slip surface moisture due to pasture cover or evapotranspiration (Figure 3.5b). Secondly, the position of the meteorological station was located on a hill top (Figure 3.5a), while both slip sites were on a class 6 slope.

3.6 Soil temperature

Button temperature probes were placed on both north and south aspect facing slips. The first set of probes was placed on the bare soil surface in order to assist in the understanding of temperature patterns on the seed landing site, during oversowing. The second set of probes were placed at a depth of 5 cm under the exposed soil surface and covered with soil.

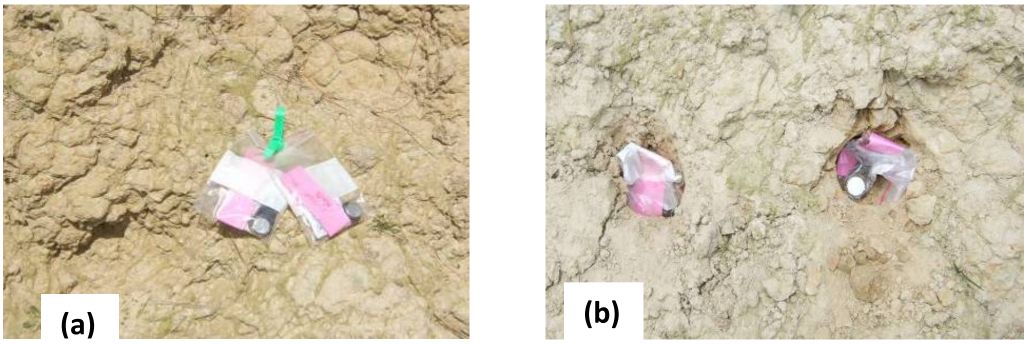

Figure 3.5. Placement of button temperature probes to record the soil surface temperature (a) and temperature at 5 cm depth (b) (covered after with soil) on both the soil slips surfaces.

The button temperature probes were adjusted to record soil temperature at two hourly intervals. From these data, a weekly mean temperature was calculated for the entire trial period. The weekly maximum and minimum temperatures were also calculated to provide a detailed approach on the climatic extremes on the north and south facing slip surfaces. The soil temperature was compared with the pattern of seedling emergence in order to identify the effects of temperature on seedling germination on the exposed soil slip surfaces.

3.7 Germination test and oversowing

Germination tests weres conducted by 'Seed Technology Services' at Massey University in order to assess the viability of the seeds. Prior to the germination tests, sample seeds were pre-chilled at 5^0C for 2 days.

The seeds were weighed and bagged separately inside the already marked sampling bags. Two grams of air-dried sand was added and mixed into the individual seed bags. Oversowing was carried out on 29th of September, 2008. The seeds were broadcasted from an approximate height of 1 m, bearing in mind that they needed to land within the area of the intended plot.

3.8 Visible seedling count

Within the individual replicates, 0.1 m^2 quadrats were placed and their positions were marked accordingly (Figure 3.6). During successive seedling counts, these quadrats were placed in the same position, within all the replicates. From this time onwards, any visible seedlings were counted with the aid of a seedling counter. Natural plant colonisers at the time of oversowing were negligible (Figure 3.1). However, any identifiable seedlings were recorded at the time of oversowing. Subsequently, seedling emergence from natural vegetation was also recorded. Field emergence was monitored at four different stages: early-spring (Day 15); late-spring (Day 45); early-summer (Day 90); and late summer (Day 120). Similarly, any other visible natural seedling emergence within the quadrat area was also recorded and thus were classed as weeds.

Figure 3.6. 0.1 m^2 quadrats were placed and positions were marked within the individual plot area.

3.9 Field materials for soil properties

1. Soil auger
2. Bulk density ring
3. Hammer
4. Wood block
5. Plastic bags

3.10 Soil sampling and analysis

Figure 3.7. Soil sampling beside the soil slips

Physical and chemical tests were conducted in order to provide a detailed picture of soil properties on both soil slip faces. Five soil auger samples, to a depth of 0-7.5 cm, within the site of revegetation trial, were randomly taken from the exposed slipped faces on the trial site and bagged together, collectively. Similarly, five auger samples were also taken separately from nearby pasture (Figure 3.7). These soil samples were air dried, mixed and sieved through a 2 mm sieve.

3.11 Soil physical properties

3.11.1 Bulk density

Bulk density is the density of the whole soil, including the volume of pores, but excluding the mass of water (Blakemore *et al.*, 1987). The samples in this study were taken from the soil surface at a depth of 0-5 cm. The size of the bulk density ring used was 5 cm in both diameter and depth. Samples filling less than 95% of the density ring by volume were rejected. Samples were put in sealed plastic bags in order to restrict moisture loss. Any extra soil was sliced to match the volume of the ring and small losses were replaced to volume. After weighing for fresh weight samples were placed in an oven at 105°C for 48 hours. Bulk density was calculated from the following formula:

$$\text{Bulk density } (P_b) = M_s / V_t$$

3.11.2 Soil porosity

Porosity (f) is the fraction of the soil volume that consists of pores (holes) and it has no unit (Blakemore *et al.*, 1987). Soil porosity is not measured directly and thus it has been calculated from the bulk density (P_b) and the particle density (P_s). The particle density of most B and C horizons is approximately (2.6 mg/m^3) (Scotter, 1985). The following formula was used to calculate the soil porosity i.e. $f = 1 – (P_b / P_s)$.

3.11.3 Gravimetric water content

Every two weeks, bulk density samples were taken from both slip faces and placed in vial plastic bags to prevent moisture loss. These samples were weighed for fresh weight and then placed in an oven at 105°C for 48 hours. They were then re-weighed and their container weights were also recorded. The percentage of gravimetric water content was calculated by the following formula:

GWC % = Total fresh weight – Total dry weight / Total dry weight – Container weight*100.

The volumetric water content (%) was calculated from the following formula:

$W(\%) = GWC(\%) * P_b$

3.12 Soil chemical properties

The following procedures have been used in conducting soil fertility tests (Blakemore *et al*., 1987).

3.12.1 Soil pH

10 g of soil was weighed (air-dry < 2 mm) into a 50 ml beaker and 25 ml of distilled water was added. This mixture was stirred and left overnight with electrodes positioned on the soil sample (well covered). A stable reading was recorded.

3.12.2 Olsen P

42 g or 0.5 molar mass (M) $NaHCO^{3-}$ (sodium bicarbonate) was dissolved in 900 ml of distilled water to prepare the soil extraction solution. This was then adjusted to the pH range of 8.45-8.50 with NaOH, to form 1 L of solution. 1 g soil was weighed into a centrifuge tube with 20 ml of extraction solution (0.5M $NaHCO^{3-}$) and shaken for 30 minutes (by an end over end shaker). The solution was centrifuged at 9000 rpm for one minute and then filtered into tubes under suction (water pump) through a Watman No 6 filter paper. 4 ml of extractant was taken out and placed into a 50 ml volumetric flask: 32 ml distilled water was then added and 10 ml Murphy & Reily (M & R) solution was added to make up the volume. This was left for 30 minutes for colour development. The results were read on a UV/visible spectrometer at 712 nm.

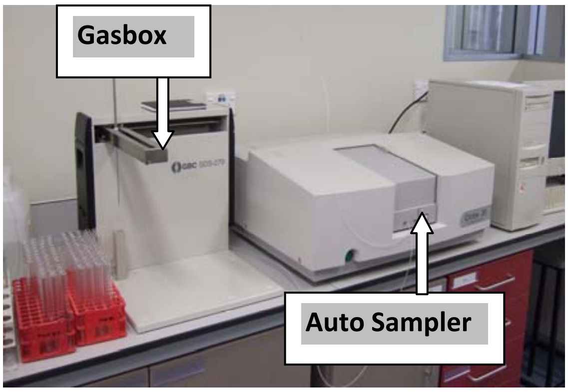

Figure 3.8. GBC atomic absorption analyser

This procedure had to be carried out on a set of eight samples placed on the centrifuge at any one time. The M & R solution was prepared in the following order; 500 ml 4N

H_2SO_{4-} > 150 ml ammonium molybdate > 100 ml abscorbic acid > 50 ml antimony potassium tartrate >200 ml distilled water.

Calculation: 4cm cell µgP/ g soil = 10/0.420 * ¼ *20/1 * abs

3.12.3 Total Carbon and Nitrogen

The LECO FP 2000 automated analyser measures carbon and nitrogen, by combustion in a resistance furnace. Gases are passed through an infrared cell, in order to determine carbon and thermal conductivity and thus nitrogen percentage was determined. 1g of 5 samples were introduced into the furnace, where it was heated to 1050°C. (N_2 and $NO_{x)}$.

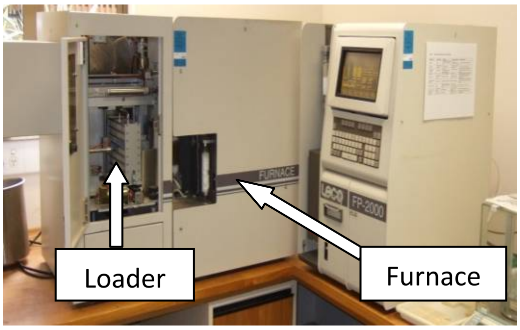

Figure 3.9. LECO FP 2000 automated analyser

After passing through a thermo-electric cooler, which removes water, the resulting combustion gases were collected in a ballast tank. A sample of gas passes through an infrared cell, which determines the carbon content. A heated copper catalyst reduces NO_x to N_2, Lecosorb (NaOH) on an insert base) removes CO_2 and anhydone (magnesium perchlorate) removes H_2O_2. Nitrogen content is then determined by thermal conductivity. The sample weight for the soil was typically 200-300 mg finely ground to <0.25 mm. The results were corrected for moisture, after drying at 105°C.

3.12.4 Cations and Cation Exchange Capacity (CEC)

The principle of this method is to displace the existing cations on the exchange site, using a single displacing cation (NH_4^+), which is not normally present in large amounts on the soil surface. The amount of displaced cations and the amount of displacing cations, retained by the soil, were measured. A high concentration (1 M) of ammonium acetate ($CH3OOH_3$) at pH 7 was used, as the displacing solution.

The pH was specified because in some soils, particularly those with large amounts of organic matter or allophone, the CEC varies with pH (the pH – dependent charge effect). The NH^{4+} ions also displace acidic cations (mostly H^+ and Al^{3+}) from the soil's surface.

The soil was dried and 1g was used in this determination. The soil samples were placed in the leaching columns. These columns were leached with 45ml of ammonium acetate, for approximately 1ml/minute. The columns were then allowed to drain before adding the next amount of ammonium acetate. This leachate was then measured up to 50 ml, by volume. The pH value of the ammonium acetate soil extracts was measured, in order to estimate the amount of hydronium ions.

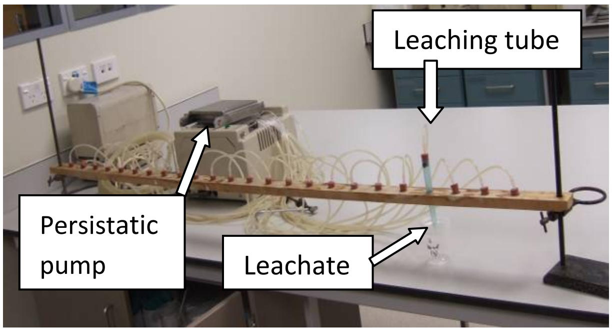

Figure 3.10. CEC Leaching Manifold

The extracted leachate was also used to determine separately soil potassium (K^+), sodium (Na^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}). The standards were aspirated and construction lines were calibrated. The concentrations of K^+ , Na^+, Ca^{2+} and Mg^{2+} (ions) were determined by atomic absorption spectroscopy on the ammonium acetate extracts.

CEC determination

The amounts of H^+,K^+, Ca^{2+}, Mg^{2+} and Na^+ associated with 1 g of soil in each leaching column was calculated. All these cations were added to provide the estimation of the CEC.

3.12.5 Extractable sulphate

Solutions – extractants

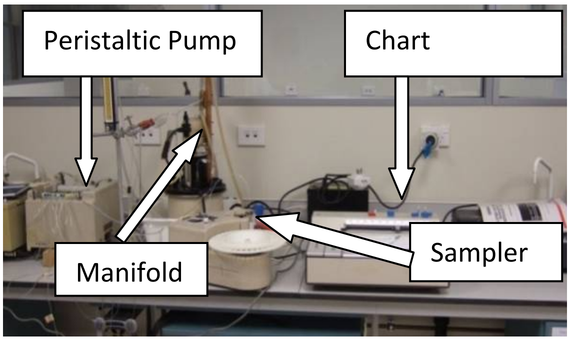

Figure 3.11. Sulphate Auto Analyser

Solution 1: Extractant ; 0.01M KH2PO4 (13.61g/5L)

Solution 2: Bismuth nitrate ; Heat 3.4 g Bi (NO3)3.5H2O in 460 m L glacial acetic acid until dissolved. Cool and add 500 to 700 mL deionised water containing 6g gelatine previously dissolved in it by warming gently while stirring. Dilute the mixture to 2L.

Solution 3: NaOH (1M) (40g/L)

Solution 4: Reducing mixture ; transfer 1000ml H I 55% w/w , 500ml 88%w/w Formic acid and 250ml hypophosphrous acid 50% w/w to a boiling flask . Reflux for 15 minutes, boiling gently while bubbling nitrogen gas through it, to remove S impurities.

Solution 5: stock standard solution ; 2.718 g K_2SO_4 AR grade dried at 105°C is dissolved and made up to 1L volume with deionised water (i.e.500ug S/mL) .

Solution 6: working standard solution; 10mL stock standard is pippetted into a 100 ml flask, then made up to the mark with deionised water (i.e.50 µg S/mL). Prepare standards of 10, 5, 2, 1 and 0.5µg S/mL for the auto-analyser from this.

Extraction procedure

5 g of soil was weighed into a centrifuge tube and 25 ml 0.01 M KH_2PO_4 solution was added and shaken for half an hour. After this the mixture was centrifuged for 3 minutes at 9000 RPM and then filtered through Watman 42 filter paper into a P35 Vial.

3.13 Total cover and herb cover

After 120 days, the sampling areas of all individual plots were photographed. The areas within the respective quadrats were extracted using the Adobe Photoshop CS3 extended software programme (Figure 3.12b). The plant cover within individual quadrats was clipped and then extracted from the respective photographs (Figure 3.12). The total plant cover, after 120 days, was estimated by subtracting it from the total quadrat area by the use of Adobe Photoshop CS3 extended pixel count.

Fig.3.12a: Treatment 1, replicate 4, south aspect after 3 months from oversowing.

Fig.3.12b: Extracted inner area from the quadrat.

Fig. 3.12c: Bare ground was erased leaving the total plant cover in the quadrant area.

Fig. 3.12d: Weeds and other plants were erased leaving only target species cover in the quadrant area.

Figure 3.12. An example of estimating vegetation and species cover using photoshop CS3 extended pixel count.

Similarly, plants colonising (other than the oversown species) were erased (Figure 3.12d). Species cover within the respective quadrats was estimated by subtraction from the total quadrat area. Pearson's correlation coefficient was used to find the relationships between, herbs and weeds, total cover, herb cover, establishment Day 120, weeds and weeds cover.

3.14 Statistical analysis - Repeated measures (ANOVA) Design

The data were analysed by SAS (9.1) (Appendices 7 & 8). Repeated measures ANOVA tests the equality of means. However, repeated measures ANOVA is used when all members of a random sample are measured, under a number of different conditions. Since the sample is exposed to each condition in turn, the measurement of the dependent variable is repeated. Using a standard ANOVA, in this case, was not appropriate because it failed to model the correlation between the repeated measures: the data violated the ANOVA assumption of independence (*SAS/ STATS User Guide*, 1989). Nevertheless, this design also had a combination of both repeated measures factors (species and aspect) and non-repeated factors (interaction - species by aspect).

Figure 3.13 Replicate that exceeded the estimated number of seedlings, resulting from the estimated number of over sown seeds.

Seedling numbers were repeatedly counted at four different stages (Day 15, 45, 90 and 120) within the designated sampling area in the respective plots. Before analysis, the final data were derived from the number of seedlings counted on different dates and then divided by the number of viable seeds oversown, within the same quadrat area. Hence, the data were transformed. This choice of transformation did not affect the outcome of the test, since the transformation matrix was orthonormal. The value of the control treatment (8 replicates) and a particular replicate that had exceeded the estimated number of viable seeds oversown were not used in this analysis. As a result the trial became an unbalanced design.

Univariate Approach

In this design, a univariate approach was used that highlighted within-subject and between-subject effects. To validate the univariate approach, tests of within subject effects required the assumption of sphericity. This sphericity assumption (G - G and H - F) was not violated and thus the F and p values were valid. Generally, the H-F correction factor was used because the G-G correction factor had been shown to be too conservative: i.e. it sometimes fails to detect a true difference between group means (*SAS/ STATS User Guide*, 1989).

In addition to these assumptions, the univariate approach was more powerful, since the sample sizes were small. Student's l t l test was used to identify differences since the sampling was less than 30. Moreover, the common spherical covariance had also been met.

The independent variables were: different pasture species on seedling emergence; effect of aspect; and species by aspect interaction. The dependent variables were: the effect of time; species by time effect; and time by aspect effect. This analysis answered the following questions:

1. How did the three pasture species differ, in terms of seedling emergence (main effect between subject)
2. Did aspect have an influence on seedling emergence and early establishment (main effect between subjects).
3. Did non-repeated measures show any other differences (interaction between species by aspect).
4. Did seedling numbers differ over time between species (main effect within subject).

The Null Hypothesis, Alpha, and p Values

The null hypothesis was that there were no differences between population means. The p value was the observed significance level. The alpha level was set at 0.05. If any p values were smaller than the alpha level, then the null hypothesis was rejected. On the other hand, if any p value was larger than 0.05, then the null hypothesis was accepted.

Pearsons correlation cofficient

CORR Procedure via Pearson correlation coefficients was used to find the associations between the number of species; the percentage of herb cover; the number of weeds; the percentage of weed cover; and the percentage of total cover, at the end of 120 days.

Chapter 4 Results

4.1 Soil fertility

Every fortnight, 36 bulk density samples were taken, from each soil slip surface, over three months. The mean bulk density on the north facing slip surface was 1.394 g/cm^3 (Appendix 1) and on the south facing slip surface was 1.368 g/cm^3. The mean soil porosity on the north facing slip surface was 0.54 and the south facing slip surface had a soil porosity of 0.55. Both soil slips had similar bulk densities and soil porosities. This subsoil environment can be termed as poor for active root penetration. The trend showed an increase in bulk density over time (Figure 4.1).

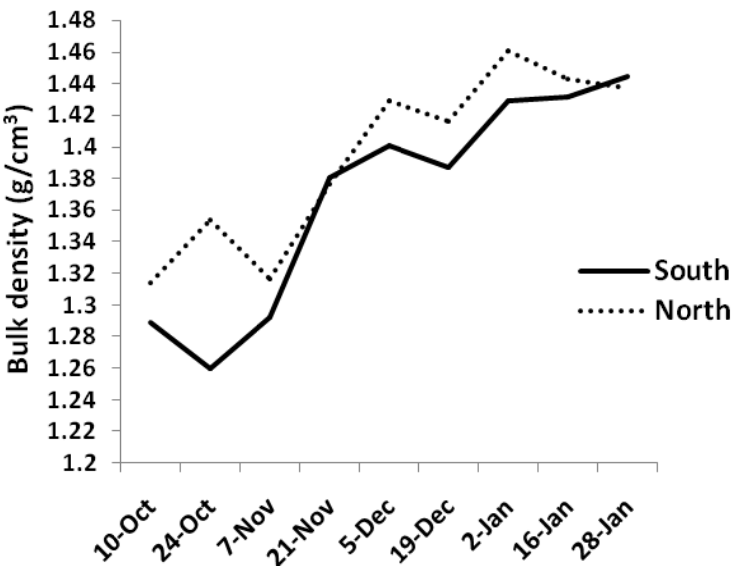

Figure 4.1. Mean bulk density on north and south aspect recent slip surfaces.

A bulk sampling technique was used for the soil chemical analyse. Samples were separately taken, from within the designated areas of both the trial sites. Similarly, samples were also taken from the adjacent un-eroded pasture surfaces of both soil slips (Table 4.1). Both adjacent pasture surfaces had higher concentrations of soil C but were low for all the other nutrients necessary for optimum pasture production.

Furthermore, both soil slip surfaces had lower soil fertility than the adjacent uneroded pasture surfaces (Table 4.1). In terms of productivity, both slip surfaces were highly deficient in soil C, soil N and Olsen P on both aspects. Low amounts of exchangeable cations (CEC) were also recorded on both slip surfaces. Soil fertility can be one of the major determining factors, in terms of early establishment of oversown pasture seeds.

Table 4.1. Soil fertility on north and south aspects of the soil slip surfaces and the remnant adjacent pasture surfaces at AgResearch's Ballantrae farm.

Aspect	**North**		**South**	
	Uneroded pasture surface	**Recent slip surface**	**Un-eroded pasture surface**	**Recent slip surface**
pH	5.5	6.5	5.3	5.7
Olsen P µg P/g	8.4	0.9	24	2.8
SO_4 µg S/g	5.3	3.0	5.5	2.5
K me/100g	0.27	0.22	0.37	0.28
Ca me/100g	3.3	2.1	5.0	4.6
Mg me/100g	3.83	8.11	1.71	3.30
Na me/100g	0.20	0.84	0.04	0.17
CEC me/100g	14.0	14.0	15.0	15.0
C (%)	3.14	0.14	3.61	0.29
N (%)	0.24	0.02	0.29	0.04

4.2 Soil temperature

Soil slip surface temperatures, on both north and south facing aspect slip surfaces, were recorded, during the trial period. Similarly, temperatures at 5 cm depth were also recorded. There was a gradual increase in soil slip surface temperatures from early-spring to early summer season (Figure 4.2, Appendix 3). During mid-December, there was a decline in surface temperatures due to continuous rainfall (low-solar-energy), but then a steady increase was seen, until this reached a peak during mid-summer (Figure 4.2).

The highest single-day temperature recorded on the soil slip surface was 46.2^{0}C and the lowest surface temperature recorded was 3.5^{0}C (data not shown). This shows that soil slip surfaces undergo daily extreme conditions, which can have an adverse effect on seedling emergence and early establishment. The north facing aspect slip surface recorded higher maximum temperatures than the south facing aspect slip surface during the entire trial period. This is an example of north facing aspect slopes receiving higher solar energy, in the southern hemisphere. Towards summer, the seedlings from the respective pasture species were well established and thus they showed negligible signs of death. Over the late-summer, surface temperature began steadily declining. The minimum surface temperatures were generally similar on both aspects and these occurred during the night.

Weekly soil mean temperatures at 5 cm depth were generally higher than the surface temperatures on both aspects (Appendix 5). Surface temperatures during the day were higher than temperatures at 5 cm depth. The mean temperatures at 5 cm soil depth tended to retain heat longer than the exposed soil surface. Surface mean temperature and also the mean temperatures at 5 cm depth on both soil slip faces, were adequate for seed germination.

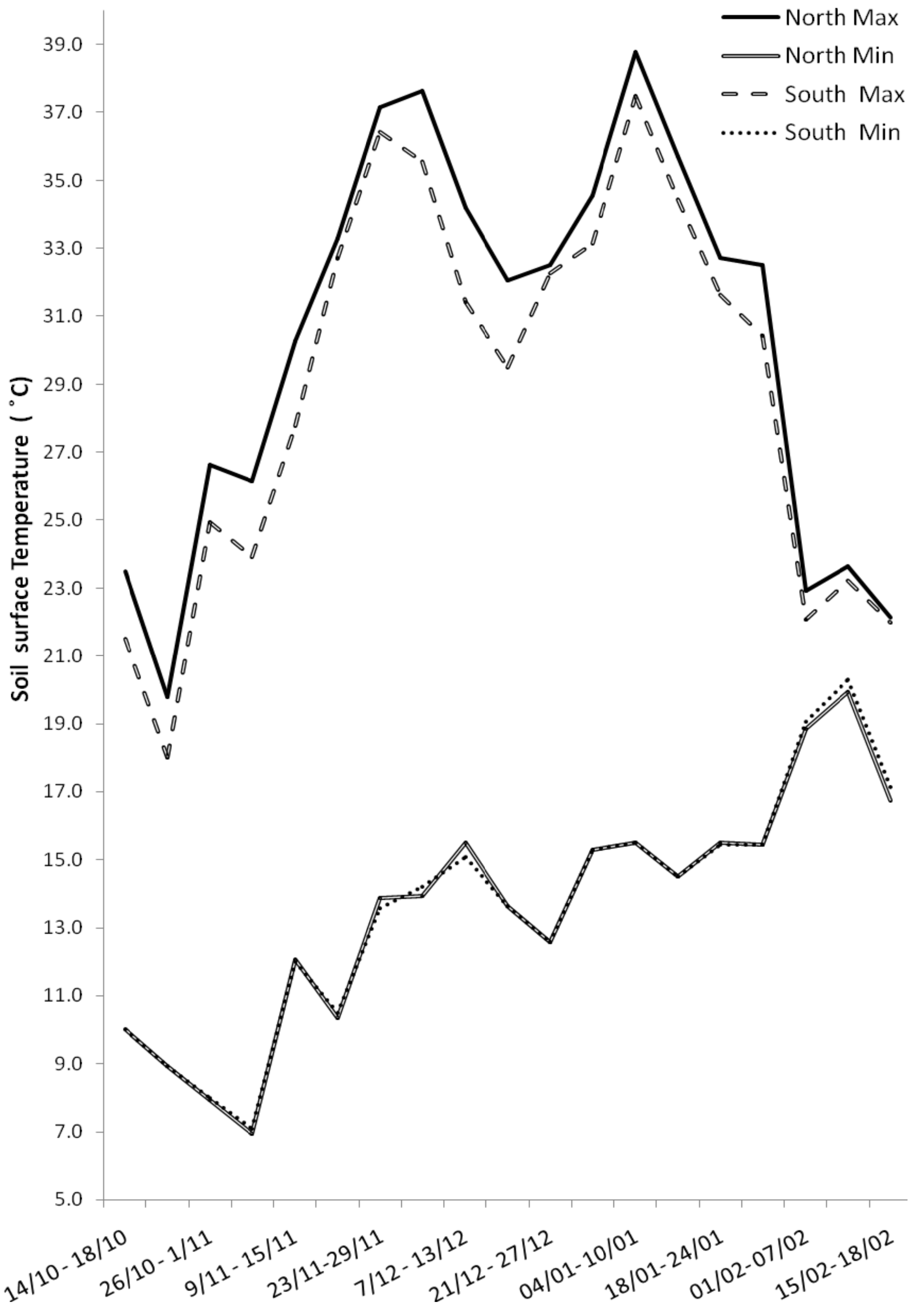

Figure 4.2. Weekly mean maximum and minimum surface temperatures on north and south facing slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville during 2008 – 2009.

4.3 Soil moisture

The monthly rainfall data, during the trial period, was recorded at Ballantrae metrological station. The previous 10 years' monthly rainfall data (1997-2007) was also available from the farm station. W (%) data was also recorded on both slip surfaces, during the trial period.

4.3.1 Ballantrae meteorological station

The 10-year-average rainfall at is 1241 mm/year and 1451 mm was recorded for the year 2008 (Appendix 6). The 10-year-average rainfall between September and February was 656 mm, but 1014 mm was recorded during this trial period (Table 4.2). This increase was a result of higher rainfall during the months of October, 2008 and (late) February, 2009. Soil moisture was recorded at a depth of 10cm. However, the designated area of the weather station had adequate pasture cover. This makes the data difficult to measure to that of a soil slip environment (Appendix 4).

Table 4.2. Monthly rainfall data and 10-year rainfall mean from the meteorological station at AgResearch's Ballantrae Hill Country Research Station during the trial period in Woodville.

Month	10-year-average (mm)	2008 (mm)
September	103	96
October	162	303
November	114	82
December	118	121
		2009
January	75	86
February	84	326
Average	**656**	**1014**

4.3.2 Volumetric Water Content (W%)

The W (%) was not significantly different ($P > 0.05$) on both slip surfaces during spring or until Day 45 of the trial period (Table 4.3). At oversowing, soil moisture was near field capacity on both trial sites, which supported adequate seedling emergence. Significant differences ($P < 0.05$) were found between the north and south aspect slip surfaces on Day 45, i.e. 21/11/08 - 05/12/08 (Table 4.3). High rainfall during mid-December (19/12/08) showed insignificant differences ($P > 0.05$) between the two aspect slip surfaces. This also had a marked effect on soil slip surface temperatures (Figure 4.2). Significant differences ($P < 0.05$) were found from the beginning of January until late-February. However, towards the end of February, high rainfall (the first autumn rain) was recorded at Ballantrae and this influenced the monthly rainfall data (Appendix 6). The south facing slip surface had higher moisture content than the north facing slip surface on all the sampling dates. Visual observations during summer on the lower leaves of the established seedlings (sown pasture species) showed signs of moisture stress on both slip surfaces, but plants were still persisting.

Table 4.3. Water content recorded at AgResearch's Ballantrae Hill Country Research Station on recent slip surfaces during the spring of 2008 and summer of 2009.

Sampling dates	**North aspect slip surface**			**South aspect slip surface**			
	GWC (%)	**Std err.**	**VWC (%)**	**GWC (%)**	**Std err.**	**VWC (%)**	
10/10/2008	39.5	± 0.43	51.9	41.8	± 0.42	53.9	NS
24/10/2008	35.9	± 0.14	48.5	37.2	± 1.05	46.8	NS
07/11/2008	31.6	± 0.09	39.5	33.8	± 0.55	43.1	NS
21/11/2008	26.8	± 0.70	36.9	29.7	± 0.40	41.0	S
05/12/2008	23.9	± 0.10	34.1	26.8	± 0.38	37.6	S
19/12/2008	20.3	± 0.35	28.8	23.3	± 0.60	32.3	NS
02/01/2009	17.7	± 0.38	25.8	21.0	± 0.20	30.0	S
16/01/2009	17.4	± 0.11	25.1	19.7	± 0.08	28.2	S
28/01/2009	17.2	± 0.12	24.6	19.1	± 0.09	26.1	S

Letter **S** represents: Significantly different ($P < 0.05$).

4.4 Seed analytical report

A seed germination test was conducted at Seed Tech. Services, Massey University, Palmerston North. The final seedling count, the number of hard seeds, any abnormal growths and the seed remainders were distinguished from the respective working samples (Table 4.4).

Germination percentages were 89% for *T. repens*, 44% for *L. pedunculatus* (including abnormal seedlings), and 91% for *H. lanatus*.

In terms of one thousand seed weight, the estimated number of seeds oversown for individual species per quadrat was different (Table 4.4). Based on this estimation, the percentage of vegetation cover was fairly different for *L. pedunculatus*, since the seeds were tetraploid or they had larger seeds by nearly two-fold, in comparison with *T. repens* seeds (Table 4.4). Similarly, *H. lanatus* seed was over three-fold that of *L. pedunculatus* seeds.

Table 4.4. Seed analytical report on the three species that were selected in this revegetation experiment (Seed Tech Services, Massey University).

	T. repens	H. lanatus	L. pedunculatus
Thousand seed weight (g)	0.5872	0.3189	1.259
Germination (%)	89	91	44
Seed rate (g/m^2)	0.6	0.6	0.6
Seeds oversown ($g/ 0.1m^2$)	0.06	0.06	0.06
Estimated number of seeds oversown ($0.1m^2$)	102	188	48
Expected field germination rate ($0.1m^2$)	91	171	21

* includes 21% abnormal

4.5 Seedling emergence and early establishment

T. repens was the most successful pasture species in terms of seedling emergence and early establishment on recent soil slip surfaces, followed by *L. pedunculatus* and then *H. lanatus* (Table 4.5). The trend showed marginal decreases in seedling numbers over the late-summer (Day 120) for all three species. In addition, seedling emergence was halted by late spring (Day 45) (21/11/08) for all three species. *L. pedunculatus* had the highest percentage losses in seedling numbers over the trial period.

Table 4.5. LS mean (%) showing the main effect of seedling emergence and early establishment from viable seeds of three pasture species on recent soil slip surfaces, oversown early-spring at AgResearch's Ballantrae farm near Woodville. (LS mean %- Least square mean %; Students t-test - Pr > l t l).

	Early-spring (Day 15)	Late-spring (Day 45)	Early-summer (Day 90)	Late-summer (Day 120)
T. repens	**60.4**	**62.4**	**60.8**	**60.8**
Std err.	±7.4	± 9.0	± 7.7	± 7.7
Pr > l t l	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
L. pendunculatus	**64.3**	**56.7**	**51.4**	**50.8**
Std err.	±6.6	±8.1	± 6.9	± 6.0
Pr > l t l	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
H. lanatus	**20.6**	**38.7**	**34.0**	**33.5**
Std err.	±6.6	± 8.1	± 6.9	± 6.9
Pr > l t l	*< 0.0001*	*< 0.0006*	*< 0.0005*	*< 0.0005*

Significant differences (Pr < 0.05) were found on Day 15, Day 90 and Day 120 but not on Day 45 (Table 4.6). Seedling emergence at Day 15 was highly significant (Pr < 0.005). Favourable environmental conditions, especially in terms of soil slip surface temperature and moisture for all the three species, partly explains the non-significant (Pr > 0.05) differences on Day 45 (21/11/08) (Tables 4.3 & 4.6).

Table 4.6. Univariate analysis of variance showing the dates of analysis and their significance on seedling emergence and early establishment between three pasture species. (DF- Degrees of Freedom; Type III SS – Sum of squares; F value - Measurement of distance between individual distributions; Pr > F or alpha value set at 0.05).

Day	**DF**	**Type III SS**	**Mean square**	**F value**	**Pr > F**
15	2	0.908	0.454	12.97	0.0013
45	2	0.228	0.114	2.15	0.1628
90	2	0.271	0.136	3.55	0.0499
120	2	0.279	0.014	3.64	0.0482

There was a significant interaction between the three pasture species and time (Figure 4.3). *L. pedunculatus* had the highest field germination rate but it decreased rapidly over time. *T. repens* had a higher seedling emergence rate and also established well over time. *H. lanatus* had the least germination at Day 15 and gradually increased by Day 45.

It was the least performing pasture species in terms of seedling emergence and early establishment.

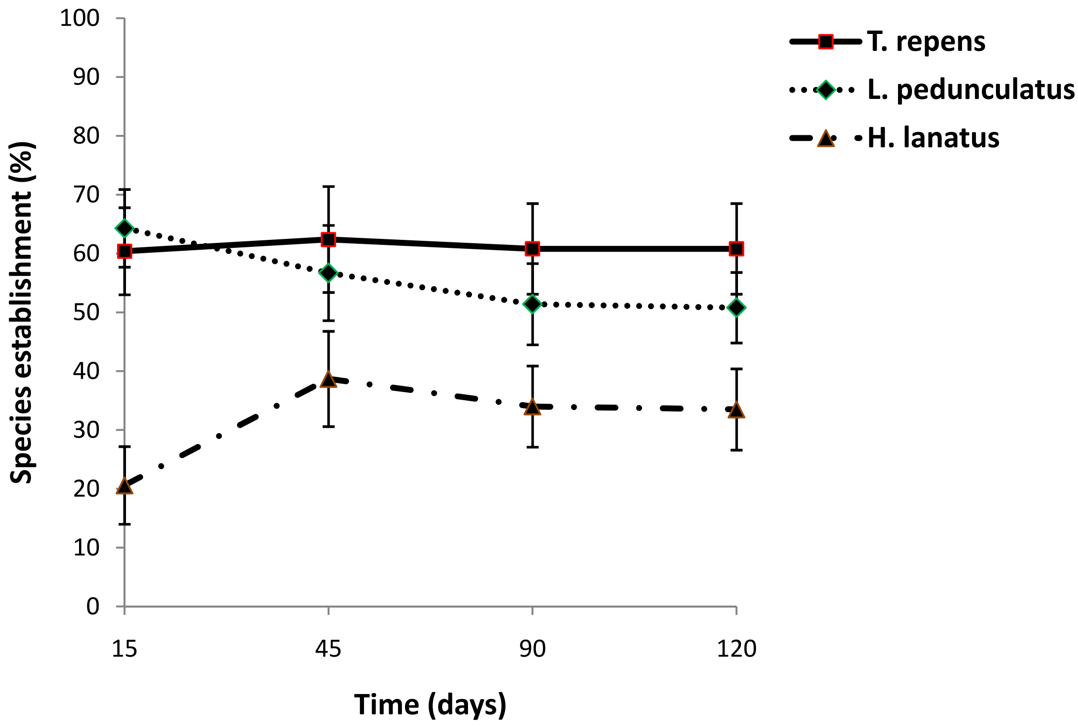

Figure 4.3. Field seedling emergence and early establishment from oversown viable seeds of three pasture species on recent slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville.

4.6 Effect of aspect on field seedling emergence and early establishment

The south aspect slip surface environment was more favourable than the north facing one, in terms of seedling emergence and early establishment (Table 4.7). This could have been as a result of higher soil moisture (Table 4.3) and also a higher level of shade, due to less solar energy received on the south facing slip surface (Figure 4.2).

Table 4.7. LS mean (%) showing the main effect of north and south aspect on recent soil slip surfaces on three pasture species field emergence and early establishment from viable seeds, oversown early-spring at Ballantrae AgResearch hill country farm, Woodville. (LS mean %- Least square mean %; Students t-test - Pr > l t l).

	Early-spring (Day 15)	Late-spring (Day 45)	Early-summer (Day 90)	Late-summer (Day 120)
North aspect slip surface	**37.0**	**41.0**	**37.0**	**36.0**
Std err.	±5.4	± 6.6	± 5.6	± 5.7
Pr > l t l	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
South aspect slip surface	**60.0**	**64.5**	**60.9**	**60.4**
Std err.	±5.4	± 7.2	± 6.0	± 6.1
Pr > l t l	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*

All four dates of analysis were significantly different (Pr < 0.05). Hence, aspect plays an important role in terms of seedling emergence and early establishment. Highly significant differences (Pr < 0.005) were found on Day 15, Day 90 and Day 120 but not on Day 45. This shows that on Day 45 (late-spring) both aspects had significant effects (Pr < 0.05) on seedling emergence and early establishment. Alternatively, the data also shows that there was no further increase in seedling emergence after Day 45 (Table 4.7 & Figure 4.3). The effect of time, together with aspect was not significant (Pr > 0.05).

Table 4.8. Univariate analysis of variance showing the dates of analysis on the role of north and south aspect recent slip surfaces on seedling emergence and early establishment. (DF- Degrees of Freedom; Type III SS – Sum of squares; F value - Measurement of distance between individual distributions; Pr > F or alpha value set at 0.05).

Day	DF	Type III SS	Mean square	F value	P r > F
15	2	0.908	0.454	12.97	0.0011
45	1	0.385	0.385	7.26	0.0209
90	1	0.403	0.403	10.55	0.0078
120	1	0.385	0.385	10.02	0.0090

All three pasture species had higher seedling emergence and early establishment on the south facing slip surface, than on the north facing slip surface. Soil moisture was also higher on the south facing aspect slip face (Table 4.3). The south facing slip surface recorded lower maximum temperatures through the entire trial period, than the north facing slip face (Figure 4.2). As surface temperatures are directly influenced by the amount of solar radiation, it can be interpreted that the south facing aspect had a higher level of shade, than the north facing one. There was an insignificant (Pr > 0.05) interaction with aspect and time (Figure 4.5 & Table 4.12).

All three pasture species had higher seedling emergence and early establishment on the south facing slip surface than on the north facing slip surface. Soil moisture was also higher on the south facing slip face (Table 4.3). South facing slip surface recorded lower maximum temperatures through the entire trial period than the north facing slip face (Figure 4.2). As surface temperatures are directly influenced with the amount of solar radiation, it can be interpreted that south facing aspect had a higher level of shade than the north facing aspect slip surface. There was no significant (Pr > 0.05) interaction between aspect and time (Figure 4.5 & Table 4.12).

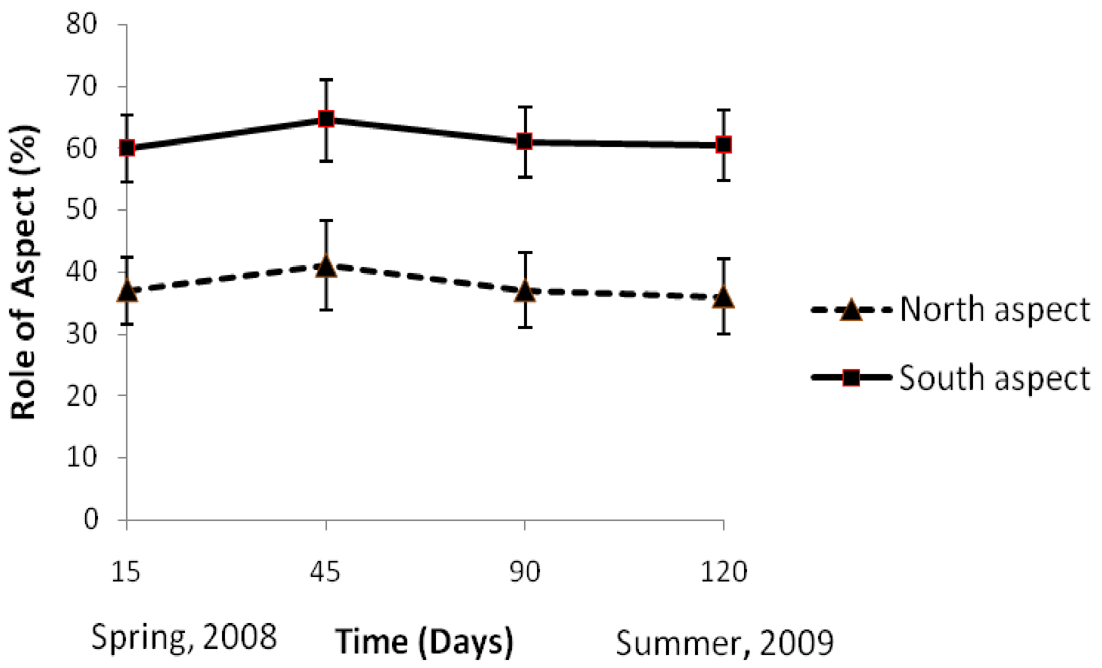

Figure 4.4. Field on seedling emergence and early establishment of three pasture species on north and south facing soil slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville.

4.7 Interaction between three pasture species and aspect

The interaction between all three species was higher on the south aspect slip surface than the north facing one. *L. pedunculatus* had the highest interaction on the south facing slip surface, followed by *T. repens* and *H. lanatus* interaction, with time. However, *L. pedunculatus* had a lower seedling emergence and early establishment on the north facing slip surface than *T. repens. H. lanatus* had the least interaction between the three pasture species on both north and south aspect slip surfaces.

Table 4.9. LS mean (%) showing interaction between three pasture species field emergence and early establishment from viable seeds on north and south aspect recent soil slip surfaces, oversown early-spring at AgResearch's Ballantrae Hill Country Research Station near Woodville.(LS mean %- Least square mean %; Students t-test - Pr > l t l).

North aspect slip	**Early-spring (Day 15)**	**Late-spring (Day 45)**	**Early-summer (Day 90)**	**Late-summer (Day 120)**
Trifolium repens	**51.8**	**55.1**	**53.6**	**53.4**
Std err.	±9.3	± 11.5	± 9.7	± 9.7
Pr > l t l	*< 0.0002*	*< 0.0006*	*< 0.0002*	*< 0.0002*
Lotus pedunculatus	**43.9**	**32.7**	**22.6**	**22.6**
Std err.	±9.3	± 11.5	± 9.7	± 9.7
Pr > l t l	*< 0.0007*	*< 0.0160*	*< 0.0409*	*< 0.0414*
Holcus lanatus	**14.7**	**34.3**	**34.6**	**33.1**
Std err.	±9.3	± 11.5	± 9.7	± 9.7
Pr > l t l	*< 0.1439*	*< 0.0125*	*< 0.0045*	*< 0.0062*
South aspect slip				
Trifolium repens	**68.9**	**69.8**	**67.9**	**68.2**
Std err.	±11.5	± 14.0	± 11.9	± 11.9
Pr > l t l	*< 0.0001*	*< 0.0004*	*< 0.0001*	*< 0.0001*
Lotus pedunculatus	**84.6**	**80.6**	**80.1**	**78.9**
Std err.	±9.3	± 11.5	± 9.7	± 9.7
Pr > l t l	*< 0.0001*	*< 0.0032*	*< 0.0001*	*< 0.0001*
Holcus lanatus	**26.6**	**43.2**	**34.7**	**33.8**
Std err.	±9.3	± 11.5	± 9.7	± 9.7
Pr > l t l	*< 0.0161*	*< 0.0001*	*< 0.0045*	*< 0.0054*

Interaction between pasture species and aspect, was not significant (Pr > 0.05) at Day 15 and Day 45, or during spring. This could have been due to a favourable microclimatic influence on seedling emergence and early establishment. No significant differences (Pr > 0.05) were also found with soil moisture on both the soil slip surfaces (Table 4.3). Significant interaction (Pr < 0.05) originated during summer (Day 90 and Day 120). This could be as a result of different species interacting differently to moisture stress and also different levels of solar energy on the north and south aspect slip surfaces.

Table 4.10. Univariate analysis showing interaction between different pasture species and aspect on recent soil slip surfaces oversown during early-spring at AgResearch's Ballantrae Hill Country Research Station near Woodville. (DF- Degrees of Freedom; Type III SS – Sum of squares; F value - Measurement of distance between individual distributions; Pr > F or alpha value set at 0.05).

Day	DF	Type III SS	Mean square	F value	P r > F
15	2	0.094	0.047	1.34	0.3025
45	2	0.173	0.087	1.64	0.2389
90	2	0.341	0.170	4.47	0.0380
120	2	0.331	0.165	4.31	0.0415

T. repens had a higher degree of interaction on the north facing soil slip surface. However, interaction between south aspect on seedling emergence and early establishment was higher for *L. pedunculatus* and then followed by *T. repens. H. lanatus* had the least interaction on both north and south aspect recent slip surfaces.

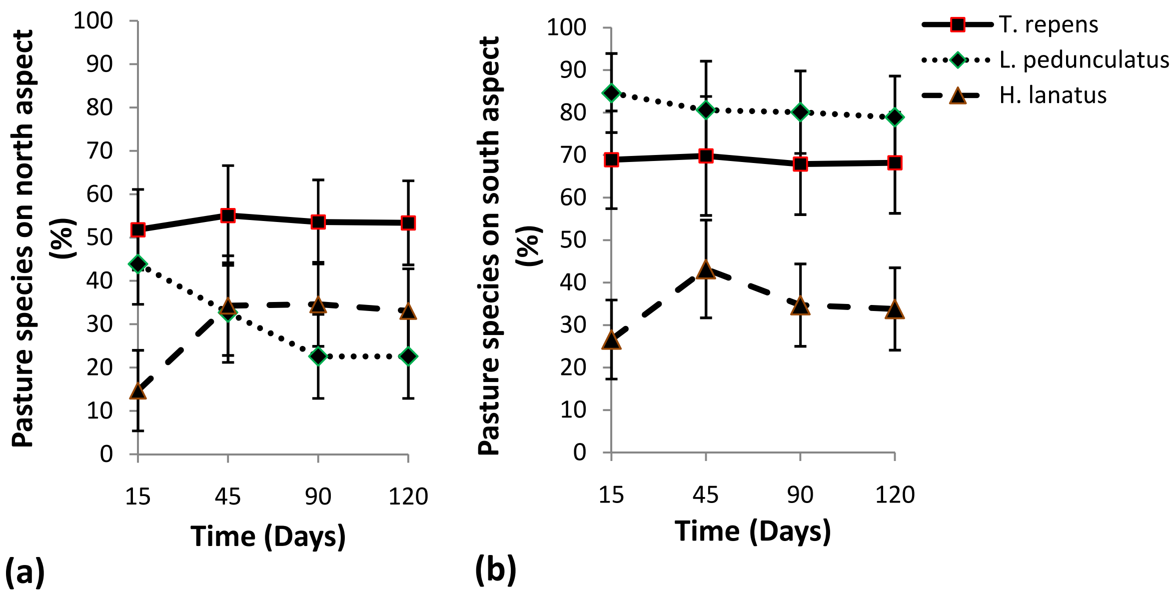

Figure 4.5. LS mean (%) showing interaction between north **(a)** and south **(b)** facing aspect on seedling emergence/early establishment from viable seeds on recent slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville.

4.8 Main effects: Between and within subjects

Upon analysing the data, by using repeated measures analysis of variance, there was a significant main effect (Pr < 0.05) found between the three pasture species (Table 4.11). Significant differences (Pr < 0.05) were found between north and south facing slip surfaces. The interaction between pasture species and aspect on seedling emergence and early establishment, was not significant Pr > 0.05.

Table 4.11. Univariate analysis showing the effects of three pasture species on seedling emergence and early establishment from viable seeds on recent soil slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville. (DF- Degrees of Freedom; Type III SS – Sum of squares; F value - Measurement of distance between individual distributions; Pr > F or alpha value set at 0.05).

Between subjects effects	DF	Type III SS	Mean Square	F value	Pr > F
Species	2	1.478	0.739	6.05	0.0169
Aspect	1	1.263	1.263	10.34	0.0082
Species*aspect	2	0.884	0.442	3.62	0.0621

There was a significant (Pr < 0.05) interaction, within the three pasture species, on recent soil slips surfaces, with time (Table 4.12). This shows that within the three pasture species, seedling emergence and early establishment was different, with time. The effect of time was not significant (Pr > 0.05) within the three species. Hence, the percentage of post-seedling-death was not significant, at the four dates of analysis, within all three species.

Table 4.12. The main effects over time on seedling emergence and early establishment on recent soil slip surfaces of three pasture species at Ballantrae AgResearch farm in Woodville. (DF- Degrees of Freedom; Type III SS – Sum of squares; F value - Measurement of distance between individual distributions; Pr > F or alpha value set at 0.05).

Within subjects effects	DF	Type III SS	Mean Square	F value	Pr > F
Time effect	3	0.028	0.009	0.67	0.5786
Time* species effect	6	0.208	0.035	2.46	0.0449
Time*aspect effect	3	0.001	0.001	0.01	0.9988
Time*species*aspect effect	6	0.055	0.009	0.65	0.6889

T. repens was the most consistent pasture species at all dates on both north and south aspect recent slips surfaces (Figure 4.6). A higher establishment percentage was seen on the south aspect slip surface for *L. pedunculatus*. In comparison, *L pedunculatus* establishment was inconsistent on the north facing slip surface. *H. lanatus* had a low and gradual establishment until Day 45 on both aspects slip surfaces. The seedling percentage decreased gradually by Day 90 until reaching a plateau by Day 120, for both slips.

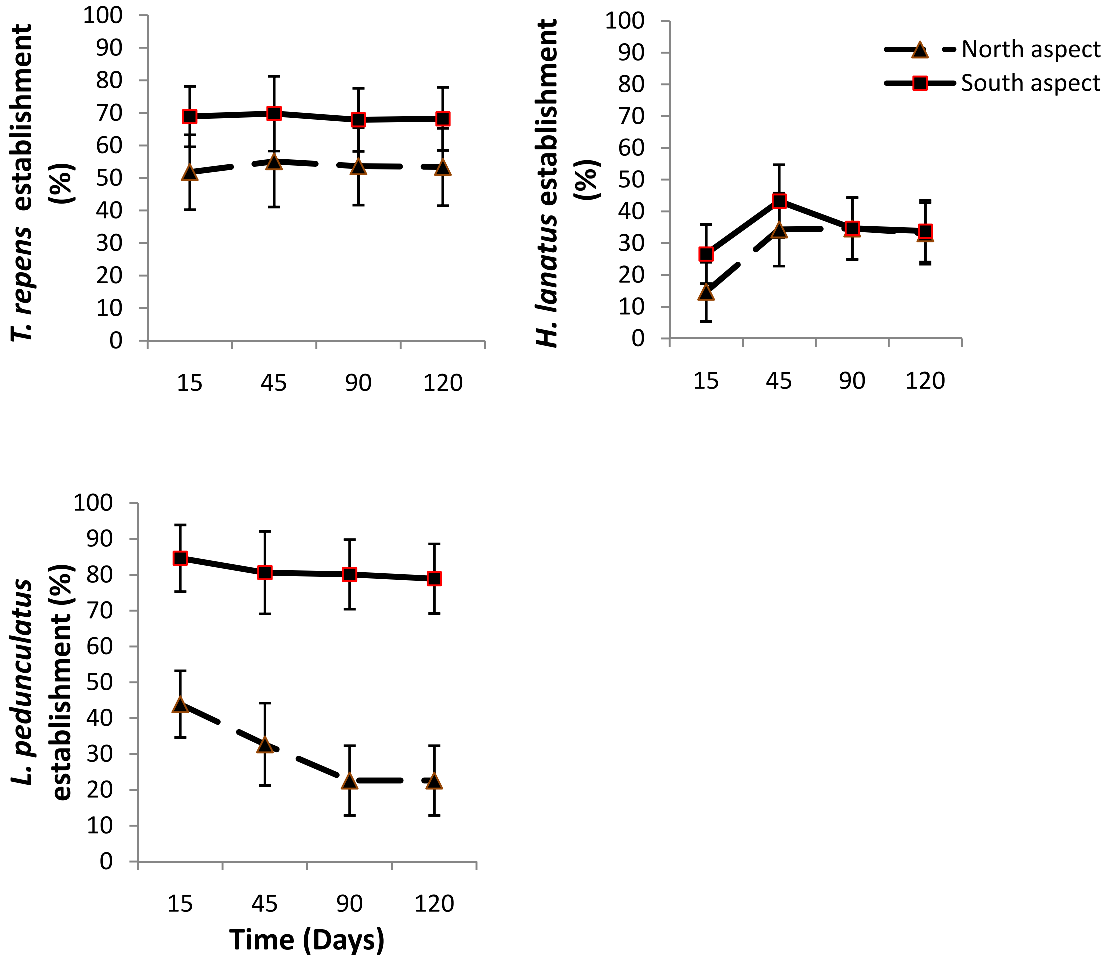

Figure 4.6. Comparison of individual pasture species and their interaction on seedling emergence and early establishment on north and south facing aspect slip surfaces at AgResearch's Ballantrae Hill Country Research Station near Woodville.

4.9 Correlation between species and weed cover after 120 days for establishment

There was a high positive correlation between weed and herbage cover. This shows natural revegetation is an on-going process. Nevertheless, any incidence of vegetation will ultimately have an impact on rehabilitation of soil slips. The correlation also showed that establishment of herbage increases with time when compared with negligible amount of vegetation cover at the oversowing date. However, within lower replicates there had been instances of seed translocation from the upper replicates, but had minor effect on the vegetation cover. This was due to allocating a 1 m work space between replicate 2 and 3 (Figure 3.3).

Table 4.13. Correlation coefficients between weeds, herbs, total cover, weed cover, herb cover and establishment at 120 days.

	Weeds (%)	Herbs (%)	Total cover (%)	Weed cover (%)	Establishment (120 days)	Herb cover (%)
Weed (%)	1.0	0.26	0.60	0.35	0.51	0.72
Pr > F		*0.16*	*0.004*	*0.05*	*0.01*	*0.001*
Observations	32	31	32	32	23	31
Herbs (%)	0.26	1.0	0.81	0.90	0.74	0.46
Pr > F	*0.16*		*0.001*	*0.001*	*0.001*	*0.001*
Observations	31	31	31	31	23	31
Total cover (%)	0.60	0.81	1.0	0.90	0.77	0.77
Pr > F	*0.001*	*0.001*		*0.001*	*0.001*	*0.001*
Observations	32	31	32	32	23	32
Weed cover (%)	0.35	0.90	0.90	1.0	0.63	0.40
Pr > F	*0.05*	*0.001*	*0.001*		*0.001*	*0.02*
Observations	32	31	31	32	23	32
Establishment (120 days)	0.51	0.74	0.77	0.63	1.0	0.72
Pr > F	*0.01*	*0.001*	*0.001*	*0.001*		*0.001*
Observations	23	23	23	23	23	23
Herb cover (%)	0.72	0.46	0.77	0.40	0.72	1.0
Pr > F	*0.001*	*0.009*	*0.001*	*0.02*	*0.001*	
Observations	32	31	32	32	23	32

There was a positive correlation of the slip surface vegetation cover within the designated areas of both trial sites. The previously bare ground covered by the three pasture species was higher on the south facing slip face. *T. repens* was more successful than *H. lanatus* and *L. pedunculatus*. *H. lanatus* percentage cover was higher than *L. pedunculatus*. This was as a result of smaller seed size for *T. repens* and *H. lanatus* than *L. pedunculatus* which influenced the estimated viable number of seeds oversown per individual quadrats.

Using repeated measures there was a significant effect for species and aspect but not for species by aspect. Analysis of each date of measurement was not significant at Day 15 and Day 45 but significant on Day 90 and Day 120.

Interaction between legumes were similar, however, *L. pedunculatus* decreased overtime. This was due to a high percentage of abnormal seedlings. The other two species increased initially (Day 15 and Day 45) and then reached a plateau. *T. repens* was the most successful pasture species both in terms of seedling emergence and early establishment after 120 days.

Chapter 5 Discussion

5.1 Influence of soil fertility on seedling emergence and their early establishment

5.1.1 Soil physical properties

The two recent soil slip surfaces resemble a subsoil environment where the regolith had been stripped, due to the soil slippage event and they were located on sedimentary mudstone lithology (Dodd *et al*., 2004). Bulk density was between the ranges of 1.3-1.5 g/cm^3 for both soil slip surfaces (Figure 4.1). Higher bulk density was always associated with a higher degree of soil penetration resistance (Milne *et al*., 1995), which is undesirable for root establishment of new seedlings and thus, active plant colonisation (McLaren & Cameron, 1996). Notably, bulk density increased over time (Figure 4.1), thus providing evidence that sedimentation losses, via rainfall are continuously occurring on these slip surfaces (R. DeRose *et al.*, 1993). Numerous studies have also highlighted that bulk density increases with soil depth (DeRose *et al.*, 1993; DeRose *et al*., 1995; Dymond *et al*., 2006; Ebeid *et al.*, 1995).

Due to the higher compactability of the subsoil, field capacity is reached far more quickly than in un-compacted soils. Once the subsoil had reached field capacity, runoff occurs, forming visible channels on the recent slip surfaces (Figure 3.2). Nevertheless, the trend shows that these recent soil slip surfaces, initially, have lower bulk density, and thus this creates higher opportunities for seedling root penetration — and eventually seedling establishment.

Soil porosity was lower on both recent slip surfaces, ranging between 54% and 55%, thus providing similar results. However, the desirable soil porosity needed for sufficient seedling growth is about 62 % for clay soils (Milne *et al*., 1995). Poor soil aeration could have restricted radical growth through this higher soil resistance (McLaren & Cameron, 1996; Murphy *et al.*, 2004). The trend shows that soil porosity also decreased over time.

5.1.2 Soil chemical properties

The north facing soil slip surface had a pH of 6.5 and the south facing soil slip surface had a pH of 5.7. Higher soil acidity restricts the availability of essential plant nutrients (McLaren & Cameron, 1996). The optimum pH for nutrient availability should be within the range of 5.8-6.5 (McLaren & Cameron, 1996). The pH of the soils on these slip faces was similar to those in a study conducted on eroded scars in Taranaki hill pasture (DeRose *et al.*, 1995) and also in Wairarapa (Prasad *et al*., 1998).

Soil C in remnant pasture adjacent to the two slip surfaces is within the range of 3.14-3.16 (Table 4.1). This shows that remnant pasture surfaces have higher concentrations of soil C than the slipped surfaces. This is similar to other studies which highlighted lower soil C on slipped surfaces (Baisden *et al.*, 2002; DeRose *et al.*, 1995). Extremely low concentrations of soil N were observed on slip surfaces, i.e. on north was (0.02% N) and south (0.04% N) aspects (Table 4.1). There is no useful range for soil N and also is a limiting nutrient on the soil surfaces (Hedley, 2005). Similarly, Quilter *et al*. (1993) expressed that soil N is the key limiting plant nutrient, in terms of revegetation on soil slip surfaces.

Olsen P is also extremely deficient on the subsoil surface of both slip surfaces. The Olsen P 'quick value', for the north facing slip surface 1 µgP/ml and the south facing slip surface is 3 µgP/ml (Appendix 2). The optimum Olsen P for ideal pasture growth should be within the range of 20-30 µgP/ml (Hedley, 2005). This could have been one of the limiting factors that affected seedling emergence. Deficiency in P hinders root/radicle formation (McLaren & Cameron, 1996, p. 208).

Soil CEC was 14-15 me/100g on the slips. Exchangeable soil magnesium on the slip subsoil surface was considerably higher than the soil potassium (K^+) and calcium (Ca^{2+}) (Appendix 2). A high concentration of soil magnesium may have displaced or restricted any availability of soil K^+ and Ca^{2+} (McLaren & Cameron, 1996).

This soil fertility report confirms that, together with other similar studies, bare ground on soil slips has poor soil physical and chemical properties (Baisden *et al*., 2002; DeRose *et al.*, 1995; Luckman *et al.*, 1999; Prasad *et al.,* 1998). Soil fertility is one of the major factors that influences the differences between the three pasture species' performance in terms of seedling emergence and early establishment.

5.2 Influence of soil temperature on seedling emergence

There was an increase in soil slip surface temperature from that recorded in early-spring to those temperatures recorded during the early-summer season (Appendix 3). During mid-December, there was a decline in surface temperatures, due to continuous rainfall (low solar energy), but this was followed by a steady increase, until it reached a peak during mid-summer (Figure 4.2).

By Day 15, the weekly (14/10/08 – 18/10/08) soil surface temperature was above 10°C (Appendix 3 & 4 & 5). For most pasture species, the minimum temperature needed for seedling emergence is usually between 10-12^{0}C (Fulkerson & Slack, 1996; White & Hodgson, 1999). The weekly mean air-temperature and surface-temperature during mid-October 2008 at Ballantrae meteorological station was 14.8^{0}C and 12.8^{0}C, respectively (Appendix 4). Similarly, the weekly mean slip surface temperatures were within the range of 16.6^{0}C – 17.0^{0}C on both soil slips (Appendix 5). This is consistent with studies, which have highlighted the ideal temperature to initiate seed germination, for *L. pedunculatus* and *T. repens* and most other temperate pasture species (Blumental & Harris, 1998; Hill & Luck, 1991).

By Day 45, the weekly (09/11/08 - 15/11/08) mean air-temperature and surface-temperature during early-December 2008, at Ballantrae meteorological station, was 16.4^{0}C and 17.0^{0}C respectively (Appendix 4). The soil slip surface temperature on the north facing slip was 19.4^{0}C and for the south facing slip surface it was 19.1^{0}C.

On Day 90, the weekly temperatures (28/12/08 – 03/01/09), on the soil slip surfaces, were between the range of 20.0^{0}C - 20.2^{0}C (Appendix 5). The Ballantrae meteorological station weekly mean air-temperature and surface-temperature had a range between 14.4 - 16.5^{0}C (Appendix 4). Similarly, the weekly mean temperature range, on the soil slip surfaces and also on data from Ballantrae meteorological station at Day 120, was above 10^{0}C. This provides one-evidence that seedling growth was not suppressed, due to low temperatures but in fact it was due to higher maximum temperatures. The weekly mean maximum temperature on the north and south slip surface, on Day 90, was within the range of 33.1^{0}C – 34.6^{0}C: The weekly minimum temperatures were ideal for seedling establishment (Appendix 3).

Daily recordings of soil slip surface temperatures provide a better insight into aspects of micro-climatic factors.

In contrast, the weekly maximum soil slip surface temperatures were adequate for optimum seedling growth (Figure 4.2), at Day 15. By Day 45 and at Day 90, the weekly mean surface temperatures recorded were between the range of 27.8^{0}C - 30.3^{0}C (Appendix 3). Similarly, weekly mean temperatures, by Day 120, were in the early 30s (Appendix 3). This was above the ideal temperature for optimum seedling emergence, which is 24^{0}C for *T. repens* and also *L. pedunculatus* and most pasture species (Hill & Luck, 1991; Karsten & MacAdam, 2001; Kelman & Forrester, 1999).Nevertheless, the highest single-day temperature recorded on the soil slip surface was 46.2^{0}C and the lowest surface temperature recorded was 3.5^{0}C (data not shown). These high fluctuations in surface temperatures were not favourable, in terms of early seedling establishment during summer, for all three pasture species.

5.3 Influence of soil moisture on seedling emergence

The rainfall decreases over the summer and are also directly comparable to the 10-year average (Table 4.2). The TDR moisture, at a depth of 10 cm, recorded a high of 43.6% and this fell to a minimum of 5.9%, at the end of January, at Ballantrae meteorological station (Appendix 4).

This was not a useful assessment for bare soil slip surface moisture, due to pasture cover and differences in soil depth level. Evapotranspiration is the second largest factor (except during winter), in terms of soil water balance or losses (Nicol, 1987; Scotter & Kelliher, 2004). Secondly, the meteorological station is located on the hill top (Figure 3.4), whilst both the slip sites were on a LUC class 6 slope.

Apart from the similar trend of soil moisture decreasing from early spring to late summer, the volumetric water content (W %) was between field capacity and it was also above wilting point during the entire trial (Table 4.3). This can be seen as lack of evapotranspiration (Nicol, 1987; Scotter & Kelliher, 2004) in the early stage of plant colonisation on recent soil slips. The meteorological station had adequate ground cover at the recording site (Figure 3.4), whilst the slip surfaces were bare in nature.

There was no water seepage on either soil slip surfaces. The W % recorded by Day 15 (Table 4.3) shows that the soil slip surfaces were within a range of 51.9% - 53.9%. In comparison, this is between field capacity and saturation point for silty-clay soils (Foth 1990; Marshall *et al*., 1999). The soil porosity for the slip surfaces was between a range of 0.54 – 0.55. Nevertheless, desirable soil moisture content for seedling emergence or plant growth should be between available water and field capacity (Foth, 1990). However, very few literatures have highlighted over-sowing and soil moisture, but there is a greater chance of seedling establishment being achieved when the soil surface is continuously made wet by rain, dew or frost (Campbell, 1967).

By Day 45, the W% was between the range of 43.1% and 39.5% (Table 4.3) and thus it was above the wilting point (Foth, 1990; Marshall *et al.*, 1999). In terms of soil moisture, non-significant differences ($P > 0.05$) were found between the south facing and north facing slip surfaces. By Day 90 and Day 120, the W% was above the wilting point and this became consistently and significantly different ($P < 0.05$) between the north and south aspects slip surfaces (Table 4.3). This difference resulted from a lesser amount of solar energy being received during late afternoon for the south facing slip (Chapman & Anderson, 1987; Gillingham, 1984; Hancox & Wright, 2005).

The wilting point for clay soils is approximately 20% (Foth, 1990, p11). A decrease in seedling percentage, via seedling death, was evident in all three species (Figure 4.3). The survival of the seedlings during this moisture deficit could have been supplemented from early morning dew and rain.

5.4 Early-spring establishment of three pasture species on recent soil slips.

5.4.1 Day 15

Significant differences ($Pr < 0.05$) were found between the three pasture species in terms of seedling emergence and their early establishment on recent soil slip surfaces. *L. pedunculatus* had the highest percentage of seedling emergence (64.4%) from viable seeds on Day 15. This higher percentage emergence rate is supportive of other studies, which have highlighted *L. pedunculatus* as a pioneer legume (used for conservation purposes) that grows well in infertile soil conditions (Hugo, *et al*., 1991). Another reason for its higher seedling emergence could be its tetraploid seeds (White & Hodgson, 1999), which are higher in seed vigour (McWilliams *et al.*, 1970). Furthermore, *L. pedunculatus* is more tolerant to water logging since (during this stage of the research) the soil moisture was between field capacity and saturation point, as compared with clay soils (Marshall *et al.,* 1999).

T. repens had a 60.4% germination rate from viable seeds, which were oversown on the soil slip surfaces. Similar results have also been seen in another study, whereby 60% germination rate was achieved from oversowing *T. repens* (Hume & Chapman, 1993).

H. lanatus was the poorest performing pasture species on Day 15. This result is similar to a study conducted at AgResearch's Whatawhata station that observed low and delayed germination during the initial two harvests (Wedderburn, *et al*., 1996). Soil surface temperature and the soil moisture present, on Day 15, was favourable for seedling emergence. The soil temperature was also above 10^0C and soil moisture was near field capacity, which were favourable for the oversown seed to germinate.

5.4.2 Day 45

Day 45 marked the end of any further seedling emergence and thus, the percentage of seedling emergence had reached a peak. Those seeds which were not viable or were dormant may have failed to germinate (Tosun *et al*., 2003). Seedling emergence was not significantly different ($Pr > 0.05$) on Day 45 between the three species. *L. pedunculatus'* percentage of seedling numbers declined from 64.3% to 56.7% (Table 4.5). This was a result of a higher percentage of abnormal seedlings, which is common in *L. pedunculatus* (Kelman & Forrester, 1999). There was an increase of percentage seedling emergence for *T. repens,* from 60.4 % to 62.4%. *H. lanatus* reached a peak of 38.7% seedling emergence. This non-significant difference ($Pr < 0.05$) was a result of an adequate supply of soil moisture and temperature and similar soil fertility, for all three species (Sections 5.2 & 5.3).

5.4.3 Day 90 and Day 120

Early establishment was significantly different ($Pr < 0.05$) between the three pasture species on Days 90 and 120. A seedling survival plateau was reached for all three species (Figure 4.3). In comparison to *L. pedunculatus* and *H. lanatus*, *T. repens* was the most consistent species, with a 60.8% survival rate on both analysis dates. Other studies have also highlighted the ability of *T. repens* to tolerate dry conditions (Abbasi & Khan, 2004; Karsten & MacAdam, 2001). As highlighted in a few studies, the decrease in seedling survival for *L. pedunculatus* is either due to a high number of abnormal seeds (Table 4.4) or lack of shade and soil moisture on slip surfaces (Chaves *et al*., 2006; Shiferaw *et al.*, 1992).

At these two stages, the soil moisture deficit was above the wilting point (Section 5.3). The soil surface maximum temperatures was within the range of 33.5-35.5^{0}C and thus, they exceeded the ideal soil temperature for optimum pasture growth (Section 5.2).

T. repens was the most successful pasture species in terms of seedling emergence and early establishment on the recent soil slip surfaces (Table 4.5). *T. repens* was consistent on all four data analysis dates (Figure 4.3). It was also more consistent than *L. pedunculatus* and *H. lanatus,* on both the aspects.

5.5 Role of aspect on seedling emergence and early establishment

Significant differences (Pr < 0.05) were found on all four analysis dates, between the north and south facing slip surfaces, on seedling emergence and early establishment. The percentage of seedling emergence and their early establishment was higher on the south facing slip surface, than on the north facing slip surface (Figure 4.4). The GWC% was not significant (P > 0.05) between the north and south soil slip surfaces during spring (Days 15 & 45), but it was (P < 0.05) significantly different during summer (Days 90 & 120). Furthermore, the south facing slip had higher soil moisture than the north facing slip surface at times (Table 4.3). This is consistent with other studies, which have highlighted that southern aspects tend to be wetter, due to the restricted sunshine hours per day, in New Zealand (Hancox & Wright, 2005; Trangmar *et al*., 2003). Seedling emergence and their early establishment is also favoured by a higher shade level (Chapman & Anderson, 1987; Dodd *et al.*, 2005). In comparison, lower maximum soil surface temperatures were recorded on the south slip surface. This was a result of a higher level of solar energy received on the north facing slip surface, since temperature and light are the measure of the same energy (Murphy *et al.*, 2004). It is evident that soil moisture, temperature and shade level were a major contributing factors associated with the percentage of seedling emergence and their early establishment, for all three species.

5.6 Interaction between three pasture species and aspect

Interaction between the pasture species and aspect was not significant (Pr > 0.05) during spring (Day 15 and Day 45), but significantly different (Pr < 0.05) in summer (Day 90 and Day 120). Similarly, W % results indicate that non-significant (P > 0.05) differences were found between both aspects during spring. This also provides evidence that soil moisture was not the major contributing factor for seedling establishment. The soil moisture was between field capacity and wilting point for the entire period of study.

5.6.1 Day 15 & Day 45 (spring)

Interaction between the pasture species by aspect was not significantly different (Pr > 0.05) during spring (Day 15 & Day 45). *T. repens'* interaction on the north facing slip surface was higher than *L. pedunculatus* and *H. lanatus.* However, it was also evident that *L. pedunculatus* has a higher tolerance to water logging and performed well under the wet and shady conditions on south aspect slip surface (Fulkerson & Slack, 1996; Shiferaw *et al*., 1992). In comparison, on Day 15, *T. repens* had 68.9% seedling emergence rate and *L. pedunculatus* had 84.6% on the south facing slip surface (Table 4.9). In terms of oversowing, the soil W% between oversowing and Day 15 was between field capacity and saturation point (Marshall *et al*., 1999), hence, soil moisture was adequate for all the oversown species.

Soil surface temperature at the slip surfaces was above 10^0C (Appendix 4). Many studies have highlighted that the ideal temperature for *T. repens* seedling emergence ranges between 10-15^0C (Hill & Luck, 1991; Rattray, 2005). Alternatively, one study highlighted that birdsfoot trefoil grew better at 24-20^0C than *T. repens* (Hill & Luck, 1991). Furthermore, the minimum temperature for seedling emergence was as low as 5^0C (Kelman & Forrester, 1999).

In comparison to *L. pedunculatus and T. repens, the interaction of H. lanatus* with the north and south facing aspects during spring, in terms of seedling emergence and early establishment on the slip surfaces, was the poorest (Table 4.5). *H. lanatus* growth is favoured by a moist environment (Chaves *et al*., 2006; Shiferaw *et al*., 1992) and thus, this observed trend of higher seedling emergence and their early establishment on the south facing slip surface is consistent. There is little available literature on the optimum soil moisture and temperature requirements for *H. lanatus.* This could be because *H.*

lanatus is often referred to as a low fertility grass or simply as a grassweed (Grant *et al*., 1973; Harrington, *et al.*, 2006).

At Day 45, the soil surface weekly mean temperature was between 18.7^{0}C and 20.2^{0}C (Appendix 4). Similarly, the weekly surface mean temperature recorded between 09/11/08 – 15/11/08, at Ballantrae meteorological station, was 12.8^{0}C (Appendix 4) indicating a desirable temperature for seedling emergence for all three pasture species (Chaves *et al*., 2006; Hill & Luck, 1991; Karsten & MacAdam, 2001). Alternatively, one study stated that full germination for *L. pedunculatus* is above 20 days (Figure 2.17) but there can be delayed germination (Bewley, 1997). Those seeds which were not viable, may have failed to germinate (Tosun *et al.*, 2003), since a germination peak was reached at Day 45 for all the species.

5.6.2 Day 90 and Day 120 (Summer)

Early establishment is a race against time and thus seedlings are most vulnerable during the initial stages of their development (Torssell, 1976). Once this stage of seedling development is surpassed the seedling's survival becomes more distinctive, but then percentage losses (due to seedling death) are different within the three species.

By Day 90 and Day 120, interaction between species and aspect became significantly different ($Pr < 0.05$) which showed that the three pasture species' seedling survival varied with aspect. *L. pedunculatus* percentage seedling numbers dropped steadily, due to a higher percentage of abnormality in its seeds.

During this stage, soil moisture became highly deficient and the temperature exceeded that desirable for all three pasture species. Significant differences were found in W%, between the north facing and south facing slip surfaces.

Higher percentage seedling emergence of *T. repens* (Grassland Tahora) on the north facing slip surface indicates that it has higher tolerance of moisture stress (Karsten & MacAdam, 2001) than *L. pedunculatus* and *H. lanatus. T. repens* was also more tolerant of the maximum temperatures of the soil slip surface than *L. pedunculatus* and *H. lanatus.*

Lotus pedunculatus percentage seedling emergence was higher on the south aspect slip surface. This was due to its response to a higher shade level and soil moisture and lower maximum temperature on the south aspect slip surface than the north aspect slip surface. One study has highlighted that *L. pedunculatus* shows no ability to outyield *T. repens* at low rates of P, especially during early spring and summer period. (Davis, 1991). In this experiment, *L. pedunculatus* performed better, in a higher level of shade and soil moisture, with lower maximum surface temperatures than *T. repens* and *H. lanatus:* on a soil slip surface which was highly deficient in available P.

There was a significant 'time by species effect' ($Pr < 0.05$) from early spring oversowing to late-summer (120 days). This shows that early spring oversowing of *T. repens* on recent soil slips is a viable option. Soil moisture is adequate on both north and south facing slip surfaces. Soil surface temperature is also adequate and thus, this creates the best possible chances of seedling emergence, from oversowing conditions on the soil slip surfaces. It also has the advantage of N fixing ability and thus, any increase in soil fertility will enhance a faster rehabilitation of the soil slips.

5.7 Seed quality

From the respective seed samples, the seeds for all three species were 'pure seeds' and thus were not contaminated with any other seed species. There was negligible percentage of inert matter and hard seeds within each sample for all three species. The final count of 10 days was used to estimate the germination percentage.

The seed laboratory test results indicated a normal germination percentage of *L. pedunculatus* of 23%. Abnormal seedlings of 21 % from *L. pedunculatus* had to be also included in the analysis, as these seeds may have emerged (Kondo, 1993). A few studies have highlighted a higher percentage of abnormal seeds in lotus species, leading to a low germination percentage (Kelman & Forrester, 1999; McKersie & Tomes, 1982). The trend of post-seedling-death was evident at the four dates after sowing for *L. pedunculatus.* In contrast, *T. repens* had an 89 % final germination count, while *H. lanatus* had a final germination count of 91%.

Germination percentage became a useful method to compare seedling emergence and early establishment within respective species due to differences in number of seeds oversown per sampling area. Hence, the initial visible seedling count data were transformed by dividing the number of visible seedling with the expected field germination.

5.8 Essence of oversowing and effects of defoliation

Visible signs of random browsing were evident on a number of occasions. Hoof prints were frequently observed, which showed signs of accessibility (to both sites) by livestock (Figure 3.2a). At this point of time, there is little chance of seedling removal by grazing, since the seedlings are thought to be safe until stem elongation commences. The young seed heads are below grazing height (Rowarth, 1990). The seedlings tended to elongate horizontally and with less vertical growth. This could have been due to adequate space, since the slips were recent. This may be applicable with 10.4 su/ha and moderate grazing, since the effects of defoliation were minimal at the end of the trial period.

5.9 Incidence of weeds and herb cover

The Pearson's correlation coefficient provided a high positive association between the percentage seedling emergence from oversown species and the incidence of weeds, at the end of 120 days of establishment. This provides evidence that natural plant colonisation is also part of the revegetation process. Similarly, positive associations were also seen between herb and weeds. Apart from resident pasture species, weeds have also been identified as some of the first plant colonising species. In addition, other literatures have also highlighted weeds as first colonisers of soil slip surfaces (Lambert *et. al*., 1993; Smale *et al.*, 1997; Prasad *et al*. 2008;). Nevertheless, all of these natural plant colonising species have an ecological effect, which leads to faster rehabilitation of soil slips.

Chapter 6 Conclusion

Soil slips are a common feature of pastoral hill country farms and they generally occur during high-rainfall events. A re-evaluation of revegetation technology is only considered after major slippage events. In the past 100 years, climatic data has provided evidence that storm events, which create major slippages, occur nearly every decade.

Soil slip surfaces are highly deficient in the soil's physical and chemical properties, which are conducive to plant growth. Initially, the bulk density is lower on recent soil slips, since the bare slip surface is continuously being subjected to sedimentation loss, via rainfall. There are also micro-climatic extremes, especially in terms of soil moisture and surface temperatures. Soil moisture (between 0-5 cm depth) is between wilting point and field capacity (during early-spring) and this situation, together with frequent rainfall, provides adequate moisture for the oversown seeds to germinate. Soil moisture during the summer, reaches a critical level of pasture wilting point and thus the survival of seedlings is only possible through moisture replenishment, either by morning dew, frost or rain.

Soil surface temperatures during early spring are ideal for seed germination. During summer, the soil surface maximum temperature greatly exceeds the ideal temperature for optimum seedling emergence — and their early establishment. Oversowing on slip surfaces, during early spring, in terms of soil moisture and temperature, is a viable option.

In terms of seedling emergence and early establishment, *Trifolium repens* was a more successful pasture species than either *Lotus pedunculatus* or *Holcus lanatus*. It was consistent on both north and south facing slip surfaces. It also showed a higher tolerance to drought and extremes of temperature and summer soil moisture deficit.

Due to *Trifolium repens*' higher survival percentage, the possibility of increasing soil fertility, through soil N fixation is important, since soil N is one of the key limiting factors for adequate pasture establishment. This will in turn also increase soil C and thus, it will actively shorten the recovery period of the slips. *Trifolium repens* is an ideal perennial legume that can regenerate itself not only from natural re-seeding, but also via stolons.

Revegetation of recent slips through oversowing *Trifolium repens* could be a first remedy.

Lotus pedunculatus was inconsistent on the north facing slip surface and its seeds were heavier than *Trifolium repens* and *Holcus lanatus.* This resulted in fewer seeds oversown. There is usually a higher percentage of abnormal seedling emergence observed in *Lotus pedunculatus* and hence, the success of theis species is again questionable.

Holcus lanatus was the poorest performing pasture species on these soil slips and it required a moist environment in order to flourish. Also, it has the disadvantage of no N fixing ability and it is also, occasionally, considered to be an un-productive grass-weed.

The south facing aspect had higher soil moisture and lower maximum temperatures and also a higher level of shade cover, which provided more opportunity for seedling survival, than the north facing slip surface. All three species had higher establishment on the south facing slip surface.

The most important factor was that the results were taken from an open grazing area and thus inputs, such as fencing and fertilisation of the soil slip surfaces, can be duly disregarded.

Stabilising recent soil slips via oversowing *Trifolium repens* during early spring, will significantly reduce recovery time, whilst providing ecological benefits to pastoral hill-country farms.

Limitations & further research

Soil slips are usually small and thus a limited number of treatments can be established on a particular soil slip site. In terms of trial establishment, steepness of the slope and accessibility to the slip site can be challenging.

Conducting measurements of soil C and soil N accumulation together with other essential nutrients for plant growth after 2-3 years may provide better understanding on the impact of oversowing and any improvements in soil fertility.

Measurement of sediment losses from the unsown recent slip site and comparing with oversown sites may provide further knowledge of the importance of revegtation.

Apart from assessing slip stabilisation, assessing the productivity after three years may provide better knowledge of oversowing and revegetation. Continuous revegetation technologies have to be re-evaluated to decrease the recovery time.

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Appendix 1

Mean bulk density from two recent soil slip surfaces at AgResearch's Ballantrae pastoral hill country farm near Woodville.

2008/2009	Mean Bulk Density (recent soil slip surface)	
Dates	South aspect (g/cm^3)	North aspect (g/cm^3)
10-Oct	1.289	1.314
24-Oct	1.260	1.354
07-Nov	1.292	1.317
21-Nov	1.381	1.376
05-Dec	1.401	1.429
19-Dec	1.387	1.416
02-Jan	1.429	1.461
16-Jan	1.431	1.443
28-Jan	1.444	1.438
Mean	**1.368**	**1.394**

Appendix 2

Soil fertility results of recent slip surfaces at AgResearch's Ballantrae pastoral hill country farm near Woodville.

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Laboratory Report

Name: Kamal Prasad **Date:** 3/12/08

Address: Institute of Natural Resources
Massey University

Type of material: Soil

ANALYSES:

SAMPLE	pH	Olsen P µgP/g	SO4 µgS/g	K me/100g	Ca me/100g	Mg me/100g	Na me/100g	CEC me/100g	Soil volume g/ml
North pasture	5.5	8.4	5.3	0.27	3.3	3.83	0.20	14	1.02
North subsoil	6.5	0.9	3.0	0.22	2.1	8.11	0.84	14	1.40
South pasture	5.3	24.0	5.5	0.37	5.0	1.71	0.04	15	0.98
South subsoil	5.7	2.8	2.5	0.28	4.6	3.30	0.17	15	1.26

Phosphate and sulphate values are expressed as µg/g (air-dry). Exchangeable cations and CEC values are expressed as me/100g (air-dry).
Soil volume is a measure of the weight of air-dry soil (g) per volume (ml) and can be used to convert results to a volume basis.

CONVERSION TO MAF 'QUICK TEST' VALUES:

SAMPLE	P µgP/ml	SO4 µgS/g	K	Ca	Mg
North pasture	9	5	4	4	89
North subsoil	1	3	5	3	260
South pasture	23	6	6	6	38
South subsoil	3	3	6	7	95

ADDITIONAL ANALYSES:

C %	N %
3.14	0.24
0.14	0.02
3.61	0.29
0.29	0.04

'Quick Test' values are calculated using conversion factors reported in Fertiliser Recommendations for Pastures and Crops in New Zealand (1984) compiled by I S Cornforth and A G Sinclair. Carbon and Nitrogen are determined by combustion in a resistance furnace. Gases are passed through an Infrared cell to determine Carbon and a Thermal Conductivity cell to determine Nitrogen. Results are reported as % on an oven-dry basis.

SIGNED: ____________________
Mr L D Currie (Senior Technical Manager)

FERTILIZER & LIME RESEARCH CENTRE

Lab Report 03 12 08

Te Kunenga Ki Pūrehuroa

Appendix 3

Weekly mean maximum and minimum surface temperatures on north and south facing slips between spring 2008 and summer 2009 at AgResearch's Ballantrae pastoral hill country farm near Woodville.

	North aspect slip surface		South aspect slip surface	
Week	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**	**Maximum temperature (^{0}C)**	**Minimum temperature (^{0}C)**
14/10 - 18/10	23.5	10	21.5	10
19/10 - 25/10	19.8	8.9	18	8.9
26/10 - 01/11	26.6	7.9	24.9	8
02/11 - 08/11	26.1	6.9	23.9	7.1
09/11 - 15/11	30.3	12.1	27.8	12
16/11 - 22/11	33.3	10.4	32.7	10.5
23/11 - 29/11	37.1	13.9	36.4	13.6
30/11 - 06/12	37.6	13.9	35.6	14.2
07/12 - 13/12	34.2	15.5	31.4	15.1
14/12 - 20/12	32.1	13.6	29.5	13.6
21/12 - 27/12	32.5	12.6	32.3	12.6
28/12 - 03/01	34.6	15.3	33.1	15.3
04/01 - 10/01	38.8	15.5	37.5	15.5
11/01 - 17/01	35.7	14.5	34.4	14.5
18/01 - 24/01	32.7	15.5	31.6	15.4
25/01 - 31/01	32.5	15.4	30.4	15.4
01/02 - 07/02	22.9	18.9	22.1	19.1
08/02 - 14/02	23.6	19.9	23.2	20.3
15/02 - 18/02	22.1	16.8	22	17.1

Appendix 4

The weekly mean climatic data recorded from metrological station at AgResearch's Ballantrae pastoral hill country farm near Woodville between spring 2008 and summer 2009.

Weekly summary	Rain (mm)	Wind (km/hr)	Air temp (°C)	Surface temp (°C)	10cm temp (°C)	Soil moisture
14/10 - 18/10	52.4	4.5	12.8	11.4	12.5	43.6
19/10 - 25/10	102.6	6.4	11.4	10.5	11.7	44.4
26/10 - 1/11	33.4	7.6	10.8	10.4	11.8	38.7
02/11 - 8/11	39.8	4.9	10.0	10.2	11.6	36.5
09/11 - 15/11	0.2	3.1	14.8	12.8	13.3	30.4
16/11- 22/11	5.0	4.4	13.2	13.4	14.0	28.2
23/11-29/11	19.2	4.2	16.5	16.8	17.0	24.1
30/11- 6/12	14.4	4.1	16.4	17.0	17.5	22.2
07/12 - 13/12	24.6	3.4	15.6	17.6	18.1	20.5
14/12- 20/12	31.4	4.8	15.7	16.8	17.3	15.3
21/12 - 27/12	58.2	4.2	14.4	16.5	16.7	13.8
28/12- 3/01	33	4.2	14.4	16.5	16.7	11.7
04/01- 10/01	15	4.6	17.0	17.4	18.4	9.7
11/01 - 17/01	14.2	3.9	16.0	16.0	17.6	9.9
18/01- 24/01	21.4	4.2	16.6	16.2	17.8	7.3
25/01- 31/01	8	4.7	17.0	16.5	18.4	5.9
01/02-07/02	8.2	5.3	17.0	16.4	18.0	1.6
08/02-14/02	181	4.1	17.2	16.9	18.6	1.2
15/02-21/02	78.6	3.2	16.8	15.6	17.4	16.3
21/02-28/02	46.6	4.1	15.9	15.7	17.6	18.8

Appendix 5

Weekly mean temperatures recorded on the slip surfaces and at the depth of 5 cm on north and south facing slips between spring 2008 and summer 2009 at AgResearch's Ballantrae pastoral hill country farm near Woodville.

	North Aspect slip		South Aspect slip	
Week	**Surface**	**5 cm**	**Surface**	**5 cm**
14/10 - 18/10	15.2	16.0	14.5	15.9
19/10 - 25/10	12.8	12.9	12.2	12.7
26/10 - 01/11	12.9	14.0	12.6	13.2
2/11 - 08/11	12.3	13.4	11.9	12.4
09/11 - 15/11	17.0	18.3	16.6	16.7
16/11 - 22/11	16.0	18.0	16.2	16.4
23/11- 29/11	19.2	21.5	19.6	19.3
30/11 - 06/12	19.1	21.2	19.4	19.3
07/12 - 13/12	19.0	20.2	18.7	19.1
14/12- 20/12	17.7	18.9	17.2	17.8
21/12 - 27/12	17.2	18.3	17.0	17.4
28/12 - 03/01	20.0	21.7	20.2	20.2
04/01 - 10/01	20.5	22.5	21.2	20.7
11/01 - 17/01	19.6	21.5	19.5	19.7
18/01 - 24/01	20.2	21.4	19.6	20.4
25/01 - 31/01	22.4	22.9	21.7	22.6
01/02 - 07/02	20.8	21.1	20.3	21.0
08/02- 14/02	21.6	21.8	21.0	21.7
15/02- 18/02	19.0	19.4	18.7	19.3

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Summary
Jan	50	80	111	112	68	80	29	121	74	77	56	46	86	76
Feb	75	84	12	13	94	112	33	405	55	43	30	48	326	102
Mar	133	49	63	67	50	85	24	62	81	105	88	57		72
Apr	92	106	76	124	40	68	64	55	51	152	63	96		82
May	83	113	115	131	191	55	107	94	96	156	40	70		104
June	30	152	64	80	54	145	169	146	82	139	147	161		114
July	61	173	152	55	88	145	55	94	75	180	90	184		113
Aug	61	76	102	75	144	109	50	82	38	122	155	187		100
Sept	98	89	72	118	11	129	190	127	134	93	77	96		103
Oct	121	232	56	104	156	77	113	158	169	322	130	303		162
Nov	75	95	244	97	127	75	176	64	73	183	78	82		114
Dec	109	51	69	109	219	104	127	209	120	119	58	121		118
Total	**988**	**1300**	**1136**	**1085**	**1242**	**1184**	**1137**	**1617**	**1048**	**1691**	**1012**	**1451**		**1260**

Rainfall data from the last 10 years at AgResearch's Ballantrae pastoral hill country farm near Woodville. The highlighted cells represent monthl rainfall accumulation during the revegetation trial period.

Appendix 6

Appendix 7

Appendix 1. Datasets for repeated measures of analysis.

1 1 1 036 049 051 052 046 046 000 000 000 000 000 000 06.4 05.7

1 1 2 035 040 040 040 039 038 000 000 000 000 000 000 11.7 11.7

1 1 3 010 022 026 027 027 027 000 001 000 000 000 000 13.5 11.7

1 1 4 022 020 006 005 005 005 000 000 000 000 000 000 04.2 04.2

1 2 1 000 000 000 000 000 000 000 000 000 000 001 001 01.9 00.0

1 2 2 004 035 046 046 045 045 000 000 000 000 000 000 25.0 25.0

1 2 3 005 014 015 014 013 013 000 000 001 001 001 001 17.7 14.8

1 2 4 012 040 053 050 050 049 000 000 001 001 001 001 35.8 10.9

1 3 1 000 000 000 000 000 000 000 000 000 000 000 000 00.4 00.4

1 3 2 005 008 009 007 002 002 000 000 000 000 000 000 08.6 00.7

1 3 3 007 004 001 001 001 001 000 000 000 000 000 000 01.7 01.7

1 3 4 010 004 004 004 003 003 000 000 000 000 000 000 03.5 03.5

1 4 1 000 000 001 001 000 000 000 000 000 000 000 000 00.0 00.0

1 4 2 000 000 000 000 000 000 000 000 001 001 001 001 02.6 00.0

1 4 3 000 000 000 000 000 000 000 000 000 000 000 000 00.0 00.0

1 4 4 000 000 001 001 001 001 000 000 001 002 002 002 09.9 00.0

2 1 1 026 027 027 026 021 021 000 000 000 002 003 003 08.7 04.1

2 1 2 . . . . . . 000 000 000 000 000 000 48.3 47.4

2 1 3 061 017 019 018 020 020 000 000 002 002 002 002 12.5 07.1

2 1 4 078 140 144 143 142 142 000 000 000 002 003 003 89.4 58.4

2 2 1 020 015 004 006 006 006 000 000 000 002 003 003 07.3 04.9

2 2 2 007 030 030 026 005 005 000 000 000 000 000 000 04.0 02.9

2 2 3 012 032 036 031 023 019 000 000 000 000 000 000 23.2 07.3

2 2 4 011 075 083 078 075 075 000 000 000 002 005 005 77.4 59.4

2 3 1 015 015 010 009 006 005 000 000 000 001 002 002 25.9 06.7

2 3 2 005 006 005 008 009 009 000 001 000 000 000 000 16.8 00.0

2 3 3 017 019 021 019 018 018 000 000 000 003 008 008 65.5 21.2

2 3 4 028 022 023 023 025 025 000 000 001 003 003 003 38.1 11.6

2 4 1 000 000 001 001 000 000 000 000 000 000 000 000 00.0 00.0

2 4 2 000 001 000 000 000 000 000 001 001 001 001 001 00.0 00.0

2 4 3 000 000 002 003 004 004 000 000 002 003 004 004 13.5 00.0

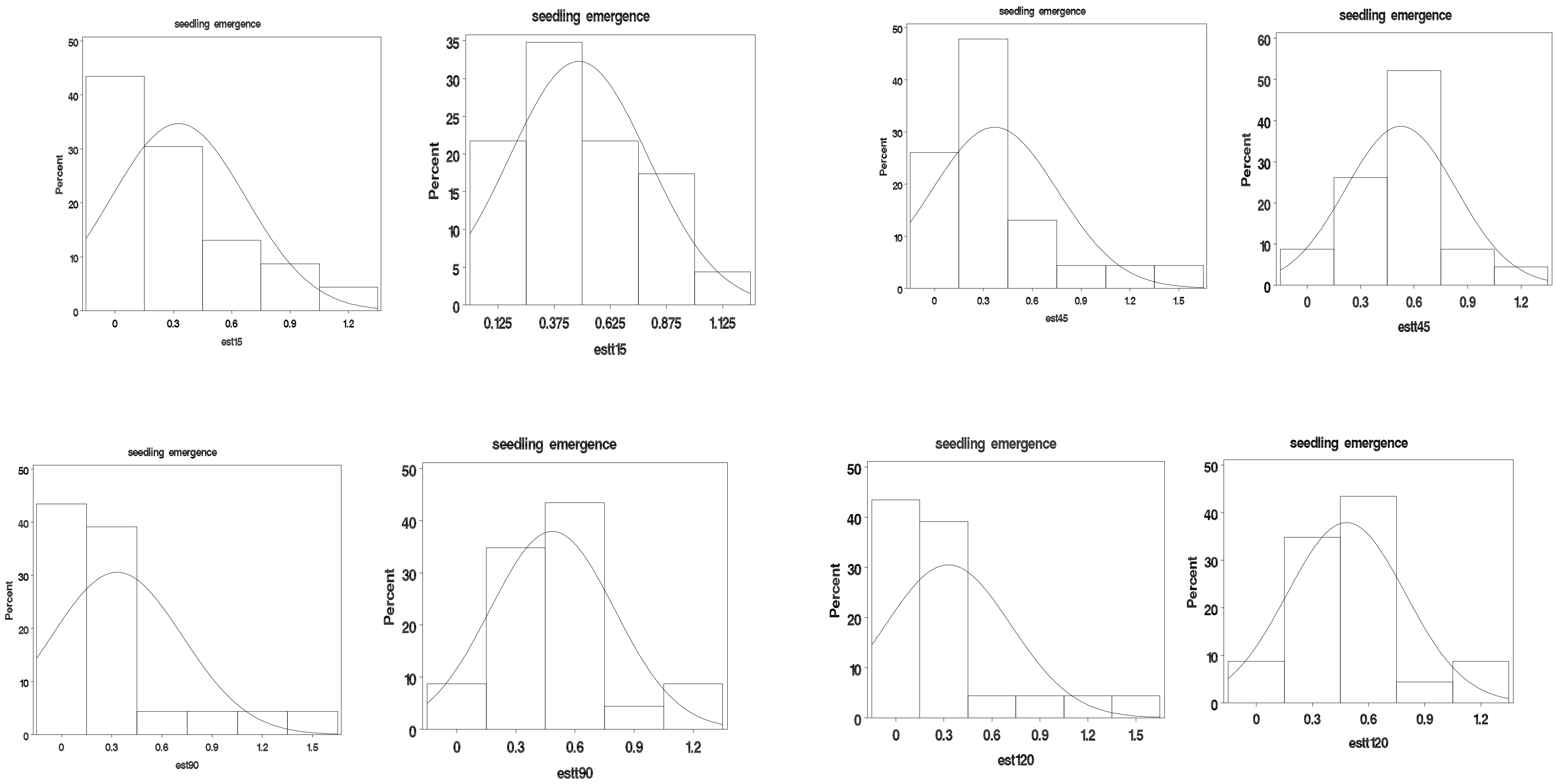
2 4 4 000 000 000 000 001 001 000 000 001 002 003 003 06.1 00.0

Appendix 8

SAS code for repeated measures of analysis.

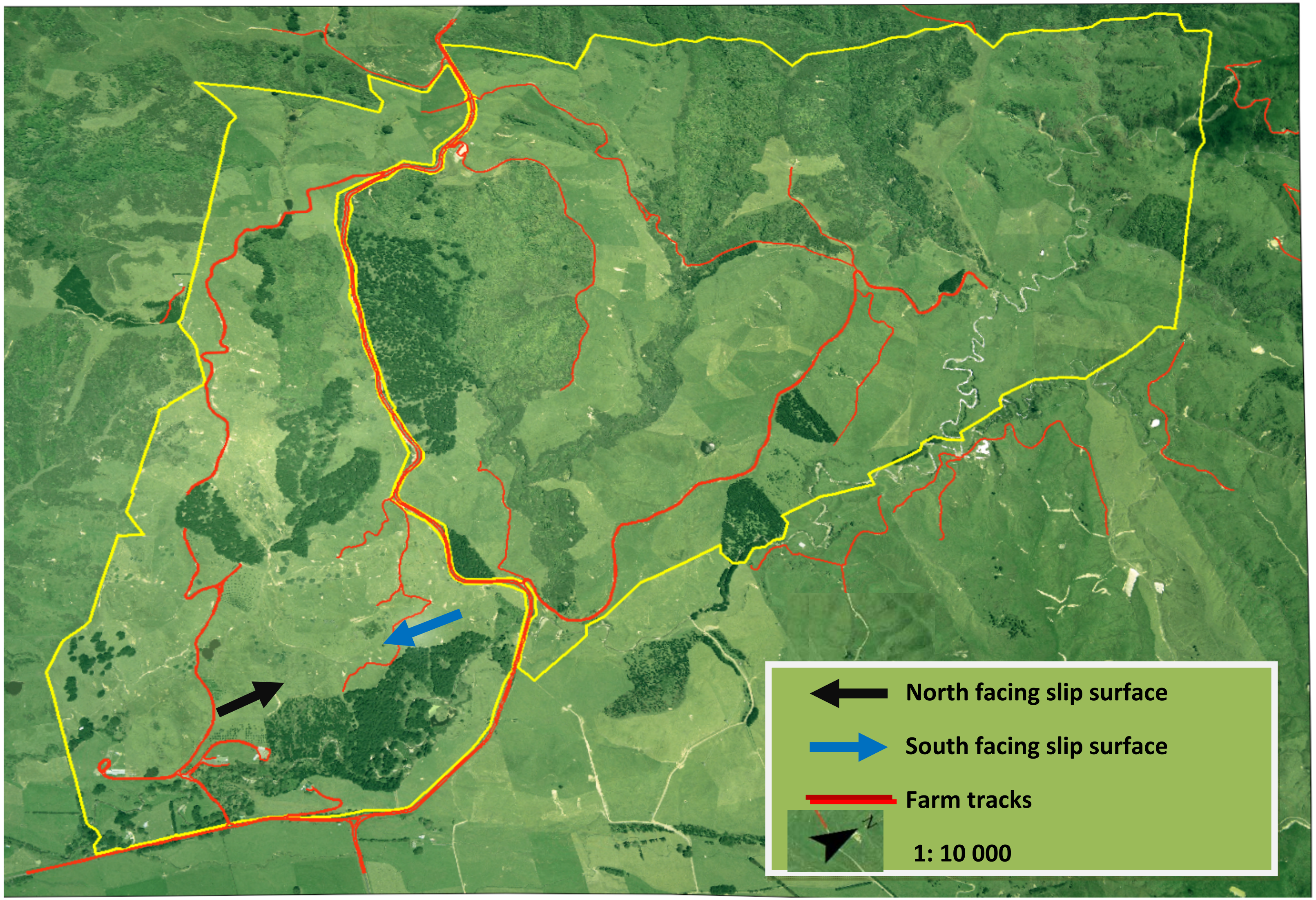
```
options ls=78 ps=60 nodate nocenter formdlim='-';
title "seedling emergence";
data seedling numbers;
infile 'G:\sas\Ballantrae.txt';
input aspect species rep herb15 herb30 herb45 herb60 herb90 herb120 weed15 weed30 weed45
weed60 weed90 weed120 totcover weedcover;
run;
data seedling; set numbers; run;
data p; set seedling;
if species=1 then est15 = herb15/91;
else if species = 2 then est15 = herb15/171;
else if species = 3 then est15 = herb15/21;
else if species = 4 then est15 = .;
if species = 1 then est120 = herb120/91;
else if species = 2 then est120 = herb120/171;
else if species = 3 then est120 = herb120/21;
else if species = 4 then est120 = .;
if species = 1 then est45 = herb45/91;
else if species = 2 then est45 = herb45/171;
else if species = 3 then est45 = herb45/21;
else if species = 4 then est45 = .;
if species = 1 then est90 = herb90/91;
else if species = 2 then est90 = herb90/171;
else if species = 3 then est90 = herb90/21;
else if species = 4 then est90 = .;
herbcover = totcover-weedcover;
estt15 = sqrt(est15);
estt45 = sqrt(est45);
estt90 = sqrt(est90);
estt120 = sqrt(est120);
run;
*Proc univariate;
*var est120 est45 est15 weed120;
proc glm data = p;
class species aspect rep;
model  estt15 estt45 estt90 estt120 = species aspect species*aspect rep(aspect);
repeated time 4;
manova h = species aspect species*aspect / canonical;
*lsmeans species aspect species*aspect/stderr;
*output out = new p=pred r=resid;
run;quit;
proc plot data = new;
plot resid*pred;
proc corr;
var weed120 herb120 totcover weedcover est120 herbcover;
run; quit;
proc cancorr data=p out=p1 all;
     *vprefix=phys vname='Physiological Measurements'
     wprefix=exer wname='Exercises';
  var estt15 estt45 estt90 estt120;
  with species aspect;
run; quit;
proc univariate data=p normal;
  var est15 est45 est90 est120;
  probplot / normal(mu=est sigma=est);
  histogram / normal(mu=est sigma=est); *barwidth=15;
run;
proc univariate data=p normal;
  var estt15 estt45 estt90 estt120;
  probplot / normal(mu=est sigma=est);
  histogram / normal(mu=est sigma=est); *barwidth=15;
run;
/* Boxplots */
proc sort data=p; by species; run;
goptions reset=all gunit=cm ftext=swissb htext=0.7 colors=(black);
title1;
proc boxplot data=p;
  plot (estt15 estt45 estt90 estt120)*species;
run; quit;
```

Appendix 9



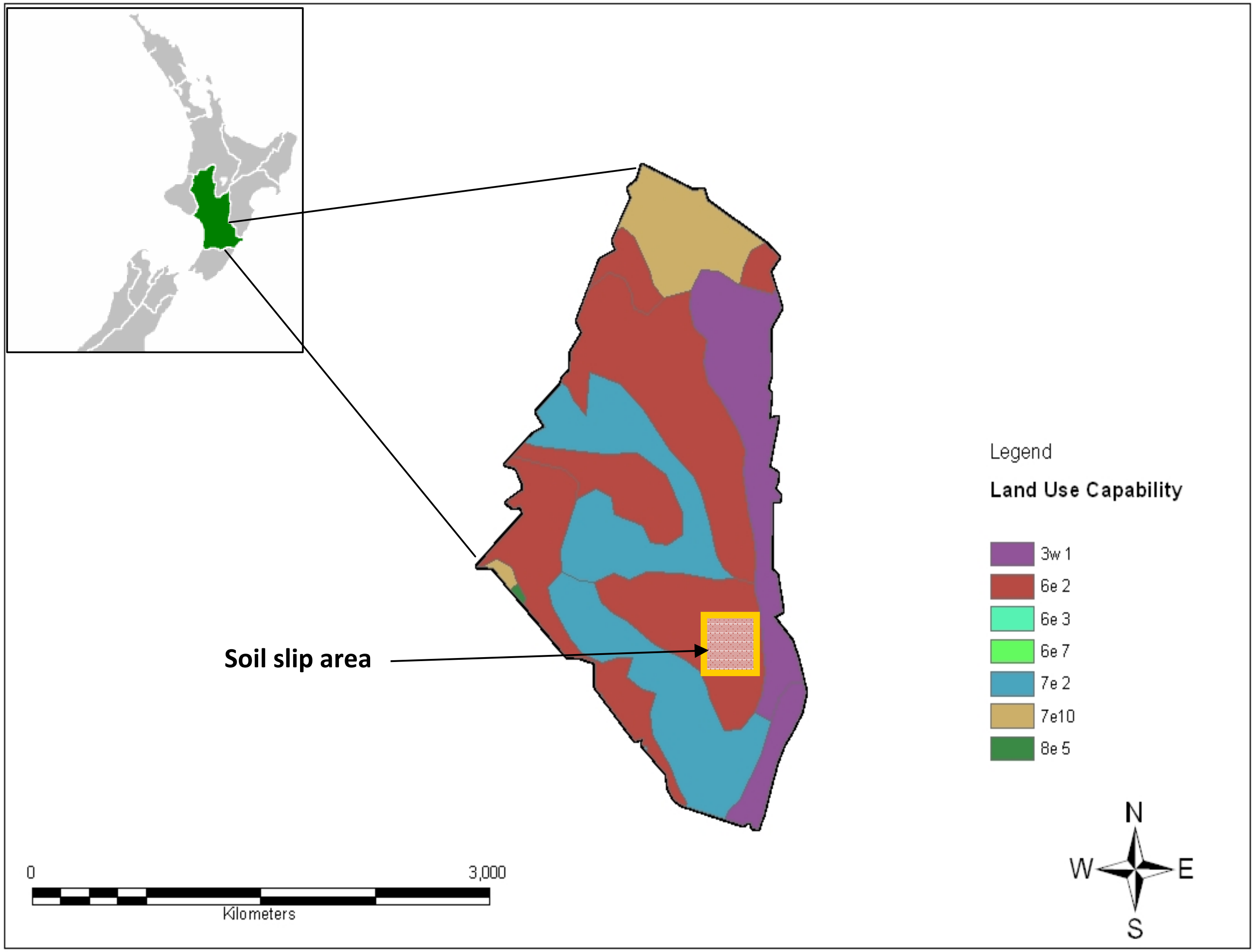
Graphs showing normalisation of the data using square root transformation at the four dates of analysis.

Appendix 10



Aerial photo showing site locations and their accessibility via farm tracks at AgResearch's Ballantrae pastoral hill country farm near Woodville.

Appendix 11



Land Use Capability Map of AgResearch's Ballantrae pastoral hill country farm near Woodville.

Prasad et al., 2009.