What are the best pasture improvement options for different South Island hill and high-country environments?

Jeff D. MORTON[1*], Jim L. MOIR[2] and Derrick J. MOOT[2]
[1] MortonAg, 8 Deacon St, Christchurch 8025, New Zealand
[2]Faculty of Agricultural and Life Sciences, PO Box 85084, Lincoln 7647, New Zealand
*Corresponding author: mortonag1@gmail.com

Abstract

A range of options exist to improve pasture in the South Island hill and high country. Pasture yield and the cost of seed, lime and fertiliser from 55 trial sites were used to calculate partial gross margins (GM) for a range of improvements on different slopes and aspects. On drillable land, for average rainfall <500 mm/yr, pastures should be based on subterranean clover or perennial lupins. Lucerne can be used where root growth is not limited by soil depth. At 500-750 mm/yr rainfall, lucerne and perennial lupins, with subterranean or Caucasian clover, are viable. Where rainfall is >750 mm, lucerne and Caucasian, white and red clover can be sown. At similar rainfall, soil moisture is more limited on non-drillable hill compared with drillable land, and aspect must be considered. At <750 mm/yr on sunny aspects, clover, *e.g*., subterranean or balansa, are the best options, and shady areas can be improved with subterranean clover. Late winter application of 30-50 kg/ha nitrogen can be used on shady aspects with less than 750 /yr rainfall or sunny aspects with higher rainfall. For >750 mm/yr rainfall on shady aspects, pasture should be managed to maximise legume content, and over-sowing white clover should be considered.

Keywords: Drillable, hill, aspect, legumes, rainfall

Introduction

South Island hill and high country is defined as those areas that were in natural grassland at the time of early European settlement (Morton et al*.,* 2021). This includes the major geographical regions of dry hill and high country in Marlborough, Canterbury and North and Central Otago, and the wet tussock grasslands of East and South Otago and Southland, most of it over 500 m altitude (Morton et al*.,* 2021). It includes the flat and rolling inland intermontane regions, such as the McKenzie and Clutha Basins and Lees Valley.

In this environment, average rainfall ranges from 400-500 mm/yr in Central Otago up to 2000/yr mm in the western fringes of the Southern Alps. As a general pattern, rainfall increases with altitude and from east to west. Temperatures can drop to below zero in winter but can be over 30°C for short periods in summer, especially in areas with a Mediterranean-type climate, such as Central Otago (Morton et al*.,* 2021).

There is still a large area of hill and high country in the South Island that could be improved sustainably by the establishment of legume-based pasture. Relatively high lamb and Merino wool prices, less suitable land to finish stock and a renewed research effort can support the opportunity to improve pastures (Morton et al*.,* 2021). There is a reasonable amount of previously published research, together with farm monitoring data and user experience, which can be used to inform farmers of the best pasture improvement options.

Hill and high country have large variation in slope, aspect, climate and soils. Therefore, a range of improvement options are usually available, although selecting the most appropriate can be difficult. Some of the major components of any improvement programme include fertiliser and lime inputs and pasture species. All three factors are determined by matching requirement and potential performance from the inherent properties of the land which is to be developed.

Since the 1950's there has been much published research in South Island hill and high country to investigate these aspects, some included in the review by Morton et al*.* (2021). In addition, for the last 10 years, the Dryland Pastures Research Group at Lincoln University have investigated the role of legumes in the improvement of hill and high-country land. The purpose of this paper is to use such data and results to guide land users in the selection of the most appropriate pasture improvement options for their hill and high-country farm.

Methods of analysis

For each combination of slope x aspect x sown species or resident vegetation options, relevant data was extracted from peer-reviewed research papers. Only trials conducted under dryland (rainfed) management of at least one year's duration were included. Annual pasture yield derived from 55 trial sites was used as the basis of production which was a limited dataset for a meaningful comparison of improvement options. Absolute levels of annual pasture yield from improved swards were used, rather than the difference in yield between improved pasture swards and resident swards. This was because there was a lack of data quantifying

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yields from unimproved resident swards from each site, which could be used as a control, except where they were treated with N fertiliser.

For each set of experimental responses, the fertiliser nutrient or lime treatment with the highest pasture yield which was significantly the greatest at the 5% level of probability ($P<0.05$) was selected. The basal or treatment applications of fertiliser nutrients and lime were included as inputs.

The pasture yield values were converted to stocking rate using a standard conversion of 70% pasture utilisation and 600 kg DM/yr intake required per stock unit (SU). Stocking rate was converted to animal production per ha based on current average per head production using current returns (2022) to calculate gross revenue per ha. A partial gross margin (GM) was calculated by deducting the costs of seed, fertiliser and lime from gross revenue.

Costs were calculated using current prices for seed, fertiliser and lime listed in March 2022. Where a high rate of lime or fertiliser were applied as a capital dressing at the start of the trial, the cost was spread over the duration of the trial. Where the sowing rate was not specified it was assumed to be 5 kg/ha for all legumes, except for lucerne and perennial lupins, which were sown at 10 kg/ha and grasses were assumed to be sown at 15 kg/ha. The costs of applying fertiliser and lime varied widely between farms, so estimated average values were used.

Drillable land was defined as being within an intermontane basin and/or part of a hill country farm. For simplicity, a sheep farming system has been assumed. At an average altitude of over 1000 m for each site, farms have been designated as running Merinos, with crossbreeds assumed at altitudes less than 1000 m.

Decision trees

The decision trees (Figures 1 and 2) showed that pasture improvement options were broadly supported by the results of the analysis of pasture yield and partial GM, as described in the results section below. Where there was a scarcity of trial data for *e.g.,* subterranean clover, so local farmer experience and observations of the effectiveness of pasture options were used. Although less validity can be given to these observations compared with quantifiable data, it was considered that all viable pasture species options should be included in the decision trees to build meaningful and practical recommendations. It was also difficult to assign specific yield and GM values to each of the options in the decision trees because of the variability in rainfall and soil fertility status between trial sites. Hence, the only feasible method of interpretation of the data was to adopt a holistic approach. The trials selected for this analysis had sufficient fertiliser and lime applied to achieve optimal soil nutrient and pH levels for lucerne and white and red clover, as defined by Morton et al*.,* (2017). Therefore, the success of the recommended options can only be achieved if these rates of fertiliser and lime are applied.

Results

Drillable land; White, red and alsike clover

On the seven sites with average rainfall of 450 to 600 mm/yr, where a combination of white (*Trifolium repens*), red (*T. pratense*) and alsike (*T. hybridium*) clover were sown (Scott and Maunsell 1981, Caradus et al*.,* 2001, Kearney et al*.,* 2010, Berenji et al*.,* 2018), average pasture yield was 3450 kg DM/ha/yr (range 2580 to 5200 kg DM/ha/yr) which resulted in a partial GM of $227/ha/yr (range $-48 to 573/ha/yr). Although positive, investment at this level of GM would probably be marginal, if other development costs such as fencing, stock and water supply were included. There was no data for higher rainfall areas, but both yield and financial return would be expected to be better because of the greater soil moisture status that would favour such legume species. On one site with average rainfall of 470 mm/yr (Caradus et al*.,* 2001), alsike clover yielded an average 6700 kg DM/ha/yr with a partial GM of $691/ha/yr.

Lucerne

There were eight sites with average rainfall of 435 to 600 mm/yr where yields from lucerne (*Medicago sativa*) was measured (Scott and Maunsell 1981, Boswell 1997, Kearney et al*.,* 2010, Berenji et al*.,* 2017, 2018, Hendrie et al*.,* 2018). These sites produced, on average, 4240 kg DM/ha/yr (range 1800 to 8410 kg DM/ha/yr) with a partial GM of $200/ha/yr (range -$269 to $667/ha/yr). The two lowest-yielding sites in the Lees Valley (Berenji et al*.,* 2017) and Omarama (Hendrie et al*.,* 2018), which had negative partial GM's, were on shallow soils unsuitable for lucerne because there was little opportunity for its tap root to extract moisture from the lower soil profile. If these sites are excluded, average partial GM increased to $348/ha/yr. Compared with the pastures based on white, red and alsike clover, input costs for lucerne were higher due to a greater requirement for lime to increase the soil pH to 6.2 to 6.4 in the top 150 mm (Morton et al*.,* 2017) and reduce the concentration of soil aluminium (Al). At higher rainfall, lucerne was expected to be more productive and profitable.

Caucasian clover

On four sites with an average annual rainfall 470 to 750 mm (Caradus et al*.,* 2001, Black et al*.,* 2014, Berenji aet al*.,* 2017, 2018) Caucasian clover (*T. ambiguum*) yielded an average of 2690 kg DM/ha (range 1300 to

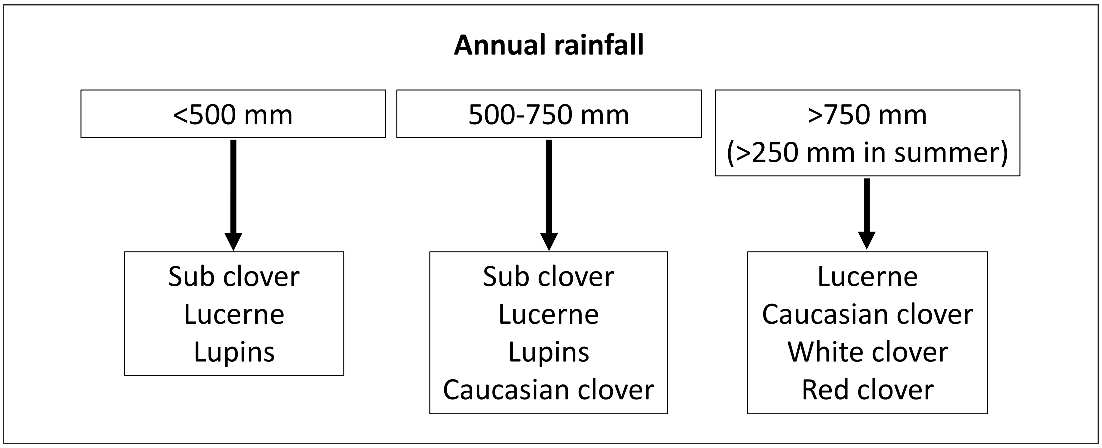

Figure 1 Decision tree for pasture improvement options on drillable land.

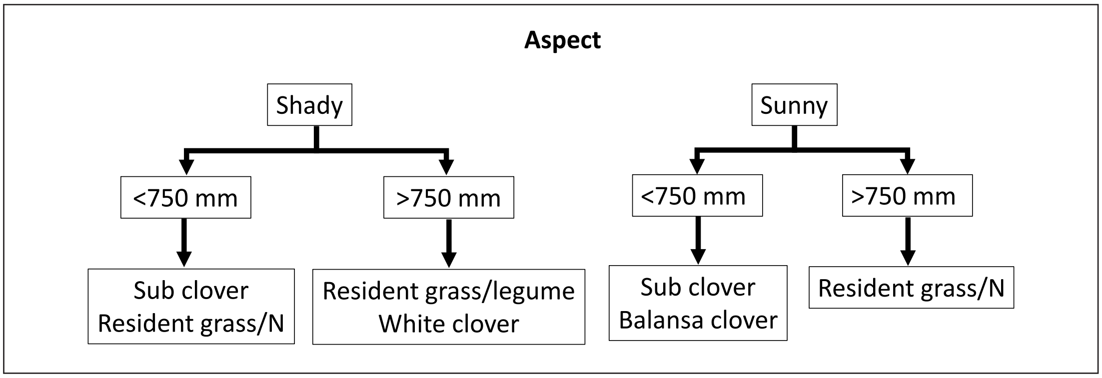

Figure 2 Decision tree for pasture improvement options on non-drillable hill land.

3570 kg DM/ha) for an average partial GM of $121/ha/yr (range $-108 to 356/ha/yr). The best performing site had been measured for 6 years compared with 2 to 3 years for the other sites, so it could be concluded that, with more time, this slow establishing legume would be higher yielding.

Balansa clover

Balansa clover yielded an average 2000 kg DM/ha/yr on one site with average rainfall of 630 mm/yr, which resulted in a partial GM of $210/ha/yr (Berenji et al., 2018). Although this performance was inadequate for flat land, based on its observed performance at Omarama Station (RT Subtill pers. comm.), it was feasible that Balansa clover may be a suitable annual legume for dry hill country where competition from resident species is low. Such sites may be identified by the presence of cluster clover (*T. glomeratum*).

Lotus species

There were two sites with *Lotus pedunculatus* sown and one site with *Lotus corniculatus* (Caradus et al., 2001, Berenji et al 2018) which yielded from 3500 to 6000 kg DM/ha/yr with a partial GM averaging $297/ha/yr for *Lotus pedunculatus* and $642/ha/yr for *Lotus corniculatus*. Based on this limited dataset, these may provide viable legume options but their use could be limited by the scarce availability of seed.

Russell lupins

Under average annual rainfall ranging from 490 to 630 mm at five sites (Black et al., 2014, Moot and Pollock 2014, Pollock and Moot 2016, Berenji et al., 2018, Hendrie et al., 2018), Russell lupins (*Lupinus polyphyllus*) yielded an average 4600 kg DM/ha/yr (range 3060 to 7000 kg DM/ha/yr). This resulted in an average partial GM of $357/ha/yr (ranging from $75 to $919/ha/yr). This partial GM would have been higher if the basal application of 3 t lime/ha at two sites had not been applied to ensure establishment of the other legumes tested. This lime would not have been necessary for this Al-tolerant species at sites where the initial soil exchangeable Al level was up to 5 ppm.

Sown grasses plus N

On three sites with rainfall of 450 to 575 mm/yr where grasses were sown (Scott and Maunsell 1981, Pollock 1989, Stevens et al., 2014, Fasi 2018), there was an average pasture yield of 5090 kg DM/ha/yr (range 3000 to 7000 kg DM/ha/yr) but a negative partial GM of -$47/ha/yr (range -$234 to $227/ha/yr). This poor financial return was mainly caused by the excessively high cost of the 345 kg N/ha/yr applied at one site and the unnecessary application of 5 t lime/ha/yr where the initial soil pH was 5.5 at another site. With the current high cost of N fertiliser, this policy in these low rainfall areas could probably only be justified by the use of more drought-tolerant grasses, such as cocksfoot and tall fescue, and the application of N in early spring when rainfall is more reliable.

Non-drillable hill land

There were 25 sites analysed on hill land where it was possible to compare pasture yield and partial GM on the basis of sown vs resident clover/grass species, sown lucerne *vs*. white and red clover, resident pasture with and without N, N on resident pasture with different aspects and Maku Lotus.

Sown *vs*. resident clover/grass species

On five sites with rainfall between 470 to 1100 mm/yr (McIntosh et al., 1984), pastures containing over sown white and red clover without applied N yielded, on average, 1700 kg DM/ha/yr (range 1100 to 2500 kg DM/ha/yr) with a partial GM (loss) of -$594/ha/yr (range -$831 to $321/ha/yr). In contrast, nine sites with resident pasture based on white and subterranean clover with no N applied and an annual rainfall of 700 to 875 mm/ha/yr (McLeod 1974. Craighead et al., 1990, Craighead and Metherell 2005, Maxwell 2013) yielded, on average, 4210 kg DM/ha/yr (range 2885 to 11000 kg DM/ha/yr) with an average partial GM of $467/ha/yr (range $296 to $984/ha/yr). The poorer performance of over sown clovers was due to the unfavourable environment of low rainfall, high soil Al levels and competition from resident grasses.

Sown lucerne *vs*. white and red clover

On four sites (Boswell and Swanney 1991), on easy slopes with both sunny and shady aspects with an average rainfall of 696 mm/ha/yr, lucerne yielded 8115 kg DM/ha/yr (range 6725 to 8755 kg DM/ha/yr) with an average partial GM of $644/ha/yr (range $495 to $770/ha/yr). Although the performance of lucerne was much higher than white and red clover, this result should be treated with caution, because of the small number of sites and the possibly higher rate of lime required to grow lucerne than the 3 t/ha applied on these high pH soils.

Resident pasture with and without N

There were eight sites with an average rainfall from 342 to 356 mm/yr where resident pasture had N applied (Smith et al., 2004, Gillingham et al., 2007, 2008). On average, these sites yielded 3790 kg DM/ha/yr (range 2000 to 6330 kg DM/ha/yr) and had a partial GM of $214/ha/yr (range -$208 to 766/ha/yr). Average pasture yield at these sites was similar to the resident pasture sites without N, but the average partial GM was much lower when N was applied ($214 *vs*. $467/ha/yr). This difference was attributed to the high cost of N fertiliser applied at 73 kg N/ha/yr. However, the fertilised sites were carried out at much lower average annual rainfall than the sites without N, and were expected to yield more at equivalent rainfall.

N on resident pasture of different aspects

There were four sites with resident pasture with both shady and sunny aspects with the same average rainfall, ranging from 342 to 548 mm/yr, that had received N (Smith et al., 2004, Gillingham et al., 2007, 2008). Annual pasture production of 4315 kg DM/ha/yr (range 2830 to 6330 kg DM/ha/yr) was higher for shady than sunny aspects, that averaged 3270 kg DM/ha/yr (range 1700 to 3820 kg DM/ha/yr). There was a difference in partial GM with an average of $262/ha/yr (range -$47 to $766/ha/yr) for shady and $162/ha/yr (range -$203 to $372/ha/yr) for sunny slopes. However, in Central Hawkes Bay hill country, which had a higher average rainfall of 800 mm, on sheep and beef farmlets there was a greater yield response to N from resident low fertility-demanding grasses on sunny than shady slopes (AG Gillingham, pers. comm.).

Lotus pedunculatus

There were six hill sites sown with Maku *Lotus pedunculatus* (McIntosh et al., 1984, Caradus et al., 2001) at an average rainfall ranging from 630 to 1100 mm/yr. *Lotus pedunculatus* yielded on average 1020 kg DM/ha/yr (range 630 to 1100 kg DM/ha/yr) with an average partial GM of -$330/ha/yr (range -$401 to $319/ha/yr). This legume yielded poorly at all the trial sites that had an initial soil pH of 4.6, regardless of whether 0 or 4 t lime/ha was applied.

Discussion

There were several limitations to this unbalanced type of analysis where pasture yield from different sites were combined and compared. These included:

1. Carrying out the measurements of pasture yield in years of atypically low annual rainfall which would have had the greatest effect where there were fewer sites for the category.
2. Sowing legume species in unsuitable environments, for example sowing white clover where annual

rainfall was low and soil Al concentrations high. These circumstances affected some sites, but not enough to have significant effect.

3. Application of greater rates of fertiliser nutrients and lime than required for optimal yield. This affected the results from some sites, but did alter greatly the overall average input costs and partial GMs.
4. Carrying out the trials for insufficient time to allow for the slow growth of legumes, such as Caucasian clover and lucerne, which take more than two years to establish in low rainfall environments.
5. The variability in the number of sites for each category, including fewer sites for clover-based pasture on flat land compared with the much larger number on hills. In addition, there were fewer sites where some of the alternative legume species were trialled, and few sites with grasses plus N.
6. A lack of data from trials on subterranean clover, either sown or resident, so recommendations in the decision trees was based on user experience, mainly in Marlborough and North Canterbury.
7. Carrying out most of the trials under more typical average rainfall of less than 750 mm/yr, meant that, for the decision trees, extrapolation was needed based on user experience and other research from higher rainfall areas.

Despite these limitations the results provided indicative information on the potential of different legume-based and N-fertilised pastures as options for improvement on South Island hill and high country. However, it would be prudent to consider the differences in average production and partial GM between each category regarding drillable x pasture type in a relative, rather than an absolute, context.

When the annual pasture yield and partial GM for grasses plus N was compared with the results from legume-based pastures, this option was expected to resulted in feed of inferior nutritive value compared to legume-based pastures.

Fertiliser and lime inputs, alongside pasture species, are essential factors for the improvement of hill and high-country pastures. This analysis did not allow these requirements to be tightly defined, but the rates of N, P, sulphur (S) and lime was consistent with levels needed for successful establishment and growth of improved pastures (Morton et al*.,* 2021). The development of aerial fertiliser applications at variable rates was expected to allow more efficient and economic use of nutrients during pasture improvement (Morton et al*.,* 2016). Other improvements in management, which have been demonstrated on farms, include provision of improved pastures on flat land, in some cases, irrigation, which would cause less grazing pressure and higher animal production on hills (Anderson et al*.,* 2014). The establishment of satellite areas of pure legume swards mixed with herbs on hill country for periods of high feed demand, such as before lambing (Chapman et al*.,* 2021) have increased the economic returns from hill and high-country pastures.

The gaps in knowledge that need filling, either from robust long-term trials or continual on-farm monitoring of sward performance, are production measurements from all potential legume species-based pastures on hill country and lucerne and alternative legume species on flat land. Specific data comparing the resident vegetation with improved pasture yields is currently lacking. This would be relatively easy to assess with cage cuts taken on adjacent sites to generate on-farm pasture production data from improved pastures that can then be used to assess gross margins. Such on-farm monitoring could then be entered into a central AgYields database (https://www.agyields.co.nz; Moot et al*.,* 2021) to provide localised information to farmers to increase their confidence when undertaking legume establishment, even in regions with highly variable rainfall patterns and soil types.

There are potential environmental impacts to consider when undertaking the establishment and management of new pastures and forage crops. These are described in Morton and Roberts (2016) for pastures and Morton et al*.* (2017) for forage crops. The Best Management Practices to minimise N, P and sediment are outlined in these farmer booklets.

Conclusions

On drillable land associated with South Island hill and high country, the establishment of pastures based on white, red and alsike clover at average rainfall of less than 600 mm/yr resulted in a marginal financial return. Lucerne established at an average rainfall of less than 600 mm/yr was higher yielding than the white, red and alsike clover pastures and was more viable when sown on deeper soils. Caucasian clover sown at average rainfall of 750 mm/yr or less was low yielding and had poor economic returns, but most of the trials were of an insufficient duration to allow this slow establishing legume to potentially show value. Under average rainfall of 630 mm/yr or less, perennial lupins were relatively high yielding and viable, particularly on soils with high Al concentrations, which cannot be economically remedied by applying lime. The application of N to sown grasses resulted in adequate yields but poor financial returns, which was partly attributed to the high current cost of N and the excessive rates applied in some of the trials.

On the non-drillable hill land, under a wide range of annual rainfall, resident pastures based on white, subterranean and alsike clover had higher pasture yield and financial returns than oversown white and red clover. On a small number of sites, oversown lucerne performed much better than on the white and red clover sites under an average rainfall of 696 mm/yr and a relatively low requirement for lime. At average rainfalls of 548 mm/yr or less, the application of N resulted in reasonable annual pasture yield on both shady and sunny aspects but the economic return was poor because of the high current cost of N.

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