

Quantifying the value proposition for white clover persistence on a New Zealand summer-dry hill-country farm

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Abstract

The improvement in forage quality and quantity of summer-dry hill country pasture resulting from the introduction of clover is well recognised. However, ensuring the persistence of the commonly available cultivars is challenging, in the face of seasonal moisture stress, intensive grazing, competition from established well-adapted pasture species, low soil fertility and low soil pH – conditions typical of the East Coast of the North Island. Here we quantify the value proposition associated with the introduction of white clover into a case study on a Gisborne sheep and beef farm, using a six-step process. A topographically explicit approach is taken, using an understanding of the underlying spatial variability, based on a combination of soil and pasture measurements, APSIM simulation modelling of pasture growth and farm system modelling of enterprise performance. We show that from a baseline of a typical low-fertility, diverse species hill country pasture, white clover introduction can increase spring and summer forage consumption by 17%, enabling inclusion of an additional 6-month bull finishing enterprise generating a 32% greater carcass weight production and leading to a 49% improvement in farm system EBIT. This represents a positive net present value of over \$360,000 for the original investment in white clover establishment into existing pastures.

Keywords botanical composition, over-sowing, simulation model, soil water.

Introduction

Large areas of temperate New Zealand low-elevation hill country consist of intensive pastoral systems (approx. 6 M ha, Mackay 2011), with introduced grassland communities and sheep/cattle breeding and finishing systems. A wide range of herbaceous species has become naturalised within these systems, because of the high spatial and temporal variation in edaphic and environmental conditions (Chapman &

Macfarlane 1985). Ideally, the grassland communities would be populated with bred cultivars of grasses, legumes and forbs that have high nutritive value and a seasonal growth pattern that matches livestock demand. However, a number of contextual factors present a challenge to the persistence of such cultivars, namely: a) seasonal soil moisture stress resulting from climate patterns, shallow soils and slope which influence radiation input and soil moisture retention; b) year-round *in-situ* intensive grazing by livestock; c) low natural soil fertility and pH, with typically inadequate fertiliser and lime inputs to remedy this; and d) a range of pests. Legumes are particularly sensitive to all these factors and are consequently of relatively low abundance in hill-country pastures, particularly in summer-dry regions such as the east coast of the North Island (Radcliffe & Sinclair 1975). This limits the productivity of the grass component, since N-fixation inputs are low. As a result, these pastures are typically comprised of a diverse array of grasses and forbs (Dodd et al. 2004) with low nutritive value (Clark et al. 1982) and seasonal growth patterns that are strongly skewed towards a late-spring peak, reflecting an emphasis on reproductive phenology (Sheath 1982). Some of these forbs are also unpalatable weeds, such as thistles, which introduce a further reinforcing feedback because a number of the herbicides typically used to control these weeds also damage clovers (e.g. clopyralid, picloram, Harrington et al. 2017).

Numerous field studies have demonstrated an improvement in pasture production and forage quality as a result of introducing both grasses and legumes into hill-country pastures (e.g., Wedderburn et al. 1996), but also by introducing clover only into existing swards (e.g. Lambert et al. 1986; Chapman et al. 1993). The rationale for this approach is based on the role of the legume in improving the nitrogen economy of the soil-pasture system, as a pre-requisite to establishing grasses of high productive potential (Ledgard et al. 1987). This presumes that the legume component will be persistent,

which is often not the case. With good management, successful legume establishment can be achieved Lambert et al. (1986), but persistence in the medium term (4–6 years) is often poor (Dodd et al. 2001).

Legumes also have a beneficial impact on animal production beyond driving greater forage supply. They have a higher metabolisable energy (ME) content in their tissue (Holmes et al. 2002) and a greater efficiency of ME conversion to animal growth (Freer et al. 2012). In a dry hill-country context, these benefits may be important in the short term by enabling young livestock to achieve live-weights suitable for slaughter prior to the onset of summer drought.

In this study we quantified the value proposition for establishing and maintaining a high pasture clover content (i.e. 20–30%) via a case study in a typical summer-dry hill-country farm system. We used soil physical data to parameterise a pasture growth model, pasture composition data to structure the model simulations for appropriate landscape units, and white clover (*Trifolium repens*) content data from an oversowing trial to confirm the model predictions of increased clover content. The pasture growth model simulations were then used in a farm systems model to examine how the added productivity and forage nutritive value could potentially drive improved economic performance through adjustments to the livestock enterprises on this farm.

Methods

The study used Tangihanga Station, a 2200 ha (1440 eff. ha) mixed sheep and cattle breeding and finishing unit located 20 km northwest of Gisborne (38.55°S, 177.88°E.). The property is part of the land holdings of the Wi Pere Trust and is very typical of the hill-country farms in this coastal region, with an elevation range between 40–320 m a.s.l. Mean annual maximum air temperature is 19 °C, mean annual minimum air temperature is 9°C and mean annual rainfall is 1121 mm (Virtual Climate Station data, Tait et al. 2006). The seasonal patterns of rainfall, potential evapotranspiration (PET), maximum and minimum daily temperatures for each month are shown in Fig. 1. The average period of soil moisture deficit, normally during January–March, is 47 days (Radcliffe & Sinclair 1975).

The six steps contributing to development of the value proposition in this study are outlined below, with a more detailed description of methods following:

1. Landscape unit mapping, to define the topographical units on the farm for structuring the pasture growth simulations;
2. Representative soil and pasture sampling, to provide soil parameters for the pasture growth model and determine where white clover was currently distributed in the landscape;

3. A white clover introduction trial, to indicate the achievable levels of clover content on targeted landscape units as a result of oversowing;
4. Modelling of seasonal pasture supply, to model the effect of clover inclusion on seasonal pasture growth across the various landscape units;
5. Modelling of the farm system, to quantify the potential improvement in system performance.
6. Investment analysis, of the costs and benefits of a potential white clover introduction programme.

This approach follows closely that of Stevens et al. (2019), who quantified the value proposition for thistle control using the same case-study farm system.

1. Landscape unit mapping

Spatial data on topography and soils for the Tangihanga farm was obtained from the New Zealand Digital Elevation Model (15-m resolution) and the New Zealand Land Resource Inventory (LRI). These data were imported into ArcGIS® (www.esri.com) to design the soil and pasture sampling procedure in order to ensure that a representative range of slope, aspect and soil types was included. Slope was divided into the four slope categories used in the Overseer® model (Vogeler et al. 2014): flat (0–7°), rolling (8–15°), easy (16–25°), steep (>26°). Aspect included all four cardinal directions. The dominant soil groups on a pumice parent material are Weathered orthic recent (66% by area) and Typic perch-gley pallic (13% by area) with other minor soil types making up <5% each.

2. Representative soil and pasture sampling

Annual soil fertility sampling of 30 sites across the farm each spring during the period 2012–2016 showed generally low fertility, with Olsen P between 12–17, sulphate S between 4–7 and Quicktest K between 8–10, while pH was between 5.5–5.6 (methods in Blakemore et al. 1987). A capital fertiliser programme to address this had been implemented and by 2018 Olsen P was 19–24 and Sulphate S was 7–8.

In June 2017 soil samples were collected for measurement of soil profile parameters required for modelling using the Agricultural Production Systems Simulator (APSIM, <https://www.apsim.info/>). Three 25-mm diameter samples were sampled at two depths (topsoil, 50–100 mm and subsoil, 150–300 mm) and bulked for 24 sites that represented each combination of four slope classes, three aspects and two soil type combinations were with per site. Rooting depths were visually assessed from small soil pits. Bulk density, saturation (-1kPa), field capacity (-10kPa), and soil texture were analysed using the methods of Houlbrooke et al. (2009). Soil organic matter (SOM) was analysed by combustion, and pH in water as per Blakemore et al. (1987).

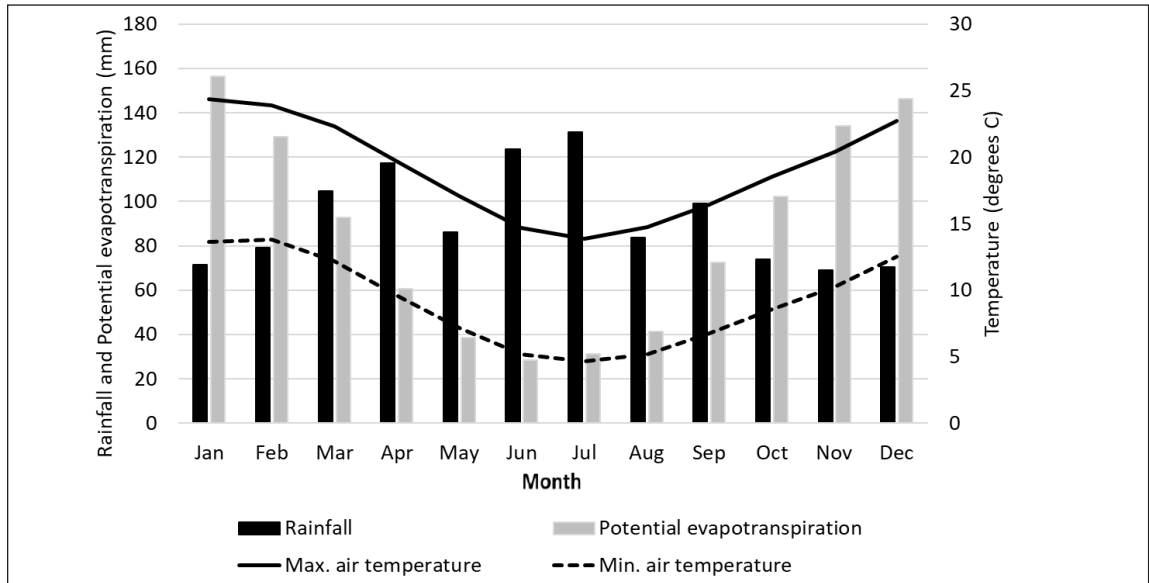


Figure 1 Climate chart for Tangihanga Station, including monthly average rainfall, potential evapotranspiration, daily maximum and minimum temperatures over the period 1975-2014.

Twenty-one different sites across 18 paddocks were selected for botanical composition measurements during April 2016, across the four aspect and four slope classes. At each site, a 20-m transect perpendicular to the slope was laid out. Along each transect, 10 plots of 1 m² at 1-m spacing were visually assessed for percentage ground cover of all pasture species. The scoring system used was: 1, <5% cover; 2, 5–24%; 3, 25–49%; 4, 50–74%; 5, 75–94%; 6 >95%. The midpoints of the score ranges were used to obtain an average level of clover cover for each botanical component. Species were grouped for analysis into: 1) perennial ryegrass (*Lolium perenne*); 2) white clover; 3) other legumes such as subterranean clover (*Trifolium subterraneum*) and annual *Lotus* spp.; 4) other C3 grasses such as browntop (*Agrostis capillaris*) and sweet vernal (*Anthoxanthum odoratum*), 5) C4 grasses such as *Paspalum dilatatum* and ratstail (*Sporobolus africanus*); and 6) dicotyledonous weeds such as *Leontodon* spp. and *Dysphania pumilo*.

3. White clover introduction trial

One south-facing paddock on Tangihanga Station including rolling, easy and steep landscape units was selected for a small-scale white clover introduction experiment to quantify the short-term potential increase in abundance resulting from over-sowing. Prior to over-sowing, a 2-ha plot within the paddock was assessed for white clover abundance in early April 2016 using ten point intersect transects. These were placed over 10 m downslope with the presence/absence of white clover recorded at 1 m intervals.

In late April the plot was close grazed with cattle to a residual of ~1200 kgDM/ha to minimise resident pasture cover. Following one week of regrowth, 1 L/ha a.i. paraquat was applied aerially to selectively suppress grass growth. The plot was over-sown with white clover cultivars Tribute and Kakariki in equal proportions, by hand spinner on 12 May 2016 using a relatively high sowing rate of 8 kg/ha. The paddock was then trampled with a large mob of ewes to increase seed-soil contact. Clover seedlings emerged in early June and abundance after sowing was measured using the same transect method as prior to sowing, on 17 October 2016, 6 December 2016, 21 March 2017, 3 April 2019 and 25 May 2020. The paddock was rotationally grazed with cattle through winter and set stocked with ewes during spring.

4. Modelling of seasonal pasture supply

To model the effect of white clover introduction on potential pasture production we used the AgPasture module of APSIM (Li et al. 2011). This modelling framework has been validated across New Zealand for mixed pastures, including two Gisborne regional sites (Li et al. 2011, their Fig. 6). It has the advantage of being able to incorporate different combinations of individual pasture species, such as ryegrass and white clover; and model different landscape units in hill country with different slopes and aspects. Vogeler et al. (2016) demonstrated the ability of the model to simulate easy and steep north-facing slopes in a summer-dry hill country situation at Whatawhata (their Fig. 8). APSIM does not explicitly model soil P but

uses a fertility growth-limiting factor (GLF) based on a Mitscherlich function as a proxy for Olsen P, which has been parameterised for individual pasture species, based on several field studies as noted in Vogeler et al. (2016).

Soil physical, pH and SOM parameters from the June 2017 landscape unit sampling were used to construct soil profiles in APSIM, and the simulations were structured as a comparison of either a browntop (*Agrostis capillaris* L.) alone or browntop/white clover mixture, under the current soil fertility levels (Olsen P = 20, GLF = 0.84 for browntop and 0.78 for white clover) and under soil fertility levels considered optimal for these soils (Olsen P = 40, GLF = 0.97 for browntop and 0.95 for white clover, Morton & Roberts 1999). Clover content in the model was derived from abiotic and biotic interactions, once this additional species was included. The aim was to show the interactive effect of soil Olsen P levels on potential pasture production with and without white clover, on the rolling, easy and steep slopes where we expected the greatest benefit to accrue compared to the baseline situation. This structure was applied to a matrix of representative sites: four aspects \times three slope classes (rolling, easy, and steep) \times two soil Olsen P levels (20 and 40). Flat slope classes were not simulated, as the pasture composition on them was ryegrass dominant and not targeted for pasture improvement by white clover introduction.

Simulations were conducted for the period 1975–2014 using the weather files generated for the site by the Virtual Climate Station, a spline interpolation tool developed by NIWA (Tait et al. 2006). All simulations received the equivalent of 15 kg N/ha to account for N fixation by free living bacteria. The frequency of simulated harvests (8–12 pa) was auto-determined in the model upon reaching masses of 2500 kgDM/ha. Residual pasture mass was set at 1500 kgDM/ha, with nutrients returned as dung and urine. The model generated daily pasture growth rates and white clover content that were summed to mean monthly and annual net herbage accumulation, using the averages of data from the 2004–2014 period. These results were used as inputs to model farm system performance, Step 5.

To confirm the performance of the APSIM model locally, the results for the period 1983–1987 from the north-facing flat slope landscape unit were compared with data collected over the same period using the double-trim exclusion cage harvest method. These mean monthly data were obtained from a similar landscape unit on a local farm near Te Karaka, approx. 20 km away, although the site differed from the model in that it included browntop, white clover and ryegrass in the sward. The individual year data were not available, so a comparison of the 5-year means was used, which is consistent with the use of long-term mean data in the Farmax modelling.

5. Farmax modelling of the farm system

The Farmax[®]Pro Sheep and Beef whole farm model was used to represent the Tangihanga Station farm system (Version 6.4.6.07 AgResearch Science Edition for S&B, <http://www.farmax.co.nz>). The “Tangihanga Base” model and associated seasonal pasture growth curves has been used previously to examine the effects of thistle infestation (Stevens et al. 2019).

The seasonal forage supply for each landscape unit was modified to reflect the results of the APSIM simulations (Figure 2), i.e. increased quantity and quality of the available forage from adding white clover at Olsen P = 20. Specifically, browntop/white clover simulation results for pasture growth were applied to easy (383 ha) and steep (329 ha) slope classes on east, west and south aspects, in place of the baseline browntop-only results. Evidence from the pasture survey indicated that these were the landscape units with greatest potential for improvement of white clover content. Sustaining white clover populations on north aspects in summer-dry hill country is known to be challenging (Chapman & Macfarlane 1985, Dodd et al. 2001), and the pasture composition data at this location is consistent with this understanding (Table 1). The pasture quality descriptor on easy and steep slope classes on east, west and south aspects was also changed from low to medium to reflect greater white clover content. The core animal enterprises of the system were retained but adjusted to maintain a biologically feasible system with realistic pasture covers, referred to as “Tangihanga Clover”. Purchase of yearling bulls in late spring (October 1) was selected by the farm manager as the most suitable option in the model for utilising the additional pasture supply. Within the model, these animals were subsequently sold store to a finishing farm in late summer (March–April). New stock purchases and sales used standard Farmax price schedules for North Island hill country 2016–2017.

The following annual or seasonal performance measures were extracted from the Farmax simulations: a) pasture consumption; b) meat and wool production; c) revenue, expenses and operating profit.

6. Investment analysis

We compared the potential farm system impact of the “Tangihanga Clover” scenario with the costs associated with clover establishment on the case study farm. These include the operating cash cost of the establishment method and the estimated opportunity cost of forage supply foregone during the period of establishment. These are detailed in Table A1 (Appendix 1), based on an actual implementation in two Tangihanga paddocks during autumn 2019 (32 ha).

A net present value (NPV) analysis for a clover implementation programme was calculated by assuming a 10-year cycle of clover introduction on 10%

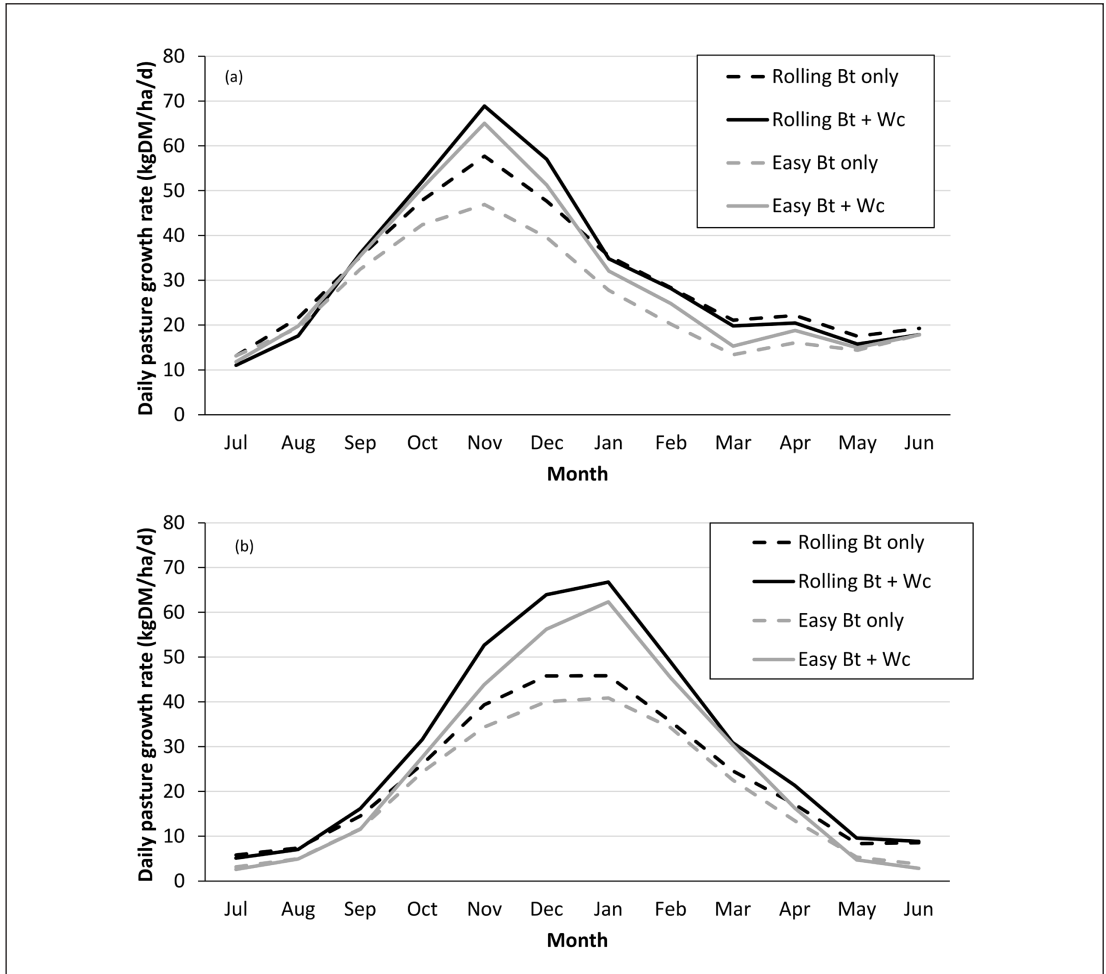


Figure 2 APSIM simulated mean daily pasture growth rates for browntop(Bt)-only and a browntop+white clover(Wc) mixture, at soil Olsen P of 20, for rolling (7–15°) and easy (16–25°) slopes on a north (a) and south (b) aspect. Monthly means of 10 consecutive years' simulation (2004–2014).

of the 712 ha each year, and a proportional increase in the bull finishing enterprise to utilise the extra pasture supply. This was to allow for limitations in the total area able to be oversown in any given year, due to foregone feed supply, livestock available for mob stocking at establishment and farm budget constraints. The costs include clover establishment (approximately \$400/ha/y; Appendix Table A1), capital P fertiliser (approximately \$230/ha/yr) and the initial cost of increasing the trading livestock enterprise to take advantage of the extra pasture production (\$115,000 per year). The other key assumption relates to the decline in clover content and animal performance after oversowing, based on the introduction trial. This was assumed to be 50% over 10 years. The NPV used a 20-year time frame and a 5% discount rate (Rendel et al. 2017).

Statistical analysis

Data from the soil sampling, pasture transects and over-sowing experiment were analysed using unbalanced ANOVA in the Genstat version 18 software (VSN International, 2015). Treatment factors included slope and aspect for the pasture data, additionally soil type and soil depth for the soil data, with interactions limited by degrees of freedom to first-order only. Over-sowing white clover abundance was analysed by date only. The pasture composition data required a square root transformation to satisfy the assumptions of the ANOVA. Results are presented as untransformed means with the average least significant difference (LSD).

Results and Discussion

Soil characteristics

The physical characteristics of soil samples collected

Table 1 Percentage cover of main botanical components and bare ground across aspect and slope categories from 21 pasture transect sites in April 2016. The balance of 100% is made up of other legumes and dicot weeds, all <5%, and dead herbage.

Landscape unit	White clover	Perennial ryegrass	Other C3 grasses	C4 grasses	Bare ground
North	0.8	5.1	30.5	7.7	19.7
East	8.3	45.1	20.2	0.1	7.3
South	2.7	32.1	36.8	0.2	4.6
West	0.9	32.2	38.6	0.4	7.9
LSD ¹ (aspect)	2.0	5.9	5.9	2.6	4.0
Flat (0–7°)	2.2	63.1	17.0	0.0	2.1
Rolling (8–15°)	10.3	41.3	22.1	0.0	4.7
Easy (16–25°)	0.7	15.0	36.1	4.2	12.6
Steep (>26°)	0.2	6.1	43.4	3.9	18.1
LSD ¹ (slope)	2.1	6.0	6.0	2.7	4.0

¹ least significant difference (5%).

in June 2017 varied significantly with slope, aspect and soil depth ($P < 0.05$), but no significant differences between the two soil types were observed. For example, subsoils had greater bulk density than topsoils (1.07 vs. 0.96 Mg/m³), north and south aspects had 18% clay content compared with east aspects (9%) and rolling and steep slopes had 19% clay content compared with flat and easy slopes (11%). Soil water-holding properties varied significantly with soil type, soil depth, aspect and slope ($P < 0.05$). For example, field capacity was greater in topsoils (35%) than subsoils (29%) and greater on south aspects (37%) than north or east aspects (33%).

The effects of depth, slope, aspect and soil type were less variable for SOM and soil pH. Soil organic matter was significantly greater in topsoils vs. subsoils (6.4% cf. 1.4%, $P < 0.01$), but not significantly different across slope, aspect and soil type factors. Similarly, soil pH was significantly lower in topsoils vs. subsoils (5.5 cf. 6.2, $P < 0.01$), but not significantly different across slope, aspect and soil type factors. Because there were significant interactions between slope, aspect and soil depth for most physical soil properties, each landscape unit in the APSIM model was assigned the unique physical and chemical characteristics measured on that unit.

The degree of variation in soil water-holding properties was as great within landscape units as it was among landscape units at this location. By contrast, Lopez et al. (2003) reported increasing slope associated with decreasing soil water holding capacity in Manawatu hill country. These differences highlight the risk of generalising soil patterns for the purpose of modelling pasture growth across landscape units. The

parameterisation of soils for the APSIM modelling was necessarily specific to this case study farm system.

Baseline pasture composition in April 2016

The transect data confirmed the low contribution of white clover on all aspects and slopes (Table 1) with other legumes comprising <3%. Main effects of slope and aspect were significant for all species composition categories ($P < 0.01$). The highest covers of white clover (8–10%) occurred on rolling slopes and east aspects. Ryegrass cover also declined steadily with increasing slope and was very sparse on north aspects. The C3 grasses were more abundant on south and west aspects, and as slope increased. The C4 grasses were most abundant on north aspects and easy to steep slopes, as was bare ground.

The pasture species composition patterns at Tangihanga were broadly consistent with numerous other studies of hill-country species abundance. Perennial ryegrass was strongly associated with lesser slopes, likely a function of higher soil nitrogen fertility driven by excreta return (Lambert et al. 1986), which has competitive implications for white clover abundance. At the other extreme, slope-induced summer soil moisture deficits (Bircham & Gillingham 1986), particularly severe on sunny north aspects, are detrimental to white clover persistence (Lambert et al. 1986). It is these landscape units where the winter-spring annual sub clover is better adapted, although the autumn timing of pasture sampling would have underestimated the contribution of this species, emerging from seedlings at this time. The significantly lower abundance of ryegrass on north aspects, and the greater abundance of C4 grasses and bare ground also reflect the landscape

unit experiencing the greatest moisture and temperature stress (Radcliffe & Lefever 1981), to which C4 species like *Paspalum dilatatum* are better adapted (Crush & Rowarth 2007).

White clover introduction in May 2016

Prior to over-sowing into the 2-ha area, white clover abundance was 7% on this particular rolling to easy sloped south aspect. Over-sowing led to a significant initial increase in abundance within the 10 months after the autumn sowing. By mid-spring (October 2016), white clover abundance had increased to 22% and was similar in early summer (December 2016) at 20%. It had declined by the following autumn (March 2017) to 14% but in autumn 2019 and 2020 was 17–18%.

The introduction of additional white clover on a single south-facing slope at Tangihanga was successful in the short term as a result of using well-recognised techniques: seasonal timing in terms of reliable soil moisture content and sufficiently warm temperature conditions; control of cover via grazing management and herbicide prior to over-sowing; and with good seed-soil contact via stock trampling (Tozer & Douglas 2016). The challenge appears to be retaining the established plants in the sward over the longer term (Tozer et al. 2016), where they are subject to selective grazing, competition from well adapted grass species and seasonal variation in soil temperature and moisture (Wedderburn et al. 1996). In the study of Lambert et al. (1986) an increase in white clover frequency from 5 to 15% over 6 years was maintained following over-sowing where soil P input was high (57 kg P/ha/y) and where pastures were rotationally grazed by cattle, as opposed to set stocking with sheep. In that situation, white clover persistence was attributed to reduced pasture density and an increase in bare soil in winter under cattle-only grazing.

Pasture growth modelling

The comparison of APSIM mean daily pasture growth rates with local data for the 1983–87 period indicated that the seasonal pasture growth pattern produced by the model was a reasonable representation of the long-term pattern at this locality (Appendix Figure A1). This comparison is similar to that for Whatawhata in Vogeler et al (2016), but as yet no long-term model-data validation across individual years and multiple landscape units at the same location has been possible.

White clover addition to browntop-based pastures improved simulated pasture growth rates mainly in the October-December period on north aspects (Fig. 2a) and for a later and longer period (November-February) on south aspects (Fig. 2b). The relative increase on north aspects appeared to be greater on easy slopes, but on south aspects the relative increase was similar for both slope classes. The modelled total annual herbage

accumulation associated with these simulations is shown in Table 2. The greatest proportional increase in annual herbage accumulation was estimated to be on the south aspects (23–24%) compared to the north aspects (14–16%). This compares favourably with the farmlet study of Chapman et al. (2017), who recorded 10–20% increases in annual herbage accumulation resulting for clover introduction into southern North island hill country.

In the browntop+white clover simulations, clover content was 12–15% during winter and peaked at 24–26% in December on north aspects, with the higher levels consistently on the easy slope class. On south aspects clover content was 10–12% during winter and peaked at 29–30% in December, with little difference between the rolling and easy slope classes.

The APSIM modelling results also showed differences in the total and seasonal herbage accumulation as a result of differences in soil fertility between Olsen P 20 to 40 (Table 2). Pastures without white clover had a negligible response to increased Olsen P, while pastures with white clover grew an additional 16–18% dry matter over the year. This increase is consistent with the expected responsiveness of relative yield in pumice soils over the range of Olsen P 20 to 40, from 80% to 95% (Sinclair et al. 1997).

The results of the clover over-sowing and APSIM modelling in terms of increased white clover content on south aspects are not strictly comparable, as the content was measured by abundance in the field trial and by percentage contribution to DM production in the model. In addition, the model results represent an average year for the site rather than a specific season. However, it is interesting to note that the levels of white clover abundance were relatively high in the spring and summer following over-sowing (20–23%) but declined in the early autumn (14%). The model indicated the white clover should be able to remain high at that time of year on that landscape unit (i.e. 20–25% of DM in March), which presents less of a climatic/edaphic challenge than north aspects. PET is likely to be lower and soil moisture retained at greater levels for longer on south aspects compared to north aspects (Radcliffe & Lefever 1981). The summer of 2016–17 was not particularly dry (260 mm of rain from Jan–Mar), and we attribute the loss of clover abundance to selective grazing by sheep.

Farm systems modelling

A comparison of the Farmax simulation for the Tangihanga Base and Tangihanga Clover scenarios is shown in Table 3, which represents the stable system once white clover is established on 712 ha (but renovated annually on 71 ha as indicated in the investment analysis assumptions). The Tangihanga

Table 2 APSIM simulated total annual pasture dry matter production for browntop only and a browntop+white clover mixture, for rolling (7–15°) and easy (16–25°) slopes on a north and south aspect, at soil Olsen P levels of 20 and 40. Means of 10 consecutive years simulation (2004–2014).

Aspect	Slope (°)	Olsen P	Dry matter production (kg DM/ha)	
			Browntop only	Browntop+white clover
North	Rolling	20	10,580	10,780
North	Rolling	40	10,760	12,520
North	Easy	20	8460	9930
North	Easy	40	8860	11,750
South	Rolling	20	8290	10,640
South	Rolling	40	8460	12,460
South	Easy	20	6990	8900
South	Easy	40	7040	10,480

Table 3 Comparison of livestock enterprise types and numbers, pasture supply, animal production and financial performance of two Tangihanga Farmax model scenarios based on almost nil or high white clover content (>20%) in south, east and west-facing landscape units.

	Tangihanga Base	Tangihanga Clover
Livestock enterprises		
Mixed age breeding ewes	9252	9252
Trade lambs (Nov–May)	3000	3000
Grazed cows (Nov–Apr)	204	204
Heifer finishing (Calves-R2)	252	252
Steer finishing (Calves-R2)	303	274
Trade bulls (Oct–April)	0	1300
Pastures		
Nitrogen boost (kg DM/ha)	760	400
Pasture eaten (kg DM/ha)	7230	8450
Animal production		
Carcass produced (kg/ha)	212	280
Wool produced (kg/ha)	53	52
Farm financials		
Sheep revenue-purchases (\$)	1,239,767	1,204,243
Cattle revenue-purchases (\$)	419,111	727,503
Farm working expenses (\$)	968,911	1,022,107
Total farm expenses (\$)	1,024,964	1,078,080
Economic farm surplus (\$)	633,914	853,666
Farm profit before tax (\$/ha)	310	462

Clover simulation required a downscaling of the 21-month steer finishing enterprise, from 303 to 274 head, to preserve target winter and early spring covers and ensure system feasibility. The additional spring

and summer pasture growth resulting from the increase in white clover content of the pastures resulted in an average of 8450 kg DM/ha/y consumed, compared with 7230 kg DM/ha/y consumed for the Tangihanga Base farm system, a 17% greater animal intake. The Tangihanga Clover system showed a 32% greater carcass weight produced, from the additional meat production of the bull enterprise, slightly offset by the smaller steer enterprise (Table 3). This resulted in a 74% greater gross revenue from the cattle enterprise. Farm working costs were slightly higher (5%), mainly the result of the large savings in nitrogen fertiliser costs (\$75,000), set against an increase in maintenance P fertiliser requirements (\$15,000), the annual cost of white clover renovation (\$28,400) and greater wage, animal health and R&M costs. Thus, the resulting difference in the farm operating profit of the Tangihanga Clover system was \$152 per ha, an increase of 49%.

The Farmax modelling has shown a substantive value proposition for increasing white clover content to >20% (annual average) on approximately 50% of the effective pastoral area. While there is general support in the literature for the benefits of white clover to hill country mixed livestock systems, only a few whole-systems analyses have been published, mostly addressing the introduction of multiple pasture species (e.g. Webby et al. 1990, who noted the critical need to effectively utilise additional pasture grown). Most recently, Rendel et al. (2017) used the AgInform[®] farm systems optimisation model to assess the added value of legumes in the context of a Whanganui hill farm system. That study also sought to quantify the potential contribution of legumes to the system in a spatially and temporally explicit way and identified between \$800–1600 per hectare benefit from increased legume content in pastures, through greater lamb and cattle productivity. Chapman et al. (2017) have also shown significant benefits to white clover introduction

in southern North Island hill country, in terms of a 14% increase in sheep liveweight gain with in a farmlet study, although the gains they observed from improving soil fertility were much greater.

Investment analysis

At the per hectare cost of white clover establishment in Appendix I, the annual cost for the Tangihanga farm system to implement white clover introduction across 712 ha of south and east-facing easy and steep landscape units would be \$28,400 each year for 10 years to reach a stable new configuration as represented in the Farmax analysis (Table 3). The 20-year calculation of the NPV of the investment, based on a 5% discount rate, leads to a value of \$360,000. This result confirms the positive value proposition associated with improving white clover abundance in the case study hill country mixed livestock system.

Practical implications

This study took an approach to assessing the value proposition for pasture improvement in summer-dry hill country that was aimed at increasing white clover on landscape units where it is most likely to persist. It has shown that this is technically possible using methods grounded in research. White clover establishment should result in substantial improvements in animal performance and farm system profitability, based on pasture growth modelling and farm system modelling for a specific case study farm near Gisborne. While clover persistence is important in maintaining productivity, a simple long-term cost benefit analysis indicates a positive net present value from ongoing pasture renovation.

ACKNOWLEDGEMENTS

Thanks are due to members of the Wi Pere agribusiness team: Brent Gallagher and Gavin Sheath for support in planning and implementing field measurements; and to the other members of the Ravensdown/AgResearch co-innovation team: Mike Manning, Ants Roberts (Ravensdown); Robyn Dynes, Sue Zydenbos (AgResearch) for constructive discussion. The following current and former AgResearch staff contributed to technical aspects in various ways: Russel McAuliffe for soil sampling design, Alec McGowan and Bill Carlson for field soil sampling and Tom Orchiston for soil physical property measurements. Note that the use of specific cultivars and herbicides does not imply and endorsement of proprietary products. This research was financially supported by Ravensdown Ltd and AgResearch SSIF Investment. Thorough review by the journal referees and editor is acknowledged.

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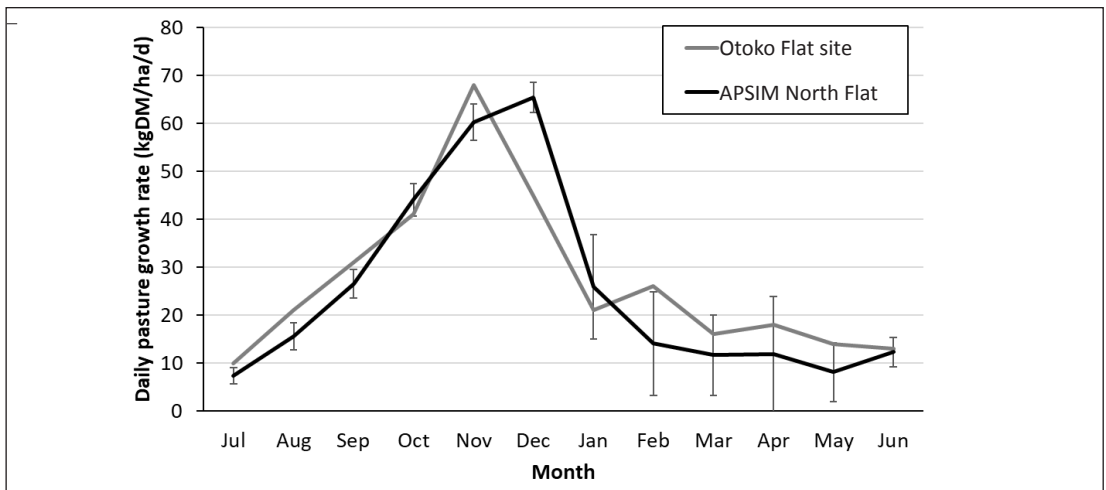
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APPENDIX

Table A1 Estimated costs of over-sowing white clover onto 32 ha of south facing portions of two paddocks in 2019, varying in slope from rolling to steep hill country, at Tangihanga.

Item	Application details	Cost (\$)	Cost per ha (\$)
Herbicide (Paraquat)	32 L by air	450	13
Aerial spraying	100 L/ha	1600	50
White clover seed	7.8 kg/ha by air	3095	97
Aerial sowing		1920	60
Stock mustering	4 hours	120	4
Lost grazing	90 days @ 7 kg DM/ha/d \$0.28 per kg DM	5645	176
Total		12,830	400

**Figure A1** Comparison of APSIM simulation of mean daily pasture growth rates in each month for the period 1983–87 at Tangihanga, with exclusion cage data from a similar north-facing flat slope landscape unit on a farm at Otoko, Te Karaka. Error bars represent the standard errors calculated from 5 years' data in the simulation.