Profit, productivity, and eco-efficiency of using Caucasian clover/ grass pastures in hill country farms

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Abstract
The following study was conducted to establish whether significant amounts of Caucasian clover-based pastures on hill country farms can increase eco-efficiency and profitability. Published data were used to predict the production of Caucasian clover-based pastures, based on weather data and soil moisture deficit prediction, for four sheep and beef farms with low rainfall in the South Island. Scenarios with 10, 20 or 30% of the flat and rolling areas improved with Caucasian clover/ grass pastures were compared to current systems based on resident white clover-based pastures. A staged approach, to utilise the extra high-quality feed produced, used a sequentially process to improve productivity by increasing lamb finishing, higher hogget liveweight, better ewe nutrition or more beef finishing, depending on initial efficiency metrics. Time to maximum production using an annual establishment programme of 5% of the target areas in Caucasian clover/grass mixtures took 4 to 6.5 years (10% and 30% respectively). Adding Caucasian clover/grass increased pasture production by 5.5% while product/kg DM consumed increased by 12.8% and profitability by 22% when either sheep or beef production were used to capture the extra amount and quality of pasture. Greenhouse gas (GHG) emissions were increased by only 6.3%, resulting in more efficient meat production.

Keywords: establishment, farm enterprise, transition, efficiency.

Introduction
Grazing legumes such as lucerne (*Medicago sativa*) and red clover (*Trifolium pratense*) are known to increase production (Moot et al., 2019) and profitability (Stevens and Casey 2017). Often grazing legumes need specialist management and perform best without grass competition (Moot et al., 2019). As legumes increase soil N, grasses become dominant (Black et al., 2000). Of the major commercially available legumes, white clover (*Trifolium repens*) contribution significantly varies year to year as soil nitrogen concentration and grazing management changes (Brock and Caradus 1996). Red clover lives for only 3 or 4 years (Hay and Ryan 1989), while lucerne needs specialist management and so is not recommended in mixtures (Moot et al., 2003).

Mixing legumes with grasses is a standard way of providing a balanced pasture. This mitigates many of the potential issues when grazing legumes alone. For example, legumes often need specialist grazing. Legumes can take longer to establish and therefore are vulnerable to weed ingress (Hurst et al., 2000), potentially reducing pasture production. High soluble protein concentrations in legumes are a leading cause of bloat, especially in cattle (Clarke and Reid 1974), often restricting the use of pure legume forage stands to sheep enterprises.

Caucasian clover (*Trifolium ambiguum*) provides the opportunity to introduce grass while maintaining high legume content more readily that other legumes (Black et al., 2000) as it consistently has a legume content of 25-30% compared to 10-15% white clover in mixed swards (Black et al., 2000; Mills and Moot 2010) and grows at lower soil fertility than many other grazing legumes (Scott 1998).

Establishment has been recognised as a potential problem for Caucasian clover (Moorhead et al., 1994). For example, establishing plants of Caucasian clover had only five leaves compared to 16 leaves on white clover and ryegrass plants with the accumulation of 774Cº/d after sowing, instead developing an extensive root network (Black et al., 2002), and this places it at risk when establishing in a grass-legume mix (Hurst et al., 2000). Once established, however, it maintains clover contents of 25-30% even when grasses are introduced (Black et al., 2000; Stevens and McCorkindale 2002). This long establishment time presents potential risks to the farmer when using Caucasian clover in a farm system.

The thermal time requirements for establishment of Caucasian clover have been reported (Black et al., 2002) and provide a method to estimate the relative time required from sowing until production potential peaks. This can then be used to develop establishment requirements and quantify the potential loss of production that may occur while establishment of Caucasian clover takes place. The results can be used to provide farmers with expectations of the time required and likely success of introducing Caucasian clover.

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online) https://doi.org/10.33584/jnzg.2022.84.3594

The following study identified the production strengths and weaknesses of four farms and used that information to test how we can capture the benefits of adding Caucasian clover into 10, 20 or 30% of the arable land on hill country sheep and beef farms in the South Island receiving between 500-650 mm rainfall/annum.

Materials and Methods

It was hypothesised that sowing Caucasian clover/grass mixtures to the flat and rolling parts of dryland hill country sheep and beef farms would increase farm profitability and decrease the greenhouse gas emissions per kg of product. To investigate this hypothesis, the introduction of Caucasian clover/grass mixtures at 10, 20 or 30% of the flat and rolling parts of the farm was tested (Table 1) using a modelling approach. Flat and rolling areas of the farm were considered suitable because Caucasian clover needs to be sown into the soil for effective establishment (Moorhead et al., 1994).

Farm selection and base modelling

Four farms (replicates) were anonymously selected from an existing database of Class 2, South Island Hill Country farms (Beef + Lamb NZ 2021) representing a low rainfall cool temperate climate in southern New Zealand (Table 2). Farm parameters have been previously reported (Taylor et al., 2021). Current production metrics were used as the base condition for each farm (Table 2) and converted into a model farm using the Farmax Red Meat (version 8.0.1.34 Science Edition, FARMAX Ltd, Hamilton NZ) whole farm modelling software (Marshall et al., 1991). Production, GHG outputs and profitability were then predicted.

Caucasian clover modelling

The estimation of pasture productivity and feed quality for Caucasian clover swards was required before adding Caucasian clover to whole farm modelling. The process required several steps using climate data and soil type.

Climate data for each farm were retrieved from the National Institute of Water and Atmosphere (NIWA) Virtual Climate Network at the nearest grid location for the period 1 July 2010 to 30 June 2019, with the mean monthly temperatures and soil moisture deficits being used to predict establishment progress and final average yield of the Caucasian clover/grass pasture. Soil moisture content on 1 July for the modelling was assumed to be a field capacity. These available soil water values were retrieved from the NZ Soils maps (S-Map Online version 4.2.28; https://smap.landcareresearch.co.nz/).

Predicting productivity during establishment

Caucasian clover was assumed to be sown alone, with a companion grass added by direct drilling after nine to twelve months (Stevens and McCorkindale 2002). Development of full pasture growth potential is regulated by temperature and can take between two and five years to reach a maximum following Caucasian clover establishment (Watson et al., 1996; Scott 1998). Therefore, further prediction of that development was done for each site. Dryland data was extracted from Figure 1 in Black and Lucas (2018), and trial site climate data for the same period (2000- 2005) downloaded from the NIWA Virtual Climate network. This was then fitted to the annual pasture yield to predict sward production during establishment using a polynomial best fit curve to derive Equation 1 (r^2=0.983):

$$\text{Annual yield (proportion of maximum yield)}=0.02+0.000238\text{GDD}-0.0000000109\text{GDD}^2 \quad \text{[Eq 1]}$$

Where GDD was the annual accumulation of daily mean temperature - 5ºC.

Annual yield was considered stable when 1.3 x

Table 1 Areas represented in adding Caucasian clover/grass mixtures on the flat and rolling parts of four model farms used to test the impacts of representing dryland hill country sheep and beef properties in the South Island of New Zealand

		Farm				
Parameter		**1**	**2**	**3**	**4**	**Average**
Effective area (ha)		860	337	490	790	619
	Flat (ha)	395	0	95	0	122
	Rolling (ha)	267	337	32	353	247
	Steep (ha)	198	0	363	437	250
Area in Caucasian clover (ha)	10%	66	34	13	35	37
	20%	133	67	25	71	74
	30%	199	101	38	106	111

resident pasture yield was reached. This threshold reflected the data presented from long term studies (Mills and Moot 2010; Black and Lucas 2018).

Pasture production of the whole farm was then scaled based on the relative time taken to reach peak yield and the proportion of the farm that was sown to Caucasian clover each year.

Adjusting the pasture production for Caucasian clover contribution

A clover/grass mixture with a consistent legume content of approximately 30% was predicted, following the results reported by Stevens and McCorkindale (2002), Mills and Moot (2010) and Black et al., (2018). Development of Caucasian clover production following establishment was estimated by fitting equations to data in Figure 5 presented by Black et al*.,* (2003), following their use of a linear response of pasture growth to temperature in spring and logistic function in summer/ autumn:

$$\text{Caucasian clover growth (kg DM/ha/d)} = 2.955 + 11.139Ts \quad \text{[Eq 2]}$$

Where Ts was mean GDD > 5ºC/d for each month from July to January.

$$\text{Caucasian clover growth (kg DM/ha/d)} = 0.7887e^{0.5583Ta} \quad \text{[Eq 3]}$$

Where Ta was mean GDD > 5ºC/d for each month from February to June.

These potential growth rates were then adjusted depending on predicted soil moisture deficit using the following.

Firstly, the potential soil moisture deficit was calculated by

SMD (mm) = Current SM + rainfall – PET (if rainfall – PET > 0)

SMD = soil moisture deficit

SM = soil moisture

PET = potential evapotranspiration

Table 2 Physical parameters of four low rainfall (B+LNZ farm class 2 South Island Hill Country) farms chosen to test the impacts of Caucasian clover introduction on production, greenhouse gas emissions and profit. Pasture production feed conversion efficiency and animal product are derived from the Farmax models.

		Farm				
Parameter		**1**	**2**	**3**	**4**	**Average**
Rainfall (mm/y)		500	585	600	675	590
Total area (ha)		871	340	736	805	688
Effective area (ha)		860	337	490	790	619
Percent	Flat	46	0	19	0	20
	Rolling	31	100	7	45	40
	Steep	23	0	74	55	40
Stocking rate (SU[1]/ha)[eff]		6.7	9.1	7.2	6.8	7.5
Sheep: cattle ratio[2]		82:18	61:39	74:26	83:17	75:25
Net pasture production (t DM/ha/y)[eff]		3.52	4.78	4.15	3.75	4.05
Ewe efficiency index (weaning wt/Dam wt expressed as a percentage)		51.5 (Low)[3]	55.5 (Low)	69.6 (High)	76.2 (High)	
Beef Breeding herd feed demand (%)[4]		56	0	77	69	
Beef Finishing herd feed demand (%)[4]	Bred	43	0	21	8	
	Purchased	0	100	1	1	
Beef herd sold store feed demand (%)[4]	Bred	0	0	0	11	
	Purchased	0	0	0	12	
Feed conversion efficiency (kg DM/kg product)[eff]		25.2	23.4	24.6	22.8	24
Animal product (kg meat and wool/ha/y)[eff]		142	211	107	161	155

[eff] Effective area;
[1]SU = stock units; [2]Sheep:cattle ratio is calculated from total feed utilised by either sheep or cattle per annum;
[3]Ewe efficiency; [4]Standard case % of beef feed demand.

Actual growth was calculated in equation 4 (derived from Black et al., 2003, Figure 6b). Maximal growth occurred between 100 to 85% of available soil water, with a linear decline in potential yield occurring as available soil water was below 85% of total using potential growth calculated in equations 2 and 3:

Caucasian clover growth (kg DM/ha/d) =Caucasian clover growth-(Caucasian clover growth* (1.2628*(SMD/-Avail soil water)-0.1057)) [Eq 4]

Where Avail soil water (mm) = Field capacity (mm) – wilting point (mm) [Eq 5]

An example of the process to generate the pasture growth profiles is provided in Table 3. In brief, the potential growth rates of Caucasian clover alone were calculated (equations 2 or 3), this was adjusted for response to potential soil moisture deficit (equation 4) and 20% of this response was added to the current pasture growth rates estimated from Farmax, to represent the increase in production from Caucasian clover. In June, July and August when no Caucasian clover growth was predicted, yields were reduced by 20% following the results published by Mills and Moot (2010) and Stevens and McCorkindale (2002) to account for the potential suppression of grass production due to high clover content during summer and autumn.

Predicting animal performance responses to higher clover content

Changes in animal performance were only made for the growing livestock. The Q-Graze software (Woodward et al., 2001) was used to predict the relative feed value of Caucasian clover pastures with a clover content of 30%, dead matter of 5% and the remainder as green grass leaf, using the mean monthly maximum air temperatures for each farm. The liveweight gain (LWG) of lambs and cattle (Figure 1) were then predicted for each month, using an amount of feed offered of 2500 kg DM/ha and a residual pasture mass of 1500 kg DM/ha. Liveweight gain of both lambs and cattle (Figure 1) were predicted for the resident pastures, using the pasture composition predicted from the Farmax pasture growth estimates.

Capturing the benefits of introducing Caucasian clover

For each of the 10%, 20% and 30% Caucasian clover scenarios, the extra feed was utilised using step-by-step management decisions (Table 4). The number of animals added in each step was determined while retaining a pasture cover profile consistent with the baseline farm i.e., supply of extra feed *vs* the feed requirements of animals added in each step.

Assumptions

Caucasian clover must be sown on flat or rolling terrain as it needs cultivation for effective and rapid establishment (Moorhead et al., 1994). The areas used represented 10, 20 or 30% of flat and rolling land only (Table 1). The spring sowing of 5% per annum of the available area in Caucasian clover mixtures each year reflected areas currently used for cropping on each farm (Taylor et al., 2021), with grasses direct drilled into the Caucasian clover swards after 12 months.

Taylor et al., (2021) provided detailed documentation of all assumptions made. This included winter crop yield standardisation using annual rainfall, and the use of nitrogen fertiliser, baleage/silage making and stock

Table 3 An example of the step-wise calculation process used to determine the contribution of Caucasian clover to mixed clover/grass pastures on a dry hill country farm using Equations 2-5 in the text.

Step	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
1	Caucasian Clover potential (kg DM/ha/d)	0	0	0	20.9	40.5	72.1	78.0	72.7	57.7	2.4	0.6	0
2	Suppression of growth by potential soil moisture deficit	0	0	0	-0.10	-0.24	-0.34	-0.51	-0.46	-0.76	-0.58	-0.27	0
3	Caucasian clover actual (=1+1*2)	0	0	0	18.8	30.8	47.7	38.6	39.2	13.8	1.0	0.5	0
4	Local predicted growth rate (from Farmax)	2.4	4	6.4	15.9	28.6	40.6	27	29.4	12.7	5.6	3.2	1.6
5	Final pasture growth rate (=4+0.2*3)	1.92[1]	3.2[1]	5.12	19.7	34.8	50.1	34.7	37.2	15.5	5.8	3.3	1.3[1]

[1] Step 4 values adjusted downwards by 20% to reflect impact of competition from Caucasian clover supressing grass yields (as per Mills and Moot 2010, Stevens and McCorkindale 2002).

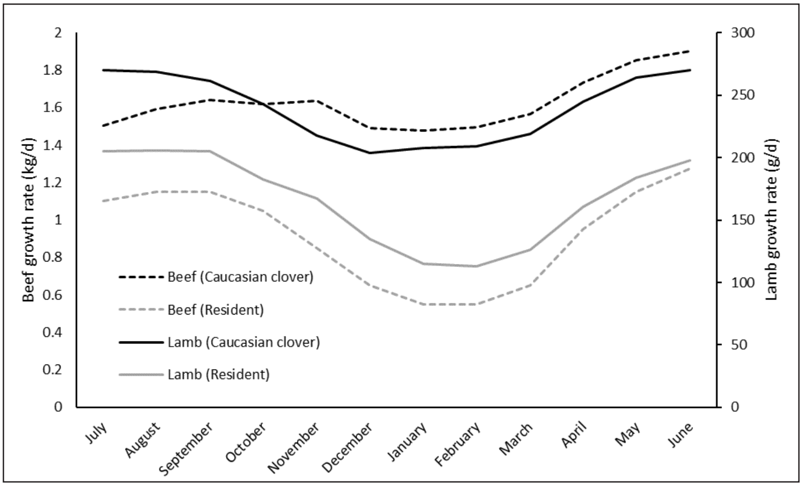

Figure 1

Average beef and lamb growth rates for four farms when grazing Caucasian clover/grass mixtures, as predicted from the Q-Graze software (Woodward et al., 2001). Standard deviation between farms for beef and lamb growth are 0.066 kg/d and 5.8 g/d respectively.

sales to produce feed supply and demand profiles which reflected recorded farm productivity.

GHG emissions, methane and nitrous oxide, were obtained from Farmax, based on algorithms from the New Zealand national inventory (Ministry for Primary Industries 2021).

Data analysis

The effect of Caucasian clover on production during the establishment phase was analysed using the proportion of Caucasian clover addition (0, 10, 20 or 30% of flat and rolling topography) as the primary factor with four replicates represented by individual farms. Ecoefficiency, production and profitability outcomes were analysed using the proportion of Caucasian clover addition (0, 10, 20 or 30% of flat and rolling topography) as the primary factor with ewe efficiency (high or low) as the secondary factor, generating two replicates of each treatment. All analyses used the REML function of the statistical package Genstat (20th Edition, 2020). Differences between treatments were determined using a Least Significant Difference (LSD) test.

Results

Establishing Caucasian clover

The slow process to establish Caucasian clover in a mixed sward was reflected in the long lead time before pasture production surpassed the status quo (Table 5). Production lag, or years to the lowest production point was 2 years when 10% was improved, and 2.75 years when both 20 and 30% renewal was the target. However, as the proportion of renewal increased, the lag phase to full production was considerable, ranging up to 11 years to achieve a renewal target of 30% (Table 3).

Pasture production at peak was significantly increased, though the margins were relatively small (Table 5). Feed quality also significantly increased (Table 5). This resulted in a greater percentage increase in total energy supply than the percentage increase in dry matter supply.

Table 4 Decision rules for utilising production from Caucasian clover/grass mixtures on four low rainfall (B+LNZ farm class 2 South Island Hill Country) farms chosen to test the impacts of Caucasian clover introduction on production, greenhouse gas emissions and profit.

Step	Management decision	Description
1	Sheep performance can be improved	If ewe efficiency index (Table 1) is below 60, start with step 2. If it is over 60 skip to step 5
2	Lambs on Caucasian clover	Increase liveweight gain of lambs and sell on 16th of each month once over 40kg
3	Hoggets on Caucasian clover	Increase liveweight gain of hoggets to grow to target weight faster
4	Ewes on Caucasian clover	Increase body condition score of ewes increase scanning result to 200%, increase lamb weaning weight, sell/grow extra lambs as per step 2
5	Increase beef finishing	Buy in as per current policy on farm. Sell at schedule that has best price (sale vs store, later vs earlier)

Utilising the extra production

The decision-making process (Table 4) was applied individually to each scenario within each farm depending on feed supply. Increasing sheep production on farms with low ewe efficiency was mostly confined to increasing lamb and hogget growth rates (Table 6), Farm 1 was able to use extra productivity to increase feeding level to ewes, though Farm 2 was only able to achieve this when 30% Caucasian clover introduction was achieved. Additional beef production was directly related to the relative area that was available for establishment of Caucasian clover grass mixtures (Table 6).

Eco-efficiency and greenhouse gases

The results are shown in Table 7. The amount of feed eaten, stocking rate, and product per ha all increased as the amount of Caucasian clover sown increased.

Table 5 Effects of transition time, production responses and metabolisable energy changes when transitioning to 10, 20 or 30% Caucasian clover/grass mixtures of the cultivable area in South Island low rainfall hill country farms.

	Caucasian clover addition (% cultivable area)					
	0	10	20	30	P value	LSD[1]
Mean time before production reaches original conditions (years)	Na[2]	4 a[3]	5.5 b	6.5 c	<0.001	0.84
Mean time to minimum production (years)	na	2 a	2.75 b	2.75 b	<0.001	0.46
Mean time to full production (years)	na	7 a	9 b	11 c	<0.001	0.65
Mean annual pasture accumulation at full production (t DM/ha/y)	4.05 a	4.13 ab	4.2 bc	4.28 c	0.003	0.099
Mean annual feed quality (MJME/kg DM)	9.86 a	10.01 b	10.08 bc	10.16 c	<0.001	0.101
Mean annual pasture energy production (GJME/ha/y)	39.93 a	41.29 ab	42.35 bc	43.51 c	0.003	1.51
Mean production dry matter increase relative to base (%)	na	1.83 a	3.67 ab	5.5 b	<0.001	2.02
Mean annual pasture energy increase relative to base (%)	na	3.38 a	5.93 ab	8.76 b	<0.001	3.07
Mean annual total greenhouse gas emissions relative to base (%)	na	2.02	4.34	6.27	Nd[4]	nd

[1]LSD = Least Significant difference;
[2] na= not applicable;
[3] values with the same letters are not significantly different;
[4] nd = not determined

Table 6 Application of the steps (Table 2) for utilising extra production from Caucasian clover/ grass mixtures (CC) on four low rainfall farms (B+LNZ farm class 2 South Island Hill Country).

			Step 1	2	3	4	5
Farm	Scenario	Caucasian clover area (%)	Ewe efficiency	% lambs on CC	% hoggets on CC	% ewes on CC	% increase in beef animals sold
1	10%	8	Low	100	100	9	0
	20%	15		100	100	34	0
	30%	23		100	100	44	76
2	10%	10	Low	100	100	0	0
	20%	20		100	100	0	0
	30%	30		100	100	40	0
3	10%	3	High	0	0	0	73
	20%	5		0	0	0	98
	30%	8		0	0	0	106
4	10%	4	high	0	0	0	41
	20%	9		0	0	0	53
	30%	13		0	0	0	64

Feed conversion efficiency showed an increasing trend ($P=0.061$) with the addition of Caucasian clover.

Total, methane, and nitrous oxide emissions all increased, as feed eaten increased (Table 7). Greenhouse gas emissions per kg of product declined as the amount of Caucasian clover mixtures increased.

Production and profitability

Results are shown in Table 8. The percentage of area potentially sown in Caucasian clover mixtures was greater on the farms with lower sheep performance. The percentage of beef stock units and beef income (net of livestock purchases) increased significantly on the farms which already had high sheep performance, while farms with low sheep performance already had uniformly high percentage beef and beef income. Conversely, sheep income increased significantly as the area of Caucasian clover increased on low sheep performance farms, while sheep income remained static when sheep performance was high. Total revenue improved as the area sown in Caucasian clover increased, though this was greater when sheep production was initially low. Working expenses were higher when sheep production was low, although were relatively similar, regardless

Table 7 Mean annual feed eaten, stocking rate, production and greenhouse gas emissions from South Island low rainfall sheep and beef farms with 0, 10, 20 or 30 % of the cultivable land sown with Caucasian clover/grass mixtures.

	Caucasian clover addition					
	0	10	20	30	LSD[1]	P value
Feed eaten (t DM/ha/y)	4.09 a	4.18 b	4.28 c	4.36 d	0.07	0.002
Winter Stocking rate (SU[2]/ha)	7.45 a	7.63 b	7.80 c	7.93 c	0.14	0.001
Production (kg meat+wool product/ha/y)	152 a	161 ab	170 b	185 c	14.3	0.006
Feed Conversion efficiency (g product/kg DM eaten)	36.8	38.2	39.5	41.5	2.2	0.061
Total CO_2 eq. (kg/ha/y)	2327 a	2374 ab	2428 bc	2473 c	54	0.003
Methane CO_2 eq. (kg/ha/y)	1877 a	1917 a	1962 b	2000b	44	0.002
Nitrous oxide CO_2 eq. (kg/ha/y)	446 a	454 ab	463 bc	469 c	10	0.006
CO_2 emissions (kg CO_2 eq./kg product)	17.03 a	16.35 ab	15.78 b	14.98 c	0.68	0.002

[1]LSD = Least significant difference
[2]SU = Stock unit

Table 8 Area sown in Caucasian clover, beef contribution, and mean annual enterprise income, expenses and effective farm surplus if South Island low rainfall hill country farms had 0, 10, 20 or 30% of pastures sown in Caucasian clover/grass mixtures on the cultivable area.

	Ewe Efficiency Index[1]									
	Low				High					
Caucasian clover addition	0	10	20	30	0	10	20	30	LSD[2]	P value
Area sown in Caucasian clover (ha)	0	50	100	150	0	23	46	69	44.4	0.004
Percent of total effective area in Caucasian clover	0	8.85	17.7	26.56	0	6.28	12.56	18.83	5.6	0.001
Beef as a percentage of total stock units	29.5	29	28	29	22	25.5	26.5	27	3.4	0.08
Beef income[3] $/ha	283	283	283	306	122	195	215	229	32	0.008
Sheep Income[3] $/ha	488	521	608	738	423	414	424	423	93	0.014
Revenue Total $/ha	771	804	891	1044	579	652	672	686	29	0.01
Working expenses $/ha	600	601	604	603	274	275	275	275	7	0.708
EFS $/ha	152	184	268	423	278	351	371	385	73	0.013
Net increase $/ha sown	na	359 d	702 cd	1030 bcd	na	2819 a	1830 b	1370 bc	880	0.022

[1] Ewe efficiency index = lamb weaning weight per ewe/ewe mating weight expressed as a percentage (see Table 2);
[2] LSD = Least significant difference;
[3] Beef and sheep income is calculated as sales - purchases.

of the percentage area of Caucasian clover sowings. This resulted in a significant increase in effective farm surplus, as the area sown to Caucasian clover increased. When calculated as net returns per ha sown, these increased when sheep performance was initially low, yet declined when sheep performance was initially high, as the percentage of Caucasian clover increased.

Discussion

This paper used published data to estimate both productivity and quality of Caucasian clover and predict animal performance responses to the addition of Caucasian clover. A step-by-step decision-making process was used to capture these responses to the benefits of the whole farm system. The strength of this approach was in creating a solid base of predicted pasture growth and quality profiles. With rules and parameters specific to each farm, more confidence was generated regarding the representation of Caucasian clover in the simulations.

Adding Caucasian clover/grass mixtures to low rainfall hill country farms generated significant increases in eco-efficiency, productivity, and profitability. However, several factors must be noted if farmers are to use this technology. These include managing the establishment phase, matching enterprise with current skills, and utilising the increased feed quality in finishing animals or increasing reproductive efficiency.

Establishment

Loss of production during the development phase, and lag to reach status quo is greater than that represented by individual experiments (*e.g.,* Hurst et al., 2000) as the process was apply to whole farm scale. This lag highlighted the implications of transferring this technology from lowland situations where much of the research occurred (and the relationships were developed *e.g*., Black et al., 2002) into a hill country environment where the accumulation of growing degree days was much slower, due to altitude. Farmers must be confident that the proposed benefits are both attainable and can be captured in saleable product before embarking on such a long, and potentially risky, process.

Decision-making in capturing benefits

Decision making, both on-farm (Gray et al., 2008) and in modelling exercises (Rendel et al., 2017), is critical to success. The step-by step process of assigning extra feed to livestock class with the addition of Caucasian clover mixtures aimed at utilising the greater legume content, and the spring summer production advantage *in situ* first, before using techniques such as stockpiling feed or making supplements to alter feed flows. This was done to minimise additional costs and potential losses. Many choices are available to farmers (Gray et al., 2008), and this research demonstrated the value of this specific set of choices. However, the choice of using Caucasian clover as the legume content of a mixed pasture provided the opportunity to capture benefits both in sheep and beef enterprises. This added utility, compared to other legume options such as lucerne and red clover monocultures that suffer from the risk of bloat in cattle (Clarke and Reid 1974), provided the opportunity to test a greater range of options. Importantly, the benefits of adding Caucasian clover were able to be captured both by increasing liveweight gain and reproductive success in sheep enterprises, as well as adding to finishing cattle.

Whole farm efficiency

Greenhouse gas emissions rose predictably as the amount of feed eaten increased, as calculators such as those in Farmax use a standard multiplier of 21.6 g methane/kg DM consumed (Ministry for Primary Industries 2021). However, emissions per unit of product declined. This was commensurate with a shift in emissions from the breeding population to the finishing population. When assessed alongside changes in profitability, this result reinforced a potential trend towards greater efficiency of production at the expense of total emissions, with the resultant profit enabling the farmer to meet any tax obligations of future regulations.

Eco-efficiency increased with the addition of Caucasian clover mixtures. The relative increase in dry matter production was up to 5.5%, greenhouse gas emissions 6.3% and energy 8.8% (Table 2), while product per unit of dry matter consumption was increased by 12.8% (Table 3). This showed that small eco-efficiency gains can occur when feed quality increases (Johnson and Johnson 1995). This highlighted the potential conflict between eco-efficiency measures and total emissions or losses from the system, as even though eco-efficiency was improved, total emissions increased concurrently (Mackay et al., 2012). An alternate approach may be to capture the potential increases in feed quality within the farm system, without increasing intensity. Unfortunately, this approach is much harder as the extra productivity of increasing legume content would need to be forgone.

The additional feed quality became the significant driver of added value. Dry matter production and stocking rate increased by similar amounts of approximately 5.5%. However, the saleable product increased by 22%. This was driven by better feed quality increasing animal liveweight gain. Correspondingly, Webby and Sheath (2000) demonstrated that altering feed quality was a much stronger driver of farm profitability than increasing dry matter production. Higher energy content in legume-based pasture has consistently been identified as key to increased profitability (Stevens et al., 2012; Rendel et al., 2017; Stevens and Casey 2017; Moot et al., 2019).

Issues

Caucasian clover has demonstrated its' potential for many years (Scott 1998; Stevens and McCorkindale 2002). However, slow establishment (Hurst et al., 2000) and limited seed supply have reduced the uptake of this species on farm. Low uptake impacts further on seed supply and further reduces potential use. Currently there are no commercial growers of seed in New Zealand. Rhizobial inoculum is specific for Caucasian clover (Patrick et al., 1994), and supplies of inoculated seed are limited to imports from Australia.

Enterprise opportunities

The stratification of the farms into high and low sheep performance produced a predictable differentiation in the source of increased income. The increase in EFS was 280% when reproductive performance was increased, compared to 140% when livestock had to be bought in. This highlighted the gain in efficiency when a farm increases reproductive performance to add extra lambs and calves for sale, rather than having to purchase these animals. This was confounded by the topography, as a smaller area of the farm was available for renewal with Caucasian clover, leading to much greater returns per ha sown when sheep performance was high ($2,819-$1370) than when it was low ($359-$1030).

The difference in potential increases in profitability highlighted the importance of two factors. The first is ensuring on-farm reproductive performance, which captured the benefits of additional lambs and calves for future sale. These extra animals can be added to the system at relatively low cost (home-grown feed) compared with purchases from other farms. Purchased animals come into the system with embedded emissions and may create a false impression of increasing eco-efficiency, as only finishing emissions are counted. The second is capturing value by using farmer experience and practice as a guide to enterprise choice. This approach ensured that the changes needed could be easily attained by the farmer, rather than introducing new enterprises that may take time to capture benefits. This factor was implied in the current results, as they are modelled rather than actual. However, it was no less valid, when considering the uptake and success of new technology introductions.

A further factor to be noted is the scope for improvement in any chosen enterprise. The stratification into high and low sheep performance provided an opportunity to ensure that potential productivity gains could be captured when Caucasian clover mixtures were added. If the opportunity to improve is not present within one enterprise, then shifting to a different one, such as increasing cattle trading, in this case, is a logical outcome. This work demonstrated that technology can benefit all enterprises and is thus applicable to a wide range of farm system configurations.

ACKNOWLEDGEMENTS

Many thanks to Beef + Lamb NZ for access to farm data and to MPI Sustainable Farming Fund (contract 405681), PGG Wrightson Seeds, Grasslanz Technology Ltd and Beef + Lamb NZ for funding.

REFERENCES

Beef + Lamb NZ. 2021. Economic Service Sheep and Beef Farm Survey, Marlborough/Canterbury 2021/22 Forecast and Quintile analysis (P21018). https://beeflambnz.com/sites/default/files/data/files/2020%20CSI.pdf Accessed 27 September 2021.

Black AD, Lucas RJ. 2018. Dry matter yield of dryland and irrigated mixtures of Caucasian clover, white clover and perennial ryegrass over 5 years at Lincoln University. *Journal of New Zealand Grasslands 80*: 71-79. https://doi.org/10.33584/jnzg.2018.80.336

Black AD, Moot DJ, Lucas RJ. 2002. Seedling development and growth of white clover, Caucasian clover and perennial ryegrass grown in field and controlled environments. *Proceedings of the New Zealand Grassland Association 64*: 197-204. https://doi.org/10.33584/jnzg.2002.64.2463

Black AD, Moot DJ, Lucas RJ. 2003. Seasonal growth and development of Caucasian and white clovers under irrigation and dryland conditions. In: Moot, DJ. Ed. *Legumes for Dryland Pastures*. *Grassland Research and Practice Series 11*. Dunedin, New Zealand: New Zealand Grassland Association, pp 81-90. https://doi.org/10.33584/rps.11.2003.2992

Black AD, Pollock KM, Lucas RJ, Amyes JM, Pownall DB, Sedcole JR. 2000. Caucasian clover/ryegrass produced more legume than white clover/ryegrass pastures in a grazed comparison. *Proceedings of the New Zealand Grassland Association 62*: 69-74. https://doi.org/10.33584/jnzg.2000.62.2394

Brock JL, Caradus JR. 1996. Influence of grazing management and drought on white clover population performance and genotypic frequency. In: Woodfield DR. Ed. *White clover: New Zealand's competitive edge. Research and Practice Series 6*: Dunedin, New Zealand: New Zealand Grassland Association, pp. 79-82. https://doi.org/10.33584/rps.6.1995.3366

Brown HE, Moot DJ, Pollock KM. 2003. Long term growth rates and water extraction patterns of dryland chicory, lucerne and red clover. In: Moot, DJ. Ed. *Legumes for Dryland Pastures*. *Grassland Research and Practice Series 11*. Dunedin, New Zealand: New Zealand Grassland Association, pp. 91-99. https://doi.org/10.33584/rps.11.2003.2991

Clarke RTJ, Reid CSW. 1974. Foamy bloat in cattle: A review. *Journal of Dairy Science 57*: 753-785. https://doi.org/10.3168/jds.S0022-0302(74)84964-7

Gray DI, Kemp PD, Kenyon PR, Morris ST, Brookes IM, Matthew C, Osborne M. 2008. Strategies used to manage climatic risk: Lessons from farmers with expertise in dryland farming. *Proceedings of the New Zealand Grassland Association 70*: 59-68. https://doi.org/10.33584/jnzg.2008.70.2725

Hay RJM, Ryan DL. 1989 A review of 10 years' research with red clovers under grazing in Southland. *Proceedings of the New Zealand Grassland Association 50*: 181-187. https://doi.org/10.33584/jnzg.1989.50.1885

Hurst RGM, Black AD, Lucas RJ, Moot DJ. 2000. Sowing strategies for slow-establishing pasture species on a North Otago dairy farm. *Proceedings of the New Zealand Grassland Association 62*: 129-135. https://doi.org/10.33584/jnzg.2000.62.2381

Johnson KA, Johnson DE. 1995. Methane emissions from cattle. *Journal of Animal Science 73*: 2483-2492. https://doi.org/10.2527/1995.7382483x

MacKay AD, Rhodes AP, Power I, Wedderburn ME. 2012. Has the ecoefficiency of sheep and beef farms changed in the last 20 years? *Proceedings of the New Zealand Grassland Association 74*: 11-16. https://doi.org/10.33584/jnzg.2012.74.2878

Marshall PR, McCall DG, Johns KL. 1991. Stockpol: a decision support model for livestock farms. *Proceedings of the New Zealand Grassland Association 53*: 137-140. https://doi.org/10.33584/jnzg.1991.53.2013

Mills A, Moot DJ. 2010. Annual dry matter, metabolisable energy and nitrogen yields of six dryland pastures six and seven years after establishment. *Proceedings of the New Zealand Grassland Association 72*: 177-184. https://doi.org/10.33584/jnzg.2010.72.2805

Ministry for Primary Industries. 2021. *Methodology for calculation of New Zealand's agricultural greenhouse gas emissions. Version 7*. 117-179. https://www.mpi.govt.nz/dmsdocument/13906/direct Accessed 27 September 2021.

Mitchell KJ. 1956. Growth of pasture species under controlled environment. 1. Growth at various levels of constant temperature. *New Zealand Journal of Science and Technology 37A*: 203-216.

Moorhead AJE, White JGH, Jarvis P, Lucas RJ, Sedcole JR. 1994. Effect of sowing method and fertiliser application on establishment and first season growth of Caucasian clover. *Proceedings of the New Zealand Grassland Association 56*: 91-95. https://doi.org/10.33584/jnzg.1994.56.2149

Moot DJ, Anderson PVA, Anderson LJ, Anderson DK. 2019. Animal performance changes over 11 years after implementing a lucerne grazing system on Bog Roy Station. *Journal of New Zealand Grasslands 81*: 75-80. https://doi.org/10.33584/jnzg.2019.81.390

Moot DJ, Brown HE, Teixeira EI, Pollock KM. 2003. Crop growth and development affect seasonal priorities for lucerne management. In: Moot, DJ. Ed. *Legumes for Dryland Pastures*. *Grassland Research and Practice Series 11*. Dunedin, New Zealand: New Zealand Grassland Association, pp. 201-208. https://doi.org/10.33584/rps.11.2003.3007

Patrick HN, Lowther WL, Trainor KD. 1994. Inoculation for successful establishment of Caucasian clover. *Proceedings of the New Zealand Grassland Association 56*: 101-105. https://doi.org/10.33584/jnzg.1994.56.2148

Rendel JM, MacKay AD, Smale PN. 2017. The value of legumes to a Whanganui hill country farm. *Journal of New Zealand Grasslands 79*: 35-42. https://doi.org/10.33584/jnzg.2017.79.555

Scott, D. 1998. Sixteen years of Caucasian clover under contrasting managements. *Proceedings of the New Zealand Grassland Association 60*: 115–118. https://doi.org/10.33584/jnzg.1998.60.2322

Stevens DR, Casey MJ, Edwards JP, Maxwell TMR. 2021. A systems approach to understanding the connection between farm systems resilience and pasture resilience. *Resilient pastures – Grassland Research and Practice Series 17*: 421-432.

Stevens DR, Casey MJ. 2017. Grazing legume forages to change farm profitability. Future farming systems. *Proceedings of the 21st International Farm Management Congress July 2017*, *Volume 2*. Edinburgh, Scotland. International Farm Management Association, Bristol, United Kingdom. https://ifmaonline.org/contents/npr-grazing-legume-forages-to-change-farm-profitability/

Stevens DR, McCorkindale B. 2002. Potentials and pitfalls of Caucasian clover in southern New Zealand. *Proceedings of the New Zealand Grassland Association 64*: 67-72.

Stevens DR, Thompson BR, Carruthers A, Wall AJ, Casey MJ, Phiskie R, Young P, Moot DJ. 2012. Understanding the role of spring grazing of lucerne in the Central Otago environment. *Proceedings of the New Zealand Grassland Association 74*: 69-76. https://doi.org/10.33584/jnzg.2012.74.2886

Taylor A, Stevens D, McCoard S. 2021. Winter crop choice and body condition loss change the ecoefficiency of sheep flocks. *Journal of New Zealand Grasslands 83*: 215-224. https://doi.org/10.33584/jnzg.2021.83.3503

Watson RN, Neville FJ, Bell NL, Harris SL. 1996. Caucasian clover as a pasture legume for dryland dairying in the coastal Bay of Plenty. *Proceedings of the New Zealand Grassland Association 58*: 183–

188. https://doi.org/10.33584/jnzg.1996.58.2212

Webby RW, Sheath GW. 2000. The impacts of change in forage quality and seasonality on sheep farm profitability. *Proceedings of the New Zealand Grassland Association 62*: 189-194. https://doi.org/10.33584/jnzg.2000.62.2380

Woodward SJR, Lambert MG, Litherland AJ, Boom CJ .2001. Can a mathematical model accurately predict intake of grazing animals? Testing the Q-Graze model. *Proceedings of the New Zealand Society of Animal Production 61*: 4-7.