Mapping groundcover of clover species in hill pastures in Wairarapa

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Abstract
Tokaroa Farm (608 ha) with sheep and beef in the Wairarapa has predominantly sunny, north-facing slopes. Average annual rainfall is 810 mm with three months summer-dry. High quality pasture is needed in late winter/early spring for lactating stock and in spring to finish stock early. The survey mapped the distribution of resident subterranean (sub) and white clovers across four land classes based on slope and aspect. ArcGIS identified 60 GPS points that were visually assessed in December 2019 and November 2021. At the majority of points in both years, both white and sub clover were present. In 2019, white clover groundcover was 18.1% and higher ($P<0.05$) than sub clover at 12.6%. Management class had no effect. In 2021 there was no species effect (both ~11%) but there was a trend ($P=0.062$) for less white clover groundcover in the 'shady' class (6.7%) than the 'flat' class at 17.5%. Pasture management was focused on promoting early season sub clover, but the unexpectedly high groundcover of white clover provided feed during wetter than average summers. Understanding the continuum from summer-dry annual sub clover areas to summer-wet perennial white clover dominance across New Zealand pastures provides tools for the selection and management of appropriate legumes.

Keywords: ArcGIS, aspect, slope, subterranean clover, white clover

Introduction
New Zealand's east coast climate is summer dry with no pasture growth expected for 2-4 months each year. This means spring is the main season of production (Mills and Moot 2010; Mills et al. 2015) for pasture to meet the nutritional demand for lactating stock. In dryland (rainfed) farming systems, the aim is to finish as many lambs as possible to slaughter weight before the onset of the summer dry. This requires increasing the amount of high quality feed produced in late winter and spring when moisture is not limiting (Macfarlane et al. 2014). Legume species have been advocated to maximise water use efficiency (Moot 2012) and overcome the nitrogen deficiency that limits pasture production in dryland environments (Mills et al. 2006). Specialist crops, such as lucerne (*Medicago sativa*), have been used (Avery et al. 2008; Moot et al. 2019) but this is not easily established or maintained on uncultivatable hill country. Therefore, forage clover species that can be over sown and managed on hill country pastures are important.

White clover (*Trifolium repens*) is the most commonly sown legume in New Zealand. This can increase animal average daily gain by 40%, compared with ryegrass, because of the greater efficiency of metabolisable energy (ME) utilisation for growth (Nicol and Edwards 2011). Annual legumes, such as subterranean (sub) (*T. subterraneum*) and balansa (*T. michelianum*) clovers, are more productive in late winter and early spring (Hyslop et al. 2003; Evans and Mills 2008; Teixeira et al. 2017; Olykan et al. 2021) than perennial white, red (*T. pratense*) or Caucasian (*T. ambiguum*) clovers, which are more productive from late spring into summer (Black et al. 2003; Brown et al. 2003; Olykan et al. 2021). Measurements of the seasonal distribution of pasture production in New Zealand confirm these patterns of annual (sub) or perennial (white) clover yields at sites with <1000 mm annual rainfall. Where sub clover was the dominant pasture clover measured in a Hawke's Bay (Radcliffe 1975) and a dryland Canterbury site (Rickard and Radcliffe 1976), it contributed ~9 kg DM/ha/d to the total spring pasture production of 32 kg DM/ha/d. In summer when sub clover dies and reseeds, it only accounted for 2.3 kg of the 14 kg DM/ha/d. Where white clover was present in Otago (Round-Turner et al. 1976; Cossens and Radcliffe 1978) and Gisborne (Radcliffe and Sinclair 1975), its spring growth contributed 6 kg DM/ha/d of total spring pasture production of 40 kg DM/ha/d, and in summer this was 10 kg of the 36 kg DM/ha/d total.

Sub and white clovers typically occupy different landscape niches in summer-dry hill country, which is related to seasonal soil moisture. In Hawke's Bay, Gillingham et al. (1998) found more white than sub clover on southern aspects, where soil moisture conditions were higher for most of the year. There was more sub than white clover on warmer, drier northern aspects. Similarly, in Waikato, white clover dominated the flatter sites where soil moisture levels were relatively high during summer and autumn, and sub clover was found on the drier gentle and steeper slopes (Ledgard et al. 1987). In Central Otago, sub clover was found on sunny, north-west aspects and white clover on shady south-eastern facing land (Smith et al. 2004). Slope and aspect significantly affect soil moisture in hill country environments (Hajdu et al. 2017). Variables such as solar radiation, air and soil temperatures, potential evapotranspiration (Radcliffe and Lefever 1981), soil moisture tension and wind speeds (Lambert and Roberts 1976) are higher on northern compared with southern aspects, and such differences are seasonal. Slope affects soil moisture because of the potential for rainfall to runoff and sub-surface flow to occur (Bircham and Gillingham 1986).

Mills et al. (2021) found that 60 to 90% of resident pasture growth on central Hawke's Bay summer-dry, rolling hill country occurred in winter/spring when moisture was not limiting. Pasture production in winter is typically higher on north-facing slopes than south-facing slopes (Gillingham et al. 1998). Modelling North Island hill country pasture production Zhang et al. (2004) showed that spring rainfall was the main factor affecting annual production and slope was the main factor for winter and spring production.

Macfarlane and Sheath (1984) identified populations of sub and white clover that had adapted to areas of summer-dry northern North Island hill country. They described the white clover as being densely leaved, with relatively small leaves and petioles, probably due to hard grazing pressures over many years. For resident sub clover, a prostrate growth habit allows it to reseed and regenerate under traditional North Island intensive spring continuous set stocking (Chapman and Williams 1990; Sheath and Macfarlane 1990). Macfarlane and Sheath (1984) concluded that a white/sub clover mix was required to provide the flexibility required to cope with the variable onset and intensity of moisture stress in these environments.

Recent research at Tokaroa Farm in the Wairarapa focussed on the management of sub clover in the hill pastures grazed by sheep and cattle (Olykan et al. 2019). Because of the predominance of flats and sunny north-facing slopes (78% of the property) and the summer-dry environment, Olykan et al. (2019) hypothesised that the best legume for this farm was sub clover. However, the authors noted that both sub and white clovers co-existed on a west-facing hill slope and, anecdotally, there were 'wetter' summers when white clover grew well.

The aim of this mapping study was to use visual assessment to validate the clover management classes developed by Olykan et al. (2019) to promote sub clover. An understanding of clover distribution may enhance pasture and grazing management practices and encourage the use of both clovers in environments that experience variable and inconsistent spring and summer rainfall.

Materials and Methods

Tokaroa Farm, a 608 ha summer-dry sheep and beef property owned and managed by Dan and Reidun Nicholson, is in the Wairarapa region of the North Island of New Zealand (GPS coordinates -41.150, 175.552). The terrain ranges from valley flats to steep hill slopes (>25°) with a predominance of gentler north-facing, sunny slopes and steeper, south-facing slopes. This study focussed on grazed paddocks in two management zones; 'middle' comprising of some flats and mainly

Table 1 Area and percent of clover management classes in two management zones, 'middle' and 'ranges', at Tokaroa Farm, Wairarapa, and the number of assessment points in 2019.

Zone/Class	Description (Aspect, slope)	Area		Assessed points	
'Middle'		**ha**	**%**	**No.**	**%**
Flat	All aspects, slope 0 - 7°	94.5	36	12	41
Sun-Dr	Northerly, drillable slope 8 - 20°	90.7	34	8	28
Sun-Un	Northerly, undrillable slope > 20°	29.8	11	3	10
Shady	Southerly, slopes 8+°	51.3	19	6	21
	Totals:	**266.3**	**100**	**29**	
'Ranges'*					
Flat	All aspects, slope 0 - 7°	14.8	8	4	13
Sun-Dr	Northerly, drillable slope 8 - 20°	44.8	23	5	16
Sun-Un	Northerly, undrillable slope > 20°	84.9	44	13	42
Shady	Southerly, slopes 8+°	48.1	25	9	29
	Totals:	**192.6**	**100**	**31**	

* While there was no intention to drill in the 'ranges' zone, the same clover management classes were included to identify clover locations.

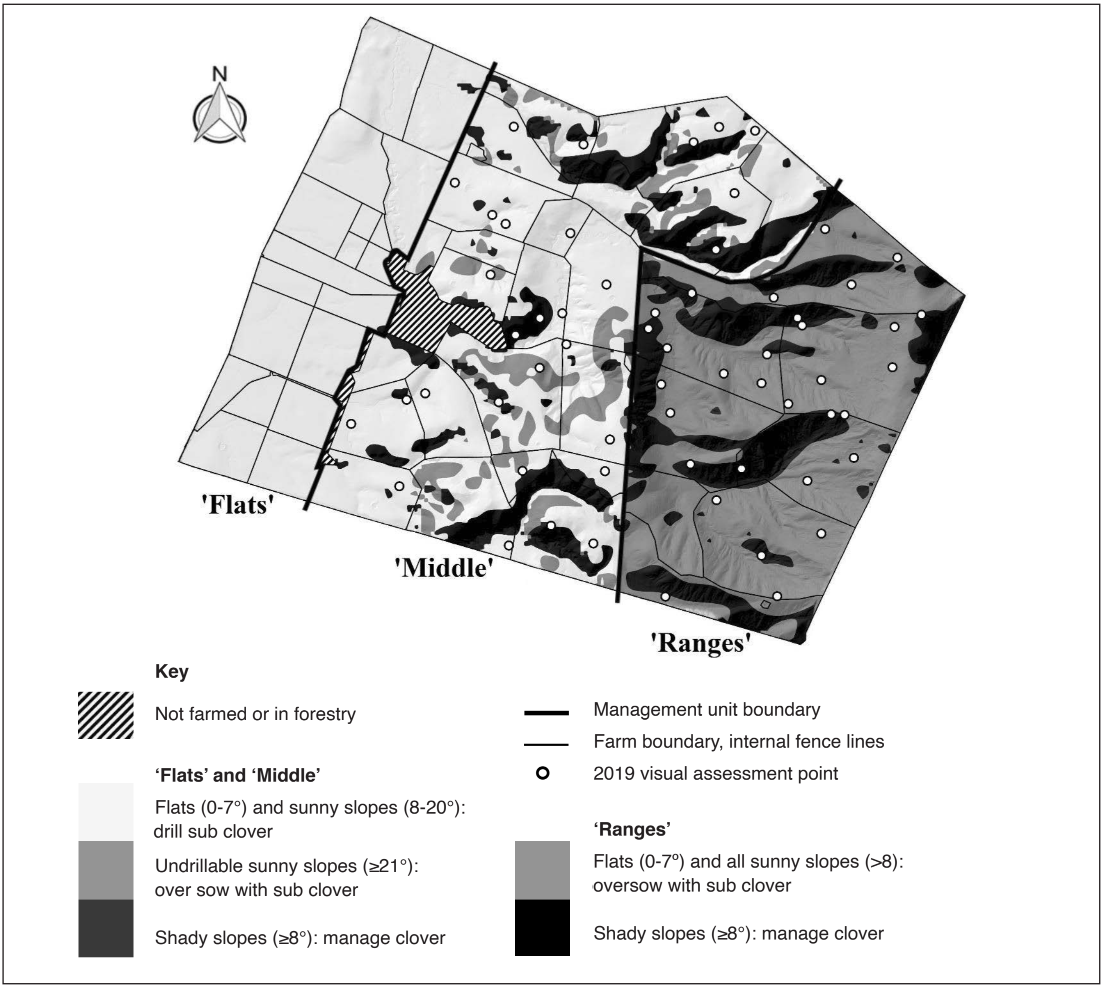

Figure 1 Clover management classes, based on slope and aspect, for the 'flats', 'middle' and 'ranges' management zones at Tokaroa Farm, Wairarapa.

rolling hills that were historically disced and cultivated; and 'ranges' where, regardless of slope, no drilling was feasible due to the more broken, steep and rough terrain (Table 1, Figure 1). The predominant resident pasture grasses were browntop (*Agrostis capillaris*), with perennial ryegrass (*Lolium perenne*), Yorkshire fog (*Holcus lanatus*) and a range of annual grasses. The main resident legumes were sub and white clovers.

The Lilburn soil type (acidic orthic brown) dominated the 'middle' zone and was a shallow (40 – 48 cm), silty soil with 60 mm of profile available water and a low anion storage capacity value of 24% (Manaaki Whenua 2022). In the 'ranges' are the Waitataura (pallic orthic brown) and Taihape (typic orthic gley) moderately deep (70 cm) silty soils that are moderately to poorly well-drained, respectively, with 116 mm and 95 mm of profile available water, respectively, and medium anion storage capacity values of ~37% (Manaaki Whenua 2022). Soil tests showed Olsen P values of 26 µg/ml in the 'middle' zone and ~30 µg/ml in the 'ranges'. Soil pH values were 5.9 in the 'middle' and 5.8 in the 'ranges'.

Fertiliser applications are applied to support clover growth. Annually the drillable country received 300 kg Sulphur Super 15 (0, 8.6, 0, 14.8) or 15 Potash Super (0, 7.7, 7.5, 9.4) depending on soil tests. Maintenance fertiliser for the hills was 250 kg Sulphur Super 15 annually and 2.5 t lime/ha every 7 to 10 years. Molybdenum, at 0.06 kg/ha, was applied with the superphosphate in 2018.

Assessment point selection

The development of the original whole farm map using ArcGIS Pro (ESRI 2022) and the slope and aspect categories have been described by Olykan et al. (2019). In brief, the sunny classes were north-facing aspects (i.e., W, NW, N, and NE, 247.5 to 67.5°), and shady were south-facing aspects (E, SE, S, SW). Slope categories were based on Land Use Capability classes (Lynn et al. 2009). Combining aspect and slope provided the four clover management classes, as described in Table 1. Non-farmed and forestry areas were excluded as were paddocks in the 'middle' zone containing annual forage crops.

Using ArcGIS Pro, 20 random points were identified in each of the 'middle' and the 'ranges' zones. The number of points per clover management class were weighted according to the percentage area they represented in the zones. An additional 20 random points were generated for assessment if time was available. In 2019, the coordinates of the 60 points were entered into ArcGIS Collector (ESRI 2019).

The most appropriate time to visually assess sub clover cover is in late spring before it senesces. Olykan et al. (2019) reported peak sub clover content on 26th November 2016. Prior to both assessments, the status of the sub clover was confirmed with the farmer. On 4-6 December 2019, the ArcGIS Collector app on mobile smartphones was used to navigate to each point with an accuracy of ±5 m. After confirming that the slope and aspect at each point matched the original criteria, the surrounding 1 to 2 m radius was visually assessed for the proportion (%) of sub and white clover groundcover. The presence of other legumes, such as suckling *(T. dubium*), cluster (*T. glomeratum*) and striated (*T. striatum*) clover or lotus (*Lotus sp.*) were noted. During the assessment, 18 of the original points were moved because they did not represent the original aspect and slope criteria, were located under planted trees in gullies, in regenerating scrub on steep slopes, in thistle patches (on several 'ranges' ridges), in eroded areas on steep slopes, or the paddock was in a forage crop and had not been previously excluded. In these situations, the point was moved to the nearest representative area with the relevant slope and aspect. Where the point was on a stock track, the assessment took place at an adjacent point. The coordinates of the new points were recorded, and ArcGIS Pro used to recalibrate the aspect and slope details. In 2019 a total of 60 points were assessed (Table 1).

On 19-20 November 2021 the same 60 points were relocated using a Trimble TDC150 Handheld GNSS Receiver (Trimble Inc.) with an accuracy of ±10 cm. Of these, 54 points were visually reassessed (as in 2019 and by the same assessor) for sub and white clover, and the groundcover of the other clovers were included. The six unassessed points were in 'middle' zone paddocks that had been cultivated since 2019. At some points the paddocks were being grazed or had been recently grazed, particularly in 2021.

ArcGIS mapping

The whole farm clover management classes map in Olykan et al. (2019) was updated (Figure 1). The 'flats' zone was not assessed. For the 'middle' zone, the '0-7° drillable flat' and '8-20° drillable sunny' classes were combined into '0-20° drillable sunny'. The '≥21° Undrillable sunny' and '≥8° shady faces' were unchanged. The two classes in the 'ranges' zone, 'flat + sunny faces' and '≥8° shady faces', were not changed.

Farm management practices

After the November 2021 assessment, the farmer was asked to comment on the previous two seasons in terms of climate and sub clover management. Prior to the 2019 assessment it was stated that "*the winter was dry but was still a relatively good set up so more control over the grass*." In early 2021 "*had some quite decent rainfalls over summer which in turn led to us losing control of pastures and going into winter with a lot of rough feed which was hard to clean up hence poor sub clover striking and quite a few false strikes. This along with a cool winter and a cold spring led to less sub clover and late rains kicked off white clover. We were wintering approximately 12 stock units/ha (quite high) to clean up feed and take advantage of high prices so… there was less grass than previous years.*"

The farmer made the following general comments: "*The system is based on a 1-year ewe policy and aims to grow lambs and ewes fast and get them off before the summer dry and the price reduction. The summer/ autumn clean-up is very important. The last few years there has been a common theme where we received rains after early lamb weaning and grass control becomes an issue. We run a late calving cow herd to help combat this. But it is a good situation to be in with stock sold at high prices and if we carry higher pasture mass into summer, we can withstand a dry period for longer. I have definitely noticed a longer sub flowering season with flowering also seen after weaning. It seems there is more 'Tallarook' [the resident white flowered sub cultivar[1]] and have had great results with 'Denmark' sub reseeding and matching lactation of early ewes. In the 'middle' zone we direct drill sub into the sunny slopes only. Have the flexibility to shut up paddocks so that the sub can reseed. Tokaroa Farm is sub [clover] country and the amount of white clover depends on the season.*"

Climate

Climate data were provided by NIWA from the Virtual Climate Station (VCS) network at GPS -41.175, 175.525 (NIWAData 2022), the nearest 5 km grid node

1 'Mount Barker' sub clover with the red band on its flower is also resident at Tokaroa Farm.

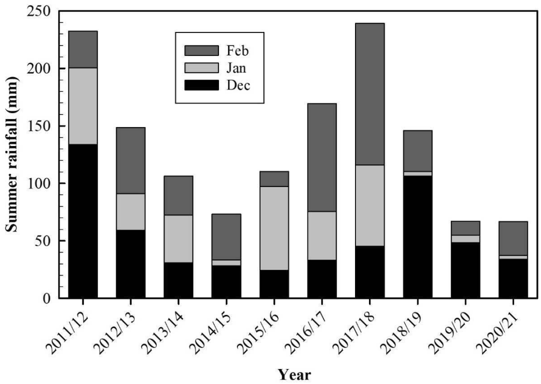

Figure 2 Summer rainfall (December to February) from 2011-12 to 2020-21 for Tokaroa Farm, Wairarapa. Data from the NIWA Virtual Climate Station (VCS) network at GPS -41.175, 175.525 (NIWAData 2022).

being 3.6 km SW from the centre of the property at an elevation of 104 m. The 30-year long-term mean (LTM, 1991-2020) annual maximum and minimum air temperatures were 17.8°C and 7.6°C, respectively. The LTM rainfall was 810 mm with 32% of this during the winter months of June to August (~85 mm rain per month) when monthly potential evapotranspiration (PET) of ~25 mm was at its lowest. During the summer months the LTM rainfall averaged 52 mm per month while PET averaged 129 mm per month. LTM monthly PET exceeded rainfall for six months from October until March, and particularly from November to February. Annual rainfall from 1 July to 30 June in 2019-20 was 684 mm and in 2020-21 was 751 mm. Average monthly rainfall for the three months before the December 2019 assessment was 53 mm, and before the November 2021 assessment was 43 mm.

During the 2011-12 to 2020-21 summers (December to February) the average total rainfall was 136±20 mm (Figure 2). Summer rainfall fluctuated from a high of 232 mm in 2011-12 to a low of 67 mm in 2019-20 and 2020-21. January was the driest month and averaged 35 mm but was <7 mm from 2018-19 to 2020-21. Over the 10 years, summer PET averaged 406±7 mm.

Separate daily soil moisture deficit (SMD) calculations, using inputs of rainfall and losses by PET or actual evapotranspiration, and drainage, for 1 July 2019 to 31 December 2021 were done for the 'middle' zone, where soil profile available water (PAW) was 60 mm, and the 'ranges', where the average PAW for the two soils was 106 mm. To compare the two zones, the SMD values were converted to PAW%. The NIWA (2022) SMD drought indicator values were converted to PAW, whereby 'in deficit' was 27 to 50% PAW, 'severely dry' 13 to 27%, and 'extremely dry' <13%. The LTM PAW% was calculated for the 'ranges' zone.

In the 'ranges' the LTM PAW was <50% from mid-November to early April, a summer-dry period of nearly 5 months, with a two-month period from early January to early March, when the soils were 'severely dry'. In 2019-20 the length of the summer-dry period (>50% PAW) was normal, however PAW became severely dry at the end of November and extremely dry from early January to the end of March. In 2020-21 the summer-dry period started mid-December, a month later than normal, but finished in mid-June resulting in a summer-dry period of six months. During that time, it was severely dry from early January until the end of March, and extremely dry from mid-January to mid-February.

Statistical analyses

Raw data were analysed using Genstat (18th edition; VSN International). The incidence and percentage groundcover of sub and white clovers and their total (sub + white clover) data were analysed by one-way ANOVA with the management classes as the factor and the zone ('middle' or 'ranges') as a covariate. Separate analyses were carried out for 2019 and 2021. The effect of year on percentage groundcover of sub, white and total clover data, from the 54 points assessed in both 2019 and 2021, were analysed by one-way ANOVA. The 2019 and 2021 sub clover, and 2021 white clover data were skewed, and, hence, were transformed using Log10(x+10) for analysis. Untransformed means are presented.

Results

Incidence of clovers

At most points assessed in 2019 and 2021, white and sub clover were both present (Figure 4). White clover was present at more points than sub clover in both years. The other most common resident clover was suckling. From 2019 to 2021 there was a decrease (P=0.028) in the points where white clover was identified (98 to 87%).

Groundcover

In 2019, clover groundcover was affected (P=0.021) by species. Across the two zones white clover (18.1%) was higher (P<0.05) than sub clover (12.6%). There was no effect of clover management class on the two species (Figure 5).

In 2021 the observed sub + white clover groundcover was 22.3% and less (P<0.05) than the 30.7% observed in 2019. While there was no change in the sub clover present after two years, white clover declined (P<0.05) to 11.8%. In 2021, clover management class had an effect (P=0.062) on white clover with the 6.7% in the 'Shady' clover management class being lower than the 'Flat' class with 17.5% (Figure 5).

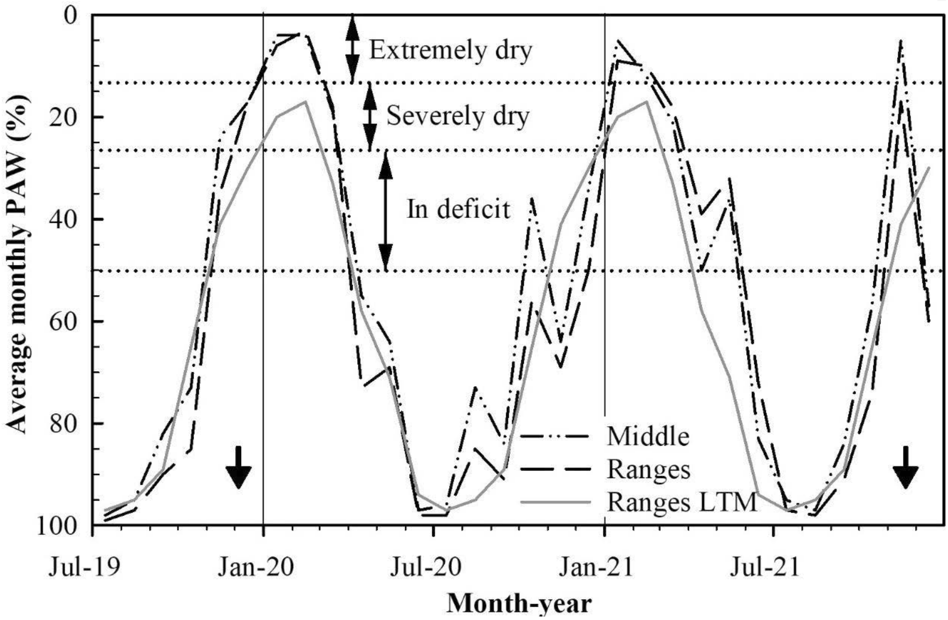

Figure 3 Average monthly profile available water (PAW) from July 2019 to December 2021 for the 'middle' and 'ranges' soils, Tokaroa Farm, Wairarapa. Data and 10-year LTM average (01/07/2011 to 30/06/2020) calculated from NIWA VCSN data at GPS -41.175, 175.525 (NIWAData 2022). 'In deficit', 'severely dry' and 'extremely dry' categories adapted from NIWA (2022). Clover assessment dates shown with an arrow.

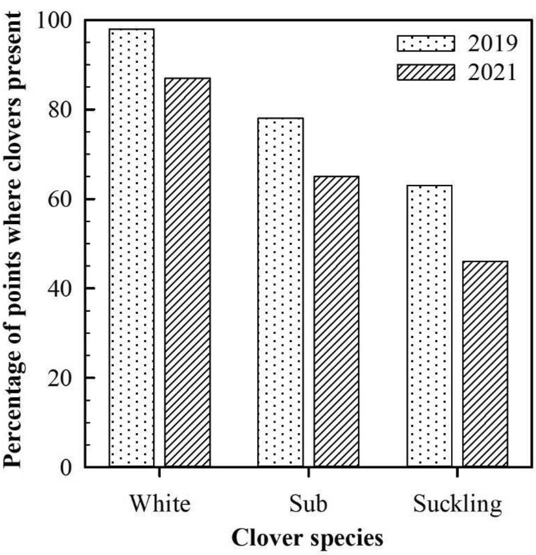

Figure 4 Percentage of assessed points where white, sub, and suckling clovers were present on 5 December 2019 (60 points) and 20 November 2021 (54 points), at Tokaroa Farm, Wairarapa.

Discussion

The distribution of white and sub clovers found on Tokaroa Farm was not the same as predicted by Olykan et al. (2019). In the late spring/early summer of 2019 and 2021, both clovers co-existed across the different management classes with white clover found at more locations than sub clover and with a higher percent groundcover in 2019. The greater than expected prevalence of white clover may have been due to several factors, including the previous three years having higher than average summer rainfall (Figure 2), improved pasture management practices, and the resident white clover population.

White clover is suited to environments with >750 mm annual rainfall, and at least 150 mm in summer (Brock et al. 2003). At Tokaroa Farm, annual rainfall averaged ~800 mm, however, more recent summer rainfall fluctuated from 70 to 240 mm and was ~150 mm or more in five out of ten years (Figure 2). As PET during the summer was ~400 mm, summer-dry conditions prevailed and there was <50% plant available water from November to April (Figure 3).

Pasture management practices at Tokaroa Farm that promoted clover included rotational grazing to minimise selective legume grazing and minimise summer and autumn grass competition. The focus was on sub clover from autumn establishment to late spring seed set, and maintaining pasture mass >1000 kg DM/ha heading into summer to reduce soil temperatures and conserve soil moisture (Olykan et al. 2019). Clover growth at the time of the survey was supported by annual fertiliser applications, including periodic (4 to 5 yearly) addition of molybdenum.

The resident white clover persisted at Tokaroa

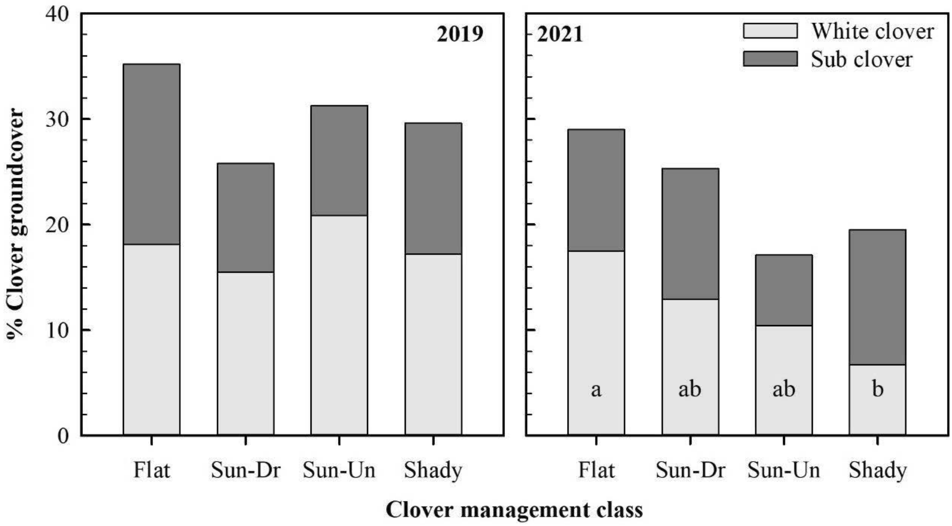

Figure 5 Average % groundcover of sub and white clovers visually assessed in four management classes, flat, sunny-drillable (Sun-Dr), sunny undrillable (Sun-Un) and shady, at Tokaroa Farm, Wairarapa, on 5 December 2019 and 20 November 2021. In 2021, white clover means with the same letter were not different ($P<0.10$).

Farm over the decades and had presumably adapted to on-farm conditions, as found by Macfarlane and Sheath (1984) for white clover growing on North Island hill country. The white clover seed bank most likely provided seed for recruitment after dry summers (Knowles et al. 2003). The presence of white clover was viewed as a bonus by the farmer as it provided high quality feed later in spring and summer. The fixing of N by both clover species improves the palatability of co-habiting grasses and pasture water-use efficiency (Moot et al. 2008) and allows the system to respond to any summer rainfall that occurs. However, developing and maintaining productive clover-dominant pastures at Tokaroa Farm was focussed on sub clover because its early spring yield met the feed requirements of lactating ewes and the need to finish lambs and cull ewes as early as possible.

Knowledge of the location and prevalence of resident clovers on-farm can be used to inform management decisions. At Tokaroa Farm, the visual assessment method enabled the creation of predetermined points that could be returned to over time. This provided a relatively quick method to assess the property across a wide range of terrains and provided semi-quantitative data to identify the presence of clovers in spring.

There were limitations in this survey. One disadvantage was that the points may not have fairly represented the wider area they were located in. There was a need to move unsuitable points and determine the impact of grazing and tall grass when quantifying clover groundcover. A single snapshot in time does not capture seasonal changes, and assessments could have been done at fixed points more frequently on-farm. Alternatively, permanent transects on the farm could have been used to assess the impacts of management on sub and white clover over time (Olykan et al. 2019). Identifying the presence of sub clover should be undertaken at peak growth, which was October/November at Tokaroa Farm. In Canterbury, peak sub clover growth rates occurred in September/October (Olykan et al. 2021). In late spring there was a risk of long grass in a wet season or sub clover senescence in a dry season may lead to an underestimation of sub clover cover.

A direct comparison between the presence of clover groundcover in the two assessment years was complicated by many factors. These included the different assessment times (4-12-2019 versus 19-11-2021), higher amount of tall grass present in 2019, more stock grazing prior to the assessment in 2021 compared with 2019, loss of permanent points in 2021, a poor start for sub in 2021 (dry autumn resulting in false strikes and late establishment) and the impact of the cooler 2021 winter spring on clover growth. The observed decline in white clover groundcover from 2019 to 2021 may have been affected by the two drier-than-average summers that occurred in 2019-20 and 2020-21 (Figure 2).

Because of their respective topography and ease of access, the 'middle' and 'ranges' zones were managed differently, and the clover map reflected this (Figure 1). These results showed more white clover than expected but the management recommendations of Olykan et al. (2019) for sub were still valid to maintain and increase its presence, and therefore the potential for it to thrive in a drier year when white clover was more challenged.

Sub clover can be direct drilled into pastures on flat and sunny slopes or over sown on undrillable sunny slopes to increase its presence and maximise early spring pasture production. The farmer has successfully introduced *cv.* 'Denmark' sub clover into Tokaroa Farm pastures using these methods.

The results suggested that sub and white clovers can occupy the same niche over time. This farm location was in a transition zone for the legume continuum from summer-dry sub clover dominance to summer-wet white clover, where dominant annual clovers were absent. The farmer asserted that the emphasis on sub clover management increased its yield over time. Balancing seasonal herbage production, livestock numbers and feed demand can be difficult in summer-dry/wet transition zones. The data showed that large areas of beef and sheep hill country pastures with 700 to 1200 mm annual rainfall, which represents the transitional zone for annual and perennial clovers, can be managed to provide complementary seasonal yield of both legumes. In hill country pastures, soil moisture deficits, *i.e*., summer drought, negatively impact on the persistence and productivity of white clover (Dodd et al. 2001; Knowles et al. 2003). Sub clover avoids the summer-dry by remaining as a seed in the soil, but rainfall variability affects persistence (Sheath and Hay 1989) and the length of the growing season (Olykan et al. 2018).

Soil moisture in dryland systems is a function of effective rainfall, PET and the ability of soils to hold moisture, both of which are affected by slope (Bircham and Gillingham 1986) and aspect (Radcliffe and Lefever 1981). Modelling these factors (Zhang et al. 2004) across the hill country pastoral landscape can provide tools to assist with the selection and management of appropriate legumes.

Conclusion

The visual assessment of pastures indicated that white and sub clover were both present across the management classes that were based on slope and aspect. As early pasture production was a necessity in this summer-dry landscape, the promotion of sub clover remained the farmer's key management strategy to increase legume content. White clover can provide later feed during wetter than average summers. The clover management classes presented can be used as a practical guide to the long-term management of clover on this, and similar properties.

The continuum from the summer-dry sub clover environment to summer-wet perennial white clover pastures in New Zealand requires tools to assist with the selection and management of appropriate legumes. Encouraging the annual sub clover can provide long-term resilience in areas which are prone to summer-dry.

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REFERENCES

Avery D, Avery F, Ogle GI, Wills BJ, Moot DJ. 2008. Adapting farm systems to a drier future. *Proceedings of the New Zealand Grassland Association 70*: 13-18. https://doi.org/10.33584/jnzg.2008.70.2710.

Bircham JS, Gillingham AG. 1986. A soil water balance model for sloping land. *New Zealand Journal of Agricultural Research 29*: 315-323. https://doi.org/10.1080/00288233.1986.10426988.

Black AD, Moot DJ, Lucas RJ. 2003. Seasonal growth and development of Caucasian and white clovers under irrigated and dryland conditions. Presented at: *Legumes for dryland pastures*. Proceedings of a New Zealand Grassland Association symposium, Lincoln University. Pp. 73-79. https://doi.org/10.33584/rps.11.2003.2992.

Brock JL, Hyslop MG, Widdup KH. 2003. A review of red and white clovers in a dryland environment. Presented at: *Legumes for dryland pastures. Proceedings of a New Zealand Grassland Association symposium*. Lincoln University. Pp. 101-107. https://doi.org/10.33584/rps.11.2003.3001.

Brown HE, Moot DJ, Pollock KM. 2003. Long term growth rates and water extraction patterns of dryland chicory, lucerne and red clover. Presented at: *Legumes for dryland pastures. Proceedings of a New Zealand Grassland Association symposium*. Lincoln University. Pp. 91-99. https://doi.org/10.33584/rps.11.2003.2991.

Chapman DF, Williams WM. 1990. Evaluation of clovers in dry hill country 8. Subterranean clover at "Ballantrae", New Zealand. *New Zealand Journal of Agricultural Research 33*: 569-576. https://doi.org/10.1080/00288233.1990.10428459.

Cossens GG, Radcliffe JE. 1978. Seasonal distribution of pasture production in New Zealand XIV. The lower Otago plateau: Hindon. *New Zealand Journal of Experimental Agriculture 6*: 47-52. https://doi.org/10.1080/03015521.1978.10426013.

Dodd MB, Sheath GW, Wedderburn ME, Tarbotton IS. 2001. Long-term performance of white clover cultivars oversown into summer-dry hill country. *Proceedings of the New Zealand Grassland Association 63*: 85-89. https://doi.org/10.33584/jnzg.2001.63.2435.

ESRI. 2019. *ArcGIS Collector*. Version 18.1.0. Redlands, CA: Environmental Systems Research Institute.

ESRI. 2022. *ArcGIS Pro*. Version 2.9. Redlands, CA: Environmental Systems Research Institute.

Evans PM, Mills A. 2008. Arrowleaf clover: potential for dryland farming systems in New Zealand. *Proceedings of the New Zealand Grassland Association 70*: 239-243. https://doi.org/10.33584/jnzg.2008.70.2702.

Gillingham AG, Gray MH, Smith DR. 1998. Pasture responses to phosphorus and nitrogen fertilisers on dry hill country. *Proceedings of the New Zealand Grassland Association 60*: 135-140. https://doi.org/10.33584/jnzg.1998.60.2319.

Hajdu I, Yule I, Bretherton M, Singh R, Grafton M, Hedley C. 2017. Integrating soil moisture measurements into pasture growth forecasting in New Zealand's hill country. Presented at: *7th Asian-Australasian Conference on Precision Agriculture (7ACPA)*. Hamilton, New Zealand. https://mro.massey.ac.nz/bitstream/handle/10179/13366/ACPAPaper128.pdf.

Hyslop MG, Slay MWA, Moffat CA. 2003. Dry matter accumulation and sheep grazing preference of six winter active annual legumes. Presented at: *Legumes for dryland pastures*. Proceedings of a New Zealand Grassland Association symposium, Lincoln University. Pp. 117-121. https://doi.org/10.33584/rps.11.2003.3006.

Knowles IM, Fraser TJ, Daly MJ. 2003. White clover: loss in drought and subsequent recovery. Presented at: *Legumes for dryland pastures. Proceedings of a New Zealand Grassland Association symposium*. Lincoln University. Pp. 37-41. https://doi.org/10.33584/rps.11.2003.2997.

Lambert MG, Roberts E. 1976. Aspect differences in an unimproved hill country pasture I. Climatic differences. *New Zealand Journal of Agricultural Research 19*: 459-467. https://doi.org/10.1080/00288233.1976.10420975.

Ledgard SF, Brier GJ, Littler RA. 1987. Legume production and nitrogen fixation in hill pasture communities. *New Zealand Journal of Agricultural Research 30*: 413-421. https://doi.org/10.1080/00288233.1987.10417951.

Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, Mackay AD, Newsome PJF. 2009. *Land Use Capability Survey Handbook - a New Zealand handbook for the classification of land*. Agresearch Hamilton, Landcare Research Lincoln, GNS Science Lower Hutt, 163 p.

Macfarlane MJ, Sheath GW. 1984. Clover – What types for dry hill country? *Proceedings of the New Zealand Grassland Association 45*: 140-150. https://doi.org/10.33584/jnzg.1984.45.1670.

Macfarlane MJ, Thomson BC, Crofoot EW, Hamilton G, Ashby H, Muir PD. 2014. Evaluating new forage systems for East Coast dryland. Presented at: *Proceedings of the New Zealand Society of Animal Production*. Napier. Pp. 108-114. http://nzsap.org/proceedings/2014/evaluating-new-forage-systems-east-coast-dryland.

Manaaki Whenua. 2022. *S-MAP Online - the digital soil map of New Zealand*. Retrieved 07/04/2022 https://smap.landcareresearch.co.nz/maps-and-tools/app/.

Mills A, Moot DJ, McKenzie BA. 2006. Cocksfoot pasture production in relation to environmental variables. *Proceedings of the New Zealand Grassland Association 68*: 89-94. https://doi.org/10.33584/jnzg.2006.68.2636.

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.

Mills A, Lucas RJ, Moot DJ. 2015. 'MaxClover' grazing experiment II: sheep liveweight production from six grazed dryland pastures over 8 years. *New Zealand Journal of Agricultural Research 58*: 57-77. https://doi.org/10.1080/00288233.2014.978481.

Mills A, Thomson BC, Muir PD, Smith NB, Moot DJ. 2021. Resident hill country pasture production in response to temperature and soil moisture over 20 years in Central Hawke's Bay. Presented at: *Resilient Pastures*. Hamilton. Grassland Research and Practice Series 17. Pp. 39-48. https://doi.org/10.33584/rps.17.2021.3451.

Moot DJ, Brown HE, Pollock KM, Mills A. 2008. Yield and water use of temperate pastures in summer dry environments. *Proceedings of the New Zealand Grassland Association 70*: 51-57. https://hdl.handle.net/10182/4475.

Moot DJ. 2012. An overview of dryland legume research in New Zealand. *Crop & Pasture Science 63*: 726-733. http://dx.doi.org/10.1071/CP12103.

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.

Nicol AM, Edwards GR. 2011. Why is clover better than ryegrass? *Proceedings of the New Zealand Society of Animal Production 71*: 71-78. http://www.nzsap.org/proceedings/2011/why-clover-better-ryegrass.

NIWA. 2022. *Soil Moisture Deficit (SMD)*. Retrieved 01/02/2022 https://www.niwa.co.nz/climate/nz-drought-monitor/droughtindicatormaps/soil-moisture-deficit-smd.

NIWAData. 2022. *VCSN climate data for -41.175, 175.525*. Accessed: 22/03/2022.

Olykan ST, Lucas RJ, Teixeira CS, Subtil RA, Moot DJ. 2018. Establishment, production and regeneration of subterranean clovers in the Mackenzie Basin, New Zealand. *Journal of New Zealand Grasslands 80*: 145-153. https://doi.org/10.33584/jnzg.2018.80.319.

Olykan ST, Lucas RJ, Nicholson DJ, Doscher C, Moot DJ. 2019. Maximising the subterranean clover content on a summer-dry Wairarapa hill-country farm through grazing management. *Journal of New Zealand Grasslands 81*: 91-99. https://doi.org/10.33584/jnzg.2019.81.391.

Olykan ST, Lucas RJ, Hunter SR, Moot DJ. 2021. Growth rates and persistence of annual and perennial clovers. *Journal of New Zealand Grasslands 83*: 69-78. https://doi.org/10.33584/jnzg.2021.83.3494.

Radcliffe JE. 1975. Seasonal distribution of pasture production in New Zealand VII. Masterton (Wairarapa) and Maraekakaho (Hawke's Bay). *New Zealand Journal of Experimental Agriculture 3*: 259-265. https://doi.org/10.1080/03015521.1975.10425813.

Radcliffe JE, Sinclair DP. 1975. Seasonal distribution of pasture production in New Zealand V. Gisborne Plains. *New Zealand Journal of Experimental Agriculture 3*: 247-251. https://doi.org/10.1080/03015521.1975.10425811.

Radcliffe JE, Lefever KR. 1981. Aspect influences on pasture microclimate at Coopers Creek, North Canterbury. *New Zealand Journal of Agricultural Research 24*: 55-66. https://doi.org/10.1080/00288233.1981.10420871.

Rickard DS, Radcliffe JE. 1976. Seasonal distribution of pasture production in New Zealand XII. Winchmore, Canterbury Plains dryland and irrigated pastures. *New Zealand Journal of Experimental Agriculture 4*: 329-335. https://doi.org/10.1080/03015521.1976.10425893.

Round-Turner NL, Scott RS, Radcliffe JE. 1976. Seasonal distribution of pasture production in New Zealand XI. Otago Downland and Taieri Plain (Invermay). *New Zealand Journal of Experimental Agriculture 4*: 321-328. https://doi.org/10.1080/03015521.1976.10425892.

Sheath GW, Hay RJM. 1989. Overview of legume persistence in New Zealand. In: Marten GC, Matches AG, Barnes RF, Brougham RW, Clements Rl et al. Ed. *Persistence of Forage Legumes*, pp. 23-36. Madison, Wisconsin, USA: John Wiley & Sons Ltd. https://doi.org/10.2134/1989.persistenceofforagelegumes.

Sheath GW, Macfarlane MJ. 1990. Evaluation of clovers in dry hill country 4. Components of subterranean clover regeneration at Whatawhata, New Zealand. *New Zealand Journal of Agricultural Research 33*: 541-547. https://doi.org/10.1080/00288233.1990.10428455.

Smith LC, Morrison JD, Trainor KD, Catto WD. 2004. Application of nitrogen and sulphur to sunny and shady aspects on South Island dry hill country. *Proceedings of the New Zealand Grassland Association 66*: 41-47. https://doi.org/10.33584/jnzg.2004.66.2557.

Teixeira C, Lucas R, Lewis T, Moot D. 2017. From establishment to re-establishment: a field evaluation of sub clover cultivars. Presented at: *Proceedings of the 18th Australian Society of Agronomy Conference, 24 – 28 September 2017*. Ballarat, VIC, Australia. http://www.agronomyaustraliaproceedings.org/images/sampledata/2017/34_ASA2017_Pires_Carmen_Final.pdf.

Zhang BS, Valentine I, Kemp PD. 2004. Modelling hill country pasture production: a decision tree approach. *Proceedings of the New Zealand Grassland Association 66*: 195-201. https://doi.org/10.33584/jnzg.2004.66.2535.