Subterranean clover (*Trifolium subterraneum*): its history and current and future research in New Zealand

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Abstract

This review covers the history of subterranean clover (*Trifolium subterraneum*) and its present occurrence in New Zealand; a review of research and conclusions to be drawn from this; and examines past and future research directions.

Subterranean clover has been important in terms of area of use in New Zealand since the late 1930's. Today it makes a significant contribution to pasture production on steep, north-facing North Island hill country where effective rainfall is low, and in other areas where soil moisture drops below wilting point for between 2 weeks and 5 months of the year.

Research has identified the superiority of cultivars possessing a compact, ground-hugging habit of growth, and flowering late, in late October – early November, for use in North Island hill country. In drier areas, more research is needed to identify superior cultivars, although there is evidence that lines in the mid-season or early mid-season flowering groups may be appropriate. A major problem for the use of subterranean clovers in New Zealand is the slow breakdown of hardseededness.

About 7 M ha of land in New Zealand is mapped as being subject to slight to severe moisture deficit (an area which could with advantage support subterranean clover), but further research is needed to identify appropriate cultivars for 4.8 M ha or more of this area.

Key words: history, New Zealand, research, *Trifolium subterraneum*

History of subterranean clover use in New Zealand

Subterranean clover (*Trifolium subterraneum*) was first recognised in New Zealand in the early 1900s growing near Auckland, where it became known as Mangere clover (Saxby 1956). Its arrival may have been associated with the transport of live sheep to the new colony, although A. W. Howard of South Australia is quoted as having "distributed seeds to all parts of Australia, New Zealand and South Africa" prior to 1906. The species was regarded as a weed until the mid-1920s, but from the late 1930s it was being sown on much easy to rolling country. (Saxby 1956). In 1936, Levy & Gorman reported the herbage production of 15 cultivars obtained from Australia. Some, including the late flowering 'Nangeela', were superior to late flowering 'Tallarook' and late mid-season flowering 'Mount Barker', but the latter two were recommended because they were the only cultivars commercially available at the time. The development of hill country by oversowing during the Depression, and later the advent of aerial oversowing from 1947 onwards, caused a substantial increase in the use of subterranean clover (Saxby 1956).

The plant received a considerable boost after Professor E. R. Hudson, Principal of Lincoln College, returned from study leave in Australia in 1930, convinced that it was the ideal plant for the shallow stony soils of the Canterbury plains.

Subsequent research (Calder 1954) and promotion by the College resulted in the development of a highly successful farming system. This took advantage of the high winter–early spring growth rates of subterranean clover enabling lambing very early in July and selling lambs prime before herbage dried off in mid-November.

Subterranean clover sown at 2-4 kg/ha, and the new perennial ryegrass proved to be much more productive than the annual types of white clover and ryegrass that farmers had been using prior to this, and carrying capacity was increased threefold (Calder 1951). However, in the 1960s, grazed lucerne was shown to be more than twice as productive as pastures based on subterranean clover (Iversen 1965). So interest in subterranean clover waned and a whole generation of young farmers grew up with scant knowledge of how to best manage the plant.

Subterranean clover is frequently only sparsely distributed in pasture, on many but not all soils where moisture drops below wilting point in summer for anything from 2 weeks to 5 months. The species occurs widely on the sunny aspect of North Island hill country where it occupies the steep slope areas that have lower fertility and less moisture than the easier country (Ledgard *et al.*1987). It is less prevalent in South Island hill country probably because of the overall drier conditions. Suckling *et al*. (1983) found that the late mid-season flowering ‘Mt Barker’, and late flowering ‘Tallarook’ were the predominant cultivars present during a survey of North and South Island hill country.

Management of these pastures on the hill country, and much of the flat, consists of close and continuous grazing during and after lambing, with periods of set-stocking and spelling during the rest of the year. Today, subterranean clover survives on most cultivable dryland properties and on hill country, although often making only a small contribution to pasture production, and with less than ideal management. Given the right management, and appropriate cultivars, subterranean clover can survive better and produce more herbage than many other legumes in dryland regions (Davies 1952).

Research results with subterranean clover cultivars

Herbage production

Initially, research was limited to comparisons of herbage productivity of cultivars, (Levy & Gorman 1936; McLeod 1967; Smetham 1968; Harris *et al.*1973) but whilst differences have been recorded, e.g. Dodd *et al.* (1995c), those between cultivars flowering at the same time are small. Later flowering cultivars will always produce higher herbage yields, if moisture allows (Scott 1969), because of the greater number of nodes bearing leaves before flowering assumes priority for assimilates (Rossiter 1959). For example Widdup & Pennell (2000) record a continual increase of productivity from 2 500 kg DM/ha for early, to 7 300 kg DM/ha for late flowering cultivars in the first (wet) season of their comparison.

Used as the legume component in a mixed sward, or sown pure, subterranean clover can result in a substantial increase in productivity. Calder (1951) records carrying capacity increasing from 0.62 ee/ha on an unimproved Canterbury dryland sward to 6.25 ee/ha on a subterranean clover ryegrass pasture. A long term average for the subterranean clover component on these flat, stony, shallow, dryland soils is 23% of the total dryland pasture production of 5 870 kg DM/ha (Rickard & Radcliffe 1976). Smetham & Jack (1995) recorded more than 5 000 kg DM/ha produced annually from hard grazed pure swards of mid-season to late flowering cultivars on similar soils in Canterbury, compared with only 764 kg DM/ha from a naturally occurring unimproved sward consisting of striated clover (*Trifolium striatum*), cluster clover (*Trifolium glomeratum*), haresfoot trefoil (*Trifolium arvense*), and vulpia (*Vulpia bromoides*).

On hill country in Canterbury, a pure sward of laxly grazed Woogenellup produced over 6 000 kg DM/ha in 1978 (White & Meijer 1979). Typical production from North Island hill country is recorded by Ledgard *et al.* (1987) who found that subterranean clover yielded 1 100 - 1 500 kg DM/ha out of a total 5 300 - 6 400 kg DM/ha. These figures apply to discreet parts of this landscape only. Subterranean clover was found only on gentle and steep slopes with a northerly aspect, and was associated with the lowest values for any landform of moisture in summer, and available levels of P and K. From similar landscape units, Sheath & Boom (1985a) obtained a three year mean of 6 130 kg DM/ha from swards where subterranean clover was the main legume. On sunny face country improved by the introduction of legumes, including subterranean clover, with fertiliser, Suckling (1959) recorded 2 700 kg DM/ha from unimproved, to 6 300 kg DM/ha for improved areas, with an increase from 3.7 ee/ha to 13.6 ee/ha in carrying capacity.

A major advantage of subterranean clover is its cool-season growth, well ahead of comparative plots of lucerne over the same periods (Table 1, Smetham & Jack 1995) and superior to published rates of winter growth (4-15 kg DM/ha/d) for one of the most winter active of perennial grasses i.e. ‘Grasslands Maru’ phalaris (Stevens *et al*. 1989). This pattern of growth fits in well with a midwinter lambing date.

Factors influencing success with subterranean clover

Adequate seedling population in autumn

Subterranean clover has been oversown by air in New Zealand at 2-4 kg/ha on hill country, and included in seed mixtures at a similar rate when drilled into worked ground.

However, this rate is totally inadequate for the establishment of an effective plant population, particularly as the individual seed weight is more than 10 times greater than that of white clover, which is normally sown at 3 kg/ha. Dear & Sandral (1997)

Table 1 Rates of green herbage accumulation (kg DM/ha/d) during the cool season for 'Otaio' Lucerne and a mean rate for six numbered accessions of subterranean clover during 1995 (Smetham & Jack 1995).

Period	12.04 to 5.08		6.08 to 13.09	14.09 to 12.10
Lucerne[1]	4.9[2]		17.1	10.1
Period	6.04 to 17.05	29.05 to 2.08	10.08 to 7.09	19.09 to 7.10
Subterranean clover	19.6	11.6	20.4	48.2

[1] Measured monthly using the Australian difference technique.

[2] See original paper for statistical analysis.

recommend 7 kg/ha as a minimum rate for subterranean clover, whilst recognising that it will take several years to obtain an adequate seedling population from reestablishment each autumn. Dear *et al.* (1993) found that more than adequate seedling numbers were achieved in the third year after an initial sowing of 25 kg/ha.

Many Australian authors, e.g. Silsbury & Fukai (1977), suggest that 1 000 seedlings/m^2 at germination in autumn is necessary if maximum herbage production is to be obtained from a pure sward. In New Zealand, Smetham & Jack (1995) found that herbage production was strongly correlated with seedling numbers in autumn ($r = 0.70$ $P<0.001$), with populations in excess of 1 700/m^2 resulting in the greatest herbage production of 4 000–5 000 kg/ha. Both Williams *et al.* (1990) and Sheath & Macfarlane (1990a) obtained a similar linear relationship between DM production and seedling numbers in hill country. Adequate seedling populations are only obtained by sowing realistic amounts of seed (viz. 7-25 kg/ha) or being prepared to wait a year or two; with appropriate management to allow full establishment by spelling during germination each autumn. Sheath & Macfarlane (1990b) have found that 2 000 seeds/m^2 are required in February to produce the 200 seedlings/m^2 in June, that Sheath & Macfarlane (1990a) considered necessary to maximise herbage production of a mixed grass clover sward in North Island summer dry hill country.

Establishing seedlings in mixed swards can face considerable competition for moisture from the grass component. Therefore it is vital for legume success to minimise such competition. On cultivable ground this can be achieved by topworking subterranean clover - grass paddocks every third year using grubber, discs or heavy harrows in mid-summer (Calder 1954). Grime *et al.* (1990) classify this legume as a near-ruderal species, indicating that it does not cope well with competition. In terms of autumn seedling numbers, Dear & Cocks (1997) found only two clover seedlings/m^2 survived to 15 May from an early March germination when subterranean clover was associated with perennial companion plants; 37 survived with annual companions, but over 950 seedlings /m^2 survived when subterranean clover was grown as a pure sward. On hill country, control of companion grasses must be obtained by rotating hard, clean-up grazing around a small number of paddocks in summer and autumn, repeating this on any one paddock once every 3 years (Emmersen 1980).

Recently germinated seedlings are easily killed by grazing below the junction of stem and the two cotyledon leaves. Therefore defoliation should not be too close.

Newly germinated stands should ideally be spelled from grazing for 3-5 weeks to allow leaf area to build up (Silsbury & Fukai 1977), since this has a compounding effect on cool season growth (Hoglund & Pennell 1989).

Flowering early enough to set seed before drought

The majority of research with subterranean clover in New Zealand has centred on the selection of cultivars that will flower, set, and mature sufficient seed before soils reach wilting point. Australian research has shown that for this to be achieved, flowering needs to start 70 to 80 days before dryness curtails growth (Dear & Sandral 1997, Rossiter 1978).

The start of flowering is governed mainly by the amount of cold required to initiate flower production (Aitken 1955). Early flowering ecotypes have little requirement for cold and therefore flower in early spring, but late flowering ecotypes require exposure to 6-10 weeks of days with temperatures below 10 °C

Table 2 Characteristics of subterranean clover cultivars recommended for use in New South Wales (after Dear & Sandral 1997).

Cultivar	Flowering commences	Days from sowing in mid-May to flowering (d)	Minimum annual rainfall for persistence (mm)	Hardseed in autumn O=nil, 5=high
Nungarin	early August	110	375	5
Dalkeith	late August	120	400	5
Seaton Park L	early September	125	475	3
York	early September	125	475	5
Trikkala	early September	122	525	2
Riverina	mid-September	128	500	3
Rosedale	mid-September	120	500	3
Gosse	late September	136	650	3
Junee	mid September	138	500	3
Woogenellup	mid September	140	525	2
Clare	late September	142	650	2
Goulburn	late September	145	525	3
Denmark	early October	149	600	2
Leura	early October	156	750	1
Nuba	early October	152	700	3

All the above cultivars are low to very low in formononetin.
Rainfall figures are a guide only and will vary with aspect, slope and soil type in Australia.
The flowering data are based on observations at Wagga Wagga, New South Wales.
Much additional information is available in Dear & Sandral (1997).

before initiation occurs and therefore they do not commence flowering until early summer. Table 2 lists Australian cultivars currently recommended for use in New South Wales. The flowering dates listed are some 3 weeks ahead of that occurrence in Canterbury (Widdup & Pennell 2000). Cultivars are usually grouped according to whether they flower "early", or in "early mid-season", "mid-season", "late mid-season, or "late". Table 4 includes both current and superceded Australian cultivars, grouped according to flowering period.

The ability to reseed adequately is of paramount importance, and Scott (1969) confirmed the Australian experience that cultivars must flower sufficiently early to allow adequate seed to mature before drought sets in. In a grass–clover sward the 200 seedlings/m^2 required for North Island hill country equates to seed production of about 120-160 kg/ha depending on seed weight. Carter & Cochrane (1985) cite 200 kg/ha as being a necessary seed reserve for a mid-season flowering cultivar in 500-600 mm annual rainfall areas in Australia. After accounting for all losses of seed and seedlings from initial germination, false strike, consumption of burrs by grazing animals, and hardseededness, Smetham (2003) suggested that for a pure sward to achieve 1,000 seedlings/m^2, early, mid-season and late flowering lines need to set 336, 288 and 218 kg/ha of seed, respectively.

In a mixed sward seed production is strongly inhibited by associated perennials. This is caused by a reduction of light reaching the clover, rather than lack of moisture. This can lead to a 50% reduction of seed yield in 2 out of 3 years (Dear *et al.* 2000).

In the following accounts, seedling numbers and the weight of seed produced are used as measures of how successful a cultivar is. A considerable amount of research has concentrated on North Island, New Zealand hill country. This is surprising, considering the average annual rainfall in these areas is often between 900 and 1 700 mm (Williams *et al.* 1990). However, much of this country is steep, and more than 50% of the rainfall runs off and is ineffective (Bircham & Gillingham 1986). In addition, from 3 to 5 moisture deficits typically occur in bursts of 1 to 2 weeks with rain between, from late November to early February (Lambert & Roberts 1976). This low effective rainfall predicates the use of subterranean clover, while periodic mid to late summer rain suggests that late flowering strains could be successful. Much research has shown this to be the case e.g. Macfarlane & Sheath (1984) and others (Chapman *et al.* 1986), with the late mid-season flowering 'Mount Barker' and late flowering 'Tallarook' being the most successful. It has been shown that over time there has been a shift in the flowering time of these naturalised populations to be later for 'Mt Barker', and earlier for 'Tallarook' (Macfarlane & Sheath 1984). The optimum flowering time to obtain maximum seed and seedling numbers is now considered to be late October to early November (Sheath & Macfarlane 1990a).

Over the 1980's, an evaluation of nine named Australian cultivars was conducted at eight sites (Figure 1) throughout New Zealand (Williams *et al.* 1990).

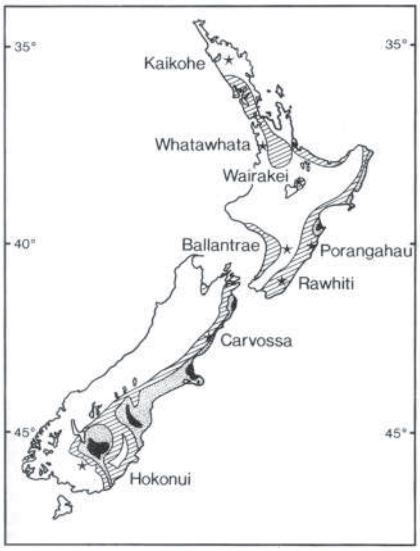

Figure 1 Location of trial sites and zones of annual average soil moisture deficits: □, 0-50 mm; ▧, 50-100 mm; ▩, 100-200 mm; ■, 200 mm +.

At Whatawhata (Sheath & Macfarlane 1990a), on steep hill country with a rainfall of 1 600 mm, and with continuous close grazing management, the mid-season 'Howard', the late mid-season 'Mt Barker' and particularly the late flowering 'Tallarook' produced seedling numbers in June that approached the optimum of 200 seedlings/m^2. The success of late flowering cultivars indicates adequate moisture for seed production from the start of flowering in late October up to the end of December. In addition, herbage yields were highest for these cultivars. However, under rotational grazing, early mid-season 'Seaton Park' and 'Trikkala', mid-season 'Woogenellup' and 'Clare', and late flowering 'Nangeela' and 'Larissa' mostly exceeded the optimum number of plants/m^2 in June, and produced more herbage than 'Mt Barker' or 'Tallarook'. The former cultivars, like many Australian selections, have an "open" habit, characterised by long internodes, a low population of large leaves carried on long petioles, and runners that do not hug the ground. Under close and continuous grazing these cultivars are heavily denuded of runners, flowers and burrs, penalising herbage and seed production. 'Mt Barker' and 'Tallarook' are the reverse in terms of growth habit, being small leaved, with a dense crown and prostrate runners (Sheath & Macfarlane 1990b). In some years, there was up to 60% loss of seed from false strike (Sheath & Macfarlane 1990a), also recorded by Dodd *et al.* (1995a), which would indicate a lack of dry conditions to promote hardseededness during seed maturation (Quinliven 1971). False strike is a characteristic of late flowering cultivars (Quinliven & Millington 1962), which typically have low levels of hardseededness (Table 3). The results at Ballantrae (Chapman & Williams 1990) were almost identical to those noted for Whatawhata. Again cultivars with an open growth habit, were disadvantaged by close grazing.

In spite of this, one of them, 'Nangeela', produced almost as many seedlings as 'Tallarook'. Under rotational grazing 'Trikkala', 'Seaton Park' and 'Howard' produced the highest seedling numbers, although not the highest dry matter yields. Generally, the outcome was much the same at Porangahau, with 700–900 mm annual rainfall (Sheath *et al.* 1990), where 'Tallarook' produced the largest reserve of seed in one year, equivalent to about 430 kg/ha. It did this also at Wairakei with 1 250 mm rainfall on free-draining sandy pumice soils (Macfarlane *et al.* 1990),

Table 3 The proportion of hard seed possessed by nine cultivars of subterranean clover at seed maturity, after four months exposure to summer temperatures in the field in Western Australia, and after six months of exposure in an oven to a diurnal fluctuating temperature regime of 15 °C night/ 60 °C day temperatures (Quinliven & Millington 1961).

Cultivar[1]	Early summer % hard	Four months in the field % hard	Six months in the oven % hard
Geraldton	97.0	64.7	29.3
Dwalganup	96.5	62.4	10.3
Burnerang	82.4	52.4	28.8
Carnamah	95.5	51.2	8.5
Morocco	80.7	35.3	26.4
Woogenellup	86.0	34.4	2.8
Palestine	89.2	29.6	3.1
Baccus Marsh	71.0	16.5	0.2
Mount Barker	58.8	11.1	2.1

[1]In sequential order of first flower appearance from 'early' to 'late mid-season' flowering.

On the very different winterwet soils overlying a pan, and with an annual rainfall of 1589 mm at Kaikohe, the subspecies *Ts. yanninicum* cultivars: 'Trikkala' and 'Larissa', were predictably superior. Cultivars in this subspecies are tolerant of winter waterlogging, and were superior in yield of herbage and regeneration, with seedling densities of 500-1 200/m^2 compared to 'Mount Barker' and 'Tallarook' with only 200/m^2 (Rumball & Cooper 1990).

Dodd *et al.* (1995a) followed up their earlier work on North Island summer dry hill country by examining the persistence of 45 lines, flowering a month earlier to four days later than 'Tallarook'. Two lines and one blend from a North Island collection gave highest total herbage yield. However five lines and one Australian breeding line were significantly better at regeneration than 'Tallarook', and achieved 400 established plants/m^2 on the steep aspect country in June. False strike ranged from 2-60%. The late mid-season flowering 'Karridale' performed similarly to 'Tallarook'. Other named cultivars were inferior. Dodd *et al.* (1995c) obtained much the same result in another evaluation, recording the highest values of 400-2 000 kg/ha for total seed production of three North Island lines and an Australian breeding line-all exceeding 'Tallarook'. Buried seed, measured in March, and hence regarded as hard seed, was 21-69% of the total. An evaluation on drier pumice hill country (Dodd *et al.* 1995b) gave an almost identical result, but with the addition of 'Karridale' to the top performing lines.

At a high rainfall site (1 292 mm) in the Hokonui hills in Southland, a high seedset resulted for all cultivars in the first autumn, but no hard seed was formed, and second year regeneration was minimal (Widdup & Turner 1990). However, at Carvossa in North Canterbury, with only 657 mm average rainfall, and soils below wilting point from late November, under periodic grazing (Hoglund 1990), the highest seed yields of 68-400 seeds/m^2 were produced by the 'Trikkala' and 'Howard'. Yields were considerably less for late-flowering cultivars. Seedling numbers, however, were lower (68-285 seedlings/m^2) than seed numbers would indicate because of the high level of hardseededness (60-92%) amongst the earlier cultivars (Smetham & Wu Ying 1991). Although this figure may have been inflated by losses of seedlings from insect predation and false strike, Smetham (1980) also measured high levels of hardseededness (70-80%) from a similar dry North Canterbury hill country site near Culverden in each of two years. At this site, 'Seaton Park' was superior, but early flowering 'Geraldton' and 'Northam A', and 'Woogenellup' all set adequate to large amounts of seed (2 000 - 8 000 seeds/m^2 or 130-450 kg/ha). In spite of high hardseed, adequate to high numbers of seedlings (240-2 500/ m^2) were evident in late autumn. On similar country near Waipara in North Canterbury, Scott (1969) also found 'Geraldton' gave the highest seed yields

Table 4 Australian cultivars of subterranean clover, grouped according to the date of start of flowering, together with current status in New South Wales, and where not recommended, the main reason for relegation, and the recommended replacement (after Dear & Sandral 1997).

Flowering Group	Cultivar	Status/reason for relegation	Replacement
Early	Nungarin	Recommended	
	Dwalganup	High oestrogen	Nungarin
	Geraldton	High oestrogen	Nungarin
	Northam	Outclassed	Nungarin; Dalkeith
	Dalkeith	Recommended	
	Daliak	Aphid prone	Dalkeith
Early mid-season	Seaton Park LF	Recommended	
	York	Recommended	
	Yarloop	High oestrogen	Trikkala
	Dinninup	High oestrogen	Riverina
	Howard	High oestrogen	Woogenellup
Mid-season	Trikkala	Recommended	
	Riverina		
	Rosedale	Recommended	
	Esperance	Recommended	
	Junee	Outclassed	
	Woogenellup	Recommended	Junee; Riverina
	Enfield	Root disease prone	Junee; Riverina
	Green Range	Low hardseededness	Junee; Riverina
	Bacchus Marsh	Leaf disease prone	Denmark
Late mid-season	Gosse	Recommended	
	Goulburn	Recommended	
	Denmark	Recommended	
	Clare	Recommended	
	Mt Barker	Leaf and root disease prone	Denmark; Leura
	Karridale	Outclassed	Denmark
Late	Leura	Recommended	
	Larisa	Outclassed	Gosse
	Meteora	Outclassed	Gosse
	Tallarook	High oestrogen	Leura

although 'Woogenellup' and the mid-season flowering subspecies *Ts. brachycalycinum '*Clare' produced over 500 kg/ha seed. 'Mt Barker' and 'Tallarook' had much lower seed yields. Predictably the highest herbage yield was from cultivars that grew long enough to exploit available moisture until its disappearance. Thus, 'Geraldton' dried off too soon.

Recently, Widdup & Pennell (2000) evaluated a large number of mid to late flowering lines including 15 Australian cultivars covering the full range of flowering time, and the latest cultivars to be released. The evaluation occurred in a 650 mm average annual rainfall area near Christchurch. In the first year, with higher than average spring and summer rainfall, most lines including mid-season flowering 'Junee', late mid-season flowering 'Goulburn', and 'Karridale', set large amounts of seed ranging from 350-600 kg/ha, confirming as reported, that moisture was adequate well into the summer. This also resulted in low levels of hard seed (19-28%). Regeneration in later years of this evaluation however was poor, except for the late flowering, small leaved and prostrate cultivars 'Denmark' and 'Leura', and one selection from the North Island which established 50% more seedlings and gave 25% more herbage than 'Mount Barker' or 'Tallarook'. Almost as good were the Sardinian ecotypes, one prostrate Whatawhata line and 'Junee'. However in the succeeding drier years with only half the average spring and summer rainfall, mid-season flowering lines including 'Junee' were best. An evaluation on a shallow Templeton soil near Lincoln in Canterbury (Smetham *et al.* 1993) where soil moisture drops below wilting point in mid November until sometime in March, supported the idea that early or early mid-season flowering lines are required under drier conditions. Measurements made 4 years after sowing on periodically heavily grazed plots of 42 early to late flowering accessions and five Australian cultivars showed that 22 lines produced seed reserves greater than 250 kg/ha. These lines, including 'Geraldton', were all in the early, or early mid-season flowering groups.

Lines and cultivars flowering later, including 'Seaton Park' and 'Tallarook' averaged only around 80 kg/ha seed. Thirty-seven lines had hardseededness exceeding 50%. However there were 11 lines which produced both seed reserves of 250 kg/ha or more and at least 1 000 seedlings/m^2.

Because of the variable nature of the New Zealand climate, a subsequent comparison at a nearby site in 1993 (Smetham *et al.* 1994) gave a very different result. This was because May, June and July experienced less than half normal rainfall, September was very wet with 133 mm instead of the normal 50 mm rainfall, October very dry with only 9 mm rainfall, and November rainfall was 90 mm or nearly twice normal. As a result, early and early mid-season flowering cultivars failed to recover after the October drought and set little seed. However, four mid-season accessions produced 97-184 kg/ha seed, and two late flowering numbered accessions produced the highest seedset of 216-270 kg/ha. The eight most successful lines, which included 'Tallarook', were characterised by the ability to 'kick-on', or recommence flowering after drought, that was strongly correlated with seed yield ($r = 0.65$ $P<0.01$). Scott (1985) has recorded high levels of seed production from subterranean clovers on shallow dry soils in the Mackenzie Basin, but subsequent performance was not recorded.

High levels of germinable seed in autumn

The seed of all varieties of subterranean clover can possess high to very high (50-90%) levels of hardseededness at early maturity (Tables 2 & 3) if conditions are sufficiently dry such that seeds dry to less than 5–7% moisture during maturation (Quinliven 1971). This mechanism prevents seed from germinating with rain in summer only to die in dry conditions thereafter.

Hard seed is unable to germinate because of an inability to imbibe water. Hardseededness declines with time (Quinliven & Millington 1962), depending on variety and the diurnal amplitude of temperature fluctuation (Table 3). In most areas of subterranean clover use in Australia, under a temperature regime of high day temperatures of 40–50 °C and a diurnal variation of >15 °C, hardseededness declines by autumn to allow germination of 50% (early flowering varieties) and 95% (late flowering varieties) (Table 3). In New Zealand such temperatures can occur (Sheath & Boom 1985b) but are unusual and hardseededness declines more slowly (Smetham & Wu Ying 1991) as a result of lower maximum temperatures and a low diurnal variation. High levels of hardseededness in naturally produced seed, ranging from 70–72% in 'Woogenellup' and 'Seaton Park', to nearly 80% for 'Northam A' and 'Geraldton' have been reported from hot dry North Canterbury (Smetham 1980) resulting in low autumn germination of 21–23%. Hardseededness is required initially at and after seed maturation, since premature germination in summer rains followed by dry conditions can cause heavy seed and seedling losses (Macfarlane & Sheath 1984; Sheath & Macfarlane 1990b; Dodd *et al.*1995c). Hardseededness is accentuated with earlier flowering lines because they mature seed under increasingly dry conditions and hence seed possesses greater hardseededness. There is no current solution to this problem, although selection for a faster rate of breakdown under cooler conditions is possible. Success with selection should be assured since considerable variation exists within ecotypes (Smith *et al*. 1996). An alternative approach is to select for very high seed production, because adequate seed will germinate subsequently even though hardseededness is high (Smetham *et al*. 1993).

Future research with subterranean clover

A priority for future subterranean clover research is to find suitable cultivars for the drier parts of New Zealand. Whilst suitable cultivars can be recommended for the North Island hill country in Zone 2 in Figure 1 (perhaps 2.2 M ha), no findings are available for the balance of this zone (perhaps 2 M ha) in the South Island. There remains concern for Zone 3 (2.32 M ha) and no work in depth has been conducted in Zone 4 (0.53 M ha). The latter two areas total 2.85 M ha, which approximates the 2.7 M ha estimate by Maunder (1971) of land with a "slight to considerable deficit", and equates to more than 10% of New Zealand's total land area. Some of this land is already supporting swards with subterranean clover as a constituent, but much of this area is supporting no more than an ephemeral mix of annual clovers and grasses with an annual productivity of less than 1 000 kg DM/ha (Smetham & Jack 1995).

Lines chosen for testing should come from areas identified as having climates as similar as possible to those where they will be used in New Zealand. To do this, climate classification and matching tools (e.g. Russell & Moore 1970) should be used to indicate which parts of the Old World might provide suitable germplasm. This will enable an approach to be made to the Australian *Trifolium* Genetic Resource Centre at Perth, since it is highly likely that material from such areas will already be catalogued and available.

The second priority must be selection for a rapid decline of hardseededness to achieve 60% or greater germination by 30 March, or the selection of lines with very high levels of seed production.

In the future, testing of accessions must be done in the areas where these will be used. A good model of testing procedure is that of the Australian National Subterranean Clover Improvement Programme system (Collins 1987) where initial screening is done at base, with subsequent general evaluation of many lines being done in areas of potential use before a few final selections are subjected to more detailed testing.

To enable both the interpretation of research findings and the extension of results to practice it is essential that in future the moisture regime during trials is adequately documented, ideally recording daily rainfall and evapotranspiration to enable soil water budgets to be calculated.

Conclusions

Herbage production

- Introduction of subterranean clover has been shown to more than double production from unimproved sunny aspect North Island hill country, and more than quadruple that from unimproved dryland in the South Island.
- The contribution from subterranean clover in existing pastures could be increased by greater attention to management.
- Subterranean clover has the ability to grow substantially faster than lucerne and perennial grasses in winter and early spring.

Choice of cultivar

- For North Island hill country with low effective rainfall, 'Karridale' with 'Denmark' or 'Leura' are recommended.
- On gumland soils with wet, poorly drained conditions over winter 'Trikkala' and 'Gosse' are recommended.
- On Canterbury hill and similar country with 600-700mm annual rainfall (Zone 3, Figure 1) 'Seaton Park LF' (low oestrogen) and 'Junee' are recommended.
- For flat to rolling country with deep soils in Zone 3, 'Denmark' or 'Leura' should be used with either 'Goulburn' or 'Junee'.
- For shallow soils in Zone 3, where moisture disappears early in the season 'Seaton Park' and 'Riverina' may be suitable.
- There is insufficient data on which to base recommendations for the driest areas of the South Island (Zone 4).

Management Issues

- Sowing at least 9 kg/ha of seed, and avoiding close grazing during autumn establishment and early winter growth are required to promote herbage yield and adequate annual reseeding.
- Subterranean clover grown as a pure sward has been shown to produce a yield equal to that from a grass-clover sward.
- The use of current recommended cultivars may be associated with the retention of high levels of hardseededness in autumn, leading to sub-optimal seedling populations.
- Future research priorities are firstly the selection of germplasm with a faster rate of decline in hardseededness under New Zealand conditions, and secondly the identification of cultivars suitable for the driest areas of the South Island.

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