Response to selection for increased taproot diameter

D.R. WOODFIELD, J.R. CARADUS, G.R. COUSINS and T. DUNN
AgResearch Grasslands, Private Bag 11008, Palmerston North

Abstract

Increased taproot diameter is an important component in maintaining white clover (*Trifolium repens* L.) growth, nitrogen fixation and persistence during short-term moisture stress. Previous reports indicated selection for large taproot diameter would result in commensurate increases in leaf size and poorer growth habit. The current research investigates the response to selection for taproot diameter and the association between taproot diameter and leaf size in large-leaved clovers suited to dairy grazing systems. Taproot diameter increased by 2.4% per cycle while leaf size and growth habit were not significantly altered. Furthermore, while taproot diameter did not increase between cycle 2 and 3, the root index which measures the ratio of taproot diameter to leaf size increased linearly across all three cycles. These results suggest it is possible to select white clovers for dairying which have larger taproot diameter while maintaining a suitable growth habit.

Keywords: dairying, drought, genetic improvement, root morphology, *Trifolium repens* L., white clover,

Introduction

Summer soil moisture deficits reduce white clover productivity, nitrogen fixation, and limit the quality of forage on offer to livestock. This can occur even in higher rainfall areas, such as the dairying areas of the Waikato, Northland and Manawatu (Kerr et al. 1986). One approach used to improve the performance of white clover has been to select for root characteristics which could increase the depth of root penetration. This is a drought avoidance strategy since plants rely on accessing soil moisture from deeper in the soil profile (O'Toole & Bland 1987). Increased taproot diameter has been identified as a key component in providing a deeper root system, and has already provided small improvements in clover yield and persistence under sheep grazing in drought-prone environments (van den Bosch et al. 1993; Woodfield 1994).

White clover cultivars suited to grazing by dairy cows tend to have larger leaves, more erect habit, and larger taproot diameters, but also have less desirable traits such as lower stolon densities and more open habits than clovers suited to sheep grazed systems. In previous studies increases in taproot diameter have been accompanied by a concomitant increase in leaf size, leading to a less desirable growth habit (Caradus 1977; Caradus & Woodfield 1986; Woodfield & Caradus 1990). The objectives of this work were to determine whether the correlation between taproot diameter and leaf size could be broken and to evaluate the rate of genetic improvement when selecting solely for taproot diameter, and hence to provide clovers with better adaptation to short-term moisture stress encountered in dairy pastures.

Materials and methods

Selection for taproot diameter was initiated within a base population consisting of four large-leaved cultivars (Aran, Dusi, SC-1, and Titan) and a medium-leaved cultivar (Grasslands Huia). The origin and characteristics of these cultivars are detailed in Caradus (1986). The first cycle of selection was done in 1989, the second cycle in 1991 and the third cycle in 1992. Seed of each successive generation were sown in trays of potting mix and grown for 10 to 14 weeks prior to measurement of taproot diameter. Taproot diameter was measured, 2 mm below the crown, using vernier calipers and selections made solely on the basis of taproot diameter. The number of plants selected for crossing to form the next generation varied depending on the number of plants evaluated in each cycle, but the overall selection intensity ranged between 9 and 16% (Table 1).

Table 1: Selection intensity, number of plants evaluated per cycle of selection, and the mean leaflet width, taproot diameter and number of stolons for each cycle of selection.

Cycle of Selection	Selection Intensity (%)	Plants Evaluated (no. cycle^{-1})	Leaflet Width (mm)	Taproot Diameter (mm)	Number of Stolons
0	16	189	23.1	2.80	5.5
1	9	186	22.9	2.88	5.1
2	10	171	23.7	3.05	5.4
3	9	189	22.4	2.98	5.3
P (<0.05)	–	–	NS	*	NS
Genetic gain (% cycle^{-1})		–	-0.5	2.4	-0.8
r^2 (%)	–	–	9	69	10

Response to selection for taproot diameter was evaluated by sowing equal progeny numbers of the base population and each of the three selection cycles. The base population (cycle 0) was reconstructed by bulking equal quantities of seed from each the five original cultivars, while each cycle of selection was represented by a balanced bulk of seed from all parents selected and intermated from the previous generation. The four lines were sown into trays containing potting mix in a randomised complete block design with 24 replicates on 22 June 1993. Individual experimental units consisted of 8 seedlings of a particular cycle of selection. While 192 seedlings per cycle were sown, death reduced final plant numbers to between 171 and 189 (Table 1). Taproot diameter (mm), width (mm) of the first fully expanded leaf on the longest stolon, and the number of primary stolons were measured on all seedlings 10 weeks after sowing. A root index (taproot diameter/leaf width) was calculated to look at the relationship between these traits over cycles of selection. Analyses of variance were performed using SAS Proc GLM. Regression analyses were done for each of the traits using the means for each cycle of selection to estimate the response to selection. The slope of the regression line was divided by the grand mean for each trait to determine the genetic gain per cycle of selection.

Results and discussion

Selection for increased taproot diameter was successful despite beginning with a base population of cultivars known to already have large taproot diameters. Taproot diameter increased by 9% in the first 2 selection cycles but did not increase between cycles 2 and 3 (Table 1). Over all three cycles, the genetic gain in taproot diameter averaged 2.4% per cycle (Table 1). In other plant species increased taproot diameters are associated with deeper penetrating root systems, better soil moisture extraction patterns, and improved drought tolerance (Sponchiado et al. 1989; O'Toole & Bland 1989; Loresto et al. 1983).

White clover seedling taproots can remain fully functional for more than 2 years in drier environments (Westbrooks & Tesar 1957; Kilpatrick & Dunn 1961), but do not generally persist more than 18 months in moister environments due to a higher prevalence of root rots and associated fungi which reduce taproot longevity (Kilpatrick & Dunn 1961; Charlton et al. 1989). In moister environments seedling taproots are probably less important than nodal roots as nutrients such as phosphorus, nitrogen and sulphur can be more limiting than moisture. In drier environments and in dry years, nodal root establishment is inhibited by dry surface soil and plants must rely on their seedling taproot and/or on deeper roots at older nodes to persist (Stevenson & Laidlaw 1985).

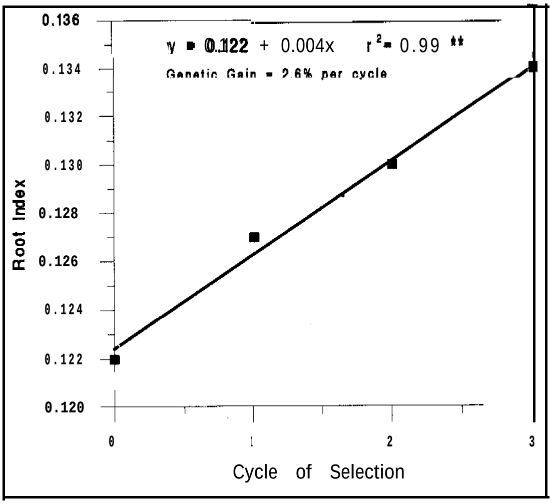
Leaf size and number of stolons did not change significantly over generations despite the increase in taproot diameter (Table 1). Strong correlations previously reported between leaf size and taproot diameter occurred in studies characterising cultivars and ecotypes with a wide range of morphology and origin (Caradus & Woodfield 1986, 1990). In this experiment the correlation between leaf size and taproot diameter was very low (r=0.18 NS), suggesting these two traits can be manipulated independently through selection. This confirms divergent selection results for taproot diameter at smaller leaf size, where a 15% difference in diameter was achieved at a common leaf size (Woodfield & Caradus 1990; Woodfield 1994). We are currently interested in what occurs at the large end of the leaf size continuum, where differences in taproot diameter were not previously achieved through divergent selection (Woodfield & Caradus 1990). While leaf size did not change in this population it is unlikely that we have reached a leaf size plateau as genotypes with substantially greater leaf size were observed in each cycle.

Indirect effects on other characters frequently occur when selecting for single traits (Hallauer & Miranda 1988). While only seedling stages were observed in this experiment, the seedling stolon numbers suggest plant habit was not adversely affected by increasing taproot diameter. These selections will require evaluation under grazing to determine whether taproot diameter has adaptive significance in New Zealand dairy pastures, or has any indirect effects on other agronomic traits. This can be readily determined by comparing the advanced selection cycles against the base population.

The major success of this selection programme is the linear increase in root index over all 3 selection cycles (Figure 1). Root index, a ratio of taproot diameter to leaf size, increased in cycle 3 even though leaf size and taproot diameter did not increase *per se* (Table 1). The genetic gains of 2.4% and 2.6% per cycle for taproot diameter and root index respectively, are higher than those observed in white clover for quantitative traits such as yield (Woodfield & Caradus 1994), but are consistent with selection responses in species such as maize (Hallauer & Miranda 1988). They are also consistent with the estimated heritabilities, both broad-sense and narrow-sense, for taproot diameter which ranged from 0.25 to 0.54 (Caradus & Woodfield 1990; Woodfield & Caradus 1990).

Improving the drought tolerance of white clover, whether through better root morphology or some other mechanism, would provide a better seasonal distribution of clover yield. Drought tolerant white clover could

Figure 1: Change in root index over three cycles of selection for taproot diameter.



provide better quality forage during summer and autumn, and significantly benefit the dairy industry through higher milk yields (Rogers et al. 1982), better milk composition (Thomson et al. 1985), and better seasonal distribution of milk-supply to dairy companies. These selections will be used to determine whether taproot diameter or root index improve the drought tolerance and competitive ability of white clover in dairy grazed pastures.

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