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Comparative growth and management of white and red clovers

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The aim of this paper is to provide the underpinning scientific basis for the optimum management of white and red clovers. Critical morphological and canopy characteristics which influence the yield and persistence of white and red clover in swards, and how management factors (choice of cultivar, defoliation and nitrogen (N) fertilizer) modify these are considered. Canopy development is vitally important as it determines the extent to which a) light is intercepted for photosynthesis needed for growth and b) the base of the sward is deprived of the red component in daylight, inhibiting branching of stolons and crowns in white and red clover, respectively. The role of cultivar, defoliation and N fertilizer in determining yield and persistence of the two legumes, mainly in mixtures with grass, are discussed principally in terms of morphological development and exploitation of light. It is concluded that optimum management for grass/white clover places emphasis on building up stolons and maximising contribution of clover leaf area to the upper layers of the mixed canopy and, while red clover is more competitive to grass than white clover, that benefit is lost when a grass/red clover sward is grazed.

Keywords: growth habit; light interception; management factors; *Trifolium pratense*; *Trifolium repens*

Introduction

White clover (*Trifolium repens* L.) and red clover (*T. pratense* L.) can offer considerable benefits in livestock systems in Ireland. Both legumes provide forage high in protein and digestibility which facilitates high intake by animals. They also fix atmospheric N in symbiosis with root nodule bacteria (rhizobia), allowing a reduction in the use of N fertilizer. A general N fixation rate for forage legumes has been summarised at about 25 kg/t of dry matter (DM) yield (Peoples and Baldock, 2001). Thus, for swards with a high red clover

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content (e.g., 75% of 12 t DM ha^{-1} $year^{-1}$), annual N fixation would be expected to be in excess of 200 kg/ha. Estimates of the contribution of white clover to the N economy of swards, i.e. over and above the contribution of soil mineral N, are generally in the region 40 to 60 kg/t clover DM (Laidlaw, 1988; Elgersma, Schleper and Nassiri, 2000). Studies from UK and Ireland showed that the amount of N fixed by white clover growing in a sward with ryegrass (*Lolium perenne* L.) ranged from 30 to 170 kg/ha per year (e.g. McNeill and Wood, 1990)

White clover is the most common forage legume in Ireland. It is typically grown in swards with a companion grass, usually ryegrass, and grazed by sheep or cattle. Grass/white clover swards may persist for several years, but reliability of white clover is a key concern. The contribution of white clover to total pasture yield and quality can be modified by the cultivar used and is strongly influenced by grazing management and N fertilizer application.

Red clover is usually utilised in short-term stands of up to 3 years with declining yields usually after 2 full harvest years, so maintaining yield in and beyond the third year is a key management objective. Red clover is grown typically with a grass, usually perennial ryegrass, Italian ryegrass (*L. multiflorum* Lam.), or a hybrid of these two, but it may also be grown as a monoculture. Grass/red clover swards are mainly cut for conservation as silage, but they are often grazed by cattle or sheep in autumn after the final cut.

The growth and management of white and red clover have been well reviewed (Frame and Newbould, 1986; Baker and Williams, 1987; Forde, Hay and Brock, 1989; Soegaard, 1994; Pederson, 1995; Taylor and Smith, 1995; Taylor and Quesenberry, 1996; Frame, Charlton and Laidlaw, 1998; Barnes *et al.*, 2003). Competitive aspects of the grass/legume association have been reviewed by Haynes (1980). Recently, reviewers have compared the persistence and regeneration mechanisms of white and red clover (Brummer and Moore, 2000) and have emphasised the importance of persistence in breeding of the two legumes (Abberton and Marshall, 2005; Taylor, 2008).

The aim of this paper is to provide the underpinning scientific basis for the optimum management of white and red clover. As the former is always, and the latter is mainly, grown with a companion grass, the relationship between each legume and grass will also be considered. Although some aspects of the growth and development of white and red clover are specific to conditions in UK and Ireland, principles established in other temperate regions, such as parts of New Zealand and Australia, are generally applicable here.

Growth habit

The growth habits of white and red clover have several important differences that confer different levels of grazing tolerance. This is the main factor determining how the two legumes are used in pastures. White clover is able to supply N and high quality forage to swards grazed by ruminants because its stoloniferous growth habit minimises the loss of growing points (buds) during grazing. In contrast, young shoots of red clover plants are located above the soil surface, which renders them more vulnerable to grazing damage. This means that red clover is normally used to supply N and increase the quality of swards cut for conservation as silage.

White clover and red clover have in common a segmental morphology, which is visible in the stems of both species (Figure 1). Each stem is made up of chains

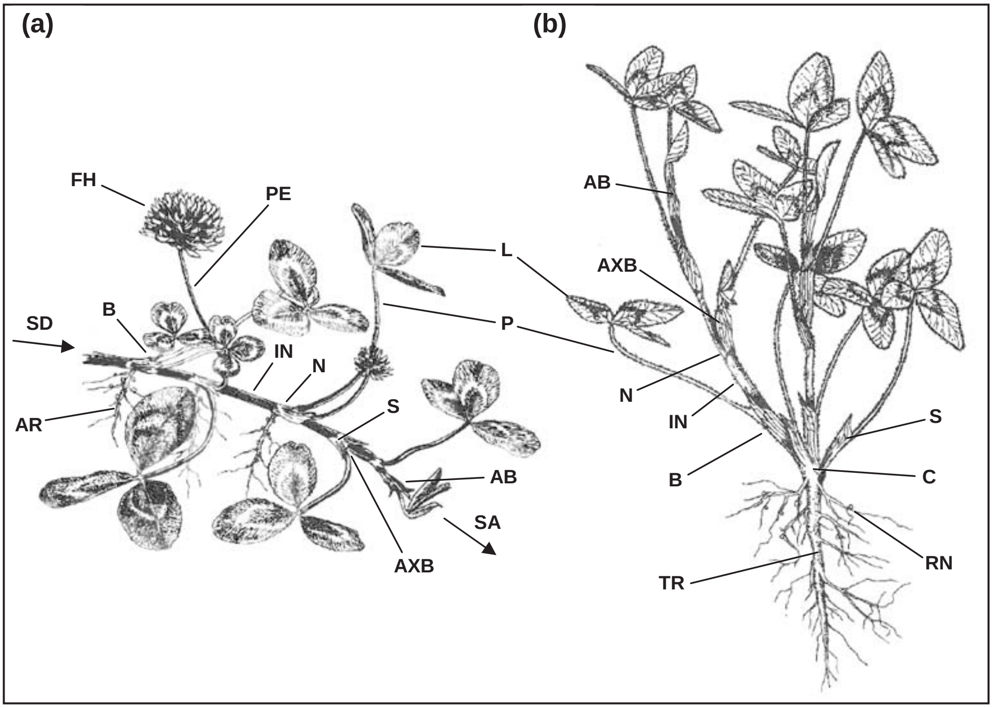

Figure 1. Morphology of (a) white clover and (b) red clover (adapted from Frame et al., 1998). AB = apical bud, AR = adventitious root, AXB = axillary bud, B = branch, C = crown, FH = flower head (inflorescence), IN = internode, L = leaflet lamina, N = node, P = petiole, PE = peduncle, RN = root nodule (contains rhizobia), S = stipule, SA = stolon advance, SD = stolon death, TR = taproot.

of segments (phytomers). New segments are formed at the apical bud at the tip of the stem. Each segment has a node, which comprises a leaf, petiole and an axillary bud, and an internode. Axillary buds are capable of forming roots, a flower or a branch stem. Each segment goes through a similar life cycle: as one segment grows old and dies, it is replaced by a new segment. Segmental morphology enables repeated harvest and regrowth of leaves and petioles. The arrangement of these segments differs markedly between the two legumes because of their different growth habits.

White clover has a 'stoloniferous' growth habit and an adventitious root system (Baker and Williams, 1987; Frame *et al.*, 1998). The seedling forms a taproot at an early stage, but this dies after about 2 years (Brock *et al.*, 2000). Once the seedling produces five or six leaves, axillary buds on the primary stem start to develop branch stems which subsequently form into stolons that grow along the soil surface (Figure 1a). The primary stem stops growing after it produces about 10 leaves so further growth is from the stolons. Leaves, petioles and adventitious roots are formed at nodes along the length of the stolons. Eventually old segments die and stolons become isolated from the parent plant. These stolon fragments then become independent plants and can branch to form new stolons. Old stolon segments continue to die as new segments are formed. This means that white clover is self-replacing and is sometimes referred to as having a 'clonal' growth habit. Flower heads usually form intermittently along the stolon, but several vegetative buds are spread between the flower heads and the apical buds remain vegetative.

In contrast to the clonal growth habit and shallow adventitious root system of white clover, red clover typically has an erect growth habit and a deep taproot (Frame *et al.*, 1998). Red clover naturally has larger shoots and a lower shoot density than white clover. Stems are formed at growing points located on the crown on top of the taproot (Figure 1b). The seedling starts to develop branches from axillary buds on the primary stem. The primary stem stops growing at similar stages of leaf development as white clover (Thomas, 2003). Stems of red clover grow upwards from the crown and new segments are formed at the tip of the stem. Vegetative stems remain relatively short but flowering stems elongate rapidly and vertically. After a flowering stand of red clover has been harvested, almost all of the regrowth takes place from basal buds lower on the crown. The taproot system rarely survives longer that 3 or 4 years, at which point the whole plant dies. Red clover is capable of forming adventitious roots under moist conditions (Hyslop *et al.*, 1996; Thomas, 2003), but not as prolifically as white clover.

Further understanding of the growth of white and red clover in swards requires some knowledge of the canopy development of each species and their companion grass because this determines the extent to which sunlight is intercepted for photosynthesis and growth.

Interception of solar radiation and canopy development

The interception of solar radiation by the leaf canopy of a sward is the main driver of photosynthesis needed for sward growth (Hay and Porter, 2006). Photosynthetically active radiation (PAR) in sunlight is either absorbed or reflected by the first surface it contacts so if it is not intercepted by green leaves, its energy is not available for plant growth. Thus, the ability of white and red clover and their associated grasses to develop a canopy of healthy green leaves is important to maximise the yield and persistence of a sward. The development of this canopy depends on the components of plant leaf area expansion, senescence and canopy architecture.

Components of plant leaf area expansion

In swards, the leaf area of a plant at a given time is determined by rates of 1) leaf appearance, 2) leaf expansion and 3) branching or tillering.

Leaf appearance: The rate of leaf appearance on stems of clover and grass plants depends mainly on temperature. The linear relationship between rate of leaf appearance from a stem and temperature between the base and optimum cardinal temperatures for plant development means that the process can be quantified by a single phyllochron in thermal time (Hay and Porter, 2006). A base temperature of 0 to 5 °C and an optimum of about 25 °C are appropriate for leaf and stem development in most temperate pasture species (Moot *et al.*, 2000; Black, Moot and Lucas, 2006). The phyllochron of white clover is shorter than red clover, but is similar to perennial ryegrass, and the phyllochrons of white clover and ryegrass are consistent across environments where water and nutrients are not limiting (Table 1). Arnott and Ryle (1982) recorded the leaf appearance of establishing white and

Table 1. Phyllochron (°C days/leaf) for primary stems and time to appearance of the first axillary leaf (°C days after sowing) for white clover, red clover and perennial ryegrass after an autumn sowing in Co. Meath, Ireland and for white clover and perennial ryegrass grown at different temperatures in controlled environments

	Autumn sowing[1]		Controlled environments[2]	
Species	Phyllochron	Axillary leaf	Phyllochron	Axillary leaf
White clover	105	551	94	532
Red clover	127	623	–	–
Perennial ryegrass	93	335	101	373

[1] Black and O'Kiely, 2007.
[2] Black *et al*., 2006.

red clover plants under a range of environmental conditions (day temperatures of 15 to 20 °C and night temperatures of 10 to 15 °C). The average rate of appearance of successive leaves for white clover was slightly faster than that for red clover (5.0 compared with 5.7 days per leaf, respectively). Thus, white clover and ryegrass produce leaves from a stem at a faster rate than red clover.

Leaf expansion: The rate of expansion of leaves after appearance (grasses) or unfolding (clovers) affects the rate of increase of leaf area. Arnott and Ryle (1982) showed that the duration of expansion of individual leaves was shorter in establishing white clover than red clover under the same environmental conditions. Leaves of white clover took an average of 10.4 days to reach full expansion from appearance compared with 12.1 days for leaves of red clover. However, the maximum area of a single leaf was about three times greater for red than white clover. Increasing the day-time temperature from 15 to 20 °C and night-time temperature from 10 to 15 °C, reduced the duration of leaf expansion by 1.6 days for white clover and 1.1 days for red clover, but increased final leaf area due to the positive effect of temperature on rate of leaf area expansion.

The rate of leaf production of white clover relative to that of the accompanying grass is important in determining their relative competitiveness in swards. In summer, the rate of petiole extension in white clover is as fast as lamina and sheath expansion in vegetative perennial ryegrass and so many of the laminae of white clover are able to be positioned favourably in the canopy. However, as petiole extension in white clover is more sensitive to temperature than leaf and sheath expansion in perennial ryegrass, the leaves of white clover are deeper in the canopy in winter than in summer and so are less able to compete for light within the mixed canopy (Woledge, Davidson and Tewson, 1989).

Branching: The segmental structure of white and red clover (and grass) allows for the development of secondary stems at each node. This increases the potential of individual plants to generate leaf area after sowing and defoliation (Hay and Porter, 2006). The extent of branching (tillering) may differ greatly between pasture species and, because branching is related to the phyllochron, these differences may be quantified in thermal time. After sowing, the appearance of the first axillary leaf in seedlings, which marks the start of branching, occurs in perennial ryegrass before it does in white or red clover, and is independent of site when quantified in thermal time (Table 1). This advantage allows perennial ryegrass to rapidly increase its leaf area after sowing to intercept light for photosynthesis and

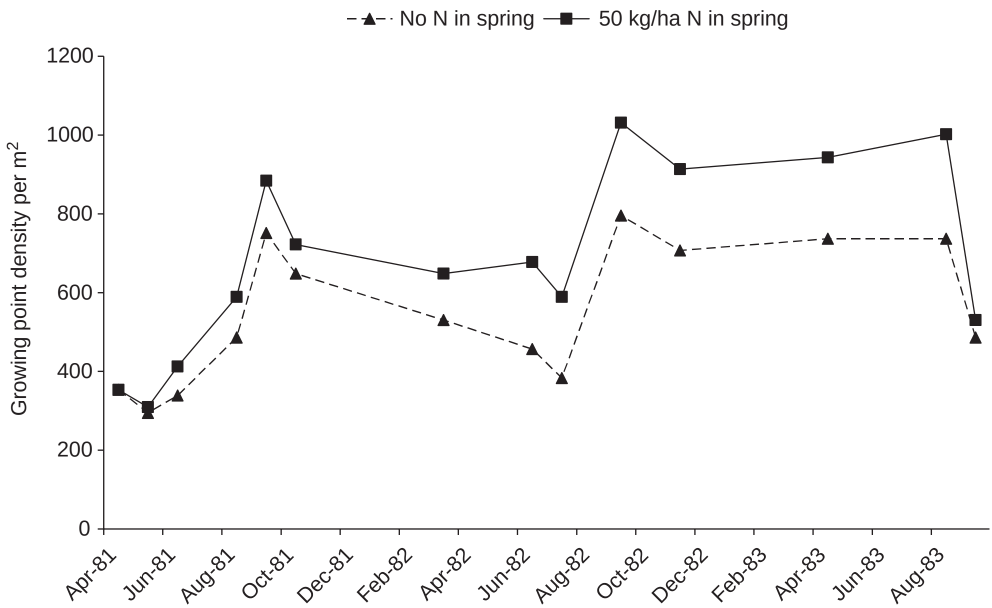

Figure 2. Stolon growing point density of white clover (excluding stolon buds) in rotationally grazed grass/clover swards receiving either no N fertilizer or 50 kg N/ha in spring in three consecutive years (Laidlaw and Stewart, 1987).

growth, thereby making it more competitive towards slower establishing species such as white clover (Black *et al.*, 2006).

In established swards, the high potential for branching in perennial ryegrass means that its tiller density is usually higher (e.g., 35 000/m^2; Jones, Collett and Brown, 1982) than the stolon density of white clover (e.g., 600/m^2; Laidlaw and Stewart, 1987). Because branching is highly influenced by temperature, defoliation, mineral nutrition and inter-plant competition, growing point density may vary greatly over time. For example, stolon growing point density of white clover varied from about 300 to 1000/m^2 over three consecutive years in a rotationally grazed grass/clover sward in the UK (Laidlaw and Stewart, 1987).

Quantitative information on the branching of red clover in swards is limited. However, its shoot density is generally lower compared with white clover, which is linked to the larger leaf area per shoot in red clover.

In dense swards, the light environment affects branching of clover and grass plants through changes in light quality with depth in the canopy. Daylight is a spectrum of wavelengths and the ratio of two of these wavelengths, red (660 nm):far red (730 nm), influences branching by its action on the plant protein phytochrome (Hay and Porter, 2006). In daylight, the red:far-red ratio is about 1.2, which triggers branching. More red light is intercepted for photosynthesis with increasing depth in the canopy. However, because leaves are transparent to far red light the red:far-red ratio declines and branching at the base of the sward is inhibited. Thus, changes in sward structure resulting from defoliation, N fertilizer or death of individual plants can alter the light environment and further influence branching.

Table 2. Growth and senescence of perennial ryegrass leaves (mm/day per tiller) and white clover laminae (cm^2/day per stolon) in grass/white clover swards continuously stocked with steers at a low and high stocking rate[1]

Year	Growth/senescence	Perennial ryegrass		White clover	
		Low stocking	High stocking	Low stocking	High stocking
1	Growth	7.8	6.4	0.30	0.30
	Senescence	5.3	4.0	0.10	0.03
	Senescence:Growth	0.67	0.63	0.33	0.10
2	Growth	6.7	5.1	0.44	0.33
	Senescence	3.8	3.0	0.08	0.03
	Senescence:Growth	0.57	0.59	0.18	0.09
3	Growth	7.9	8.0	0.46	0.45
	Senescence	5.1	4.6	0.09	0.10
	Senescence:Growth	0.65	0.58	0.20	0.22

[1] Laidlaw and Steen, 1989.

Leaf senescence

The lifespan (appearance to senescence or death) of leaves in all pasture species is genetically programmed. The regular pattern of leaf appearance, expansion and senescence means there are usually three green leaves on a perennial ryegrass tiller at any one time; as the fourth leaf is being produced, the first leaf appeared is senescing.

In frequently grazed swards, the senescence:growth ratio of leaf laminae is much lower in white clover than grass because most leaves of white clover are grazed before they die whereas parts of grass laminae remain after defoliation (Laidlaw and Steen, 1989). Thus, the lifespan of a white clover leaf seems to be less important in continuously stocked swards than in swards rotationally grazed infrequently.

For red clover, each stem carries four to six green leaves during vegetative development (Arnott and Ryle, 1982), but this may be higher on flowering stems.

Leaf area index and canopy architecture

The canopy characteristics that are important for determining interception of solar radiation are leaf area index and canopy architecture. Leaf area index (LAI) is the unit area of leaf per unit area of ground it covers. It continues to form after defoliation until the canopy intercepts about 95% of available light when the critical LAI is reached. In monocultures, this is about 3 to 3.5 for the two legumes at vegetative stages and about 5 for flowering red clover (Joggi, Hofer and Nösberger, 1983). However, a grass/white clover sward will have a critical LAI of about 4 to 6 (Brougham, 1958).

Canopy architecture refers to the position and angle of leaves within a canopy. Leaves of both legumes are folded early in development, and then are raised by the petiole to be close to the top of the canopy where they unfold to be displayed almost horizontally. During flowering in red clover, young leaves are further extended to the upper layers of the canopy by extension of internodes on a reproductive stem. Most light is intercepted by young leaves in the upper part of the canopy with little getting onto older, lower leaves, causing these to senesce.

White clover leaves are almost horizontal while grass leaves tend to be more vertical, so in swards light interception by the two components differs, particularly in the upper layers of the canopy.

This means that leaves of white clover are in a favourable position at the top of the canopy to intercept a high proportion of the available light (Figure 3, Laidlaw and Withers, 1997). For red clover, the distribution of leaf area within the canopy is greatest in the intermediate layers for both vegetative and reproductive stands (Figure 4, Joggi *et al.*, 1983).

Effects of management factors

So far the focus has been on the critical morphological and canopy characteristics of white and red clovers which influence their yield and persistence, and on how the development of their leaf canopy is regulated by grass competition and environmental factors (mainly solar radiation and temperature). In this section, the focus is on how management factors (choice of cultivar, defoliation and N fertilizer) regulate the yield and persistence of the two legumes, principally in terms of morphological development and exploitation of light in swards with grass.

Cultivar and defoliation

The effects of cultivar and defoliation on the yield and persistence of white and red clover are intrinsically linked so they can be considered together.

White clover: White clover is usually classified according to leaf size, with small-leaved cultivars considered suitable for continuous sheep grazing, medium leaf types for rotational grazing and large-leaved cultivars mainly for lax cattle grazing or conservation. Small-leaved cultivars have a high stolon density and larger-leaved cultivars typically have a low stolon density (Wilman and Asiegbu, 1982; Swift *et al.*, 1992; Caradus, Hay and Woodfield, 1996; Brock and Hay, 1996; Department of Agriculture and Rural Development, 2008).

The relationship between cultivar morphology and grazing management in white clover is an example of 'size density compensation' (i.e., the inverse relationship between leaf size and stolon growing point density). Plant breeders have exploited this relationship to develop cultivars which are suited to different defoliation regimes. Each cultivar also retains an inbuilt plasticity that allows a certain level of morphological adaptation to changes in defoliation in an attempt to maintain its LAI to intercept light at different levels of herbage mass. For example, as grazing frequency and intensity increase, white clover responds by producing smaller leaves, shorter petioles and shorter and thinner stolons which increases the stolon growing point density (Carlson, 1966; King, Lamb and McGregor, 1978).

However, the potential of white clover to compensate to changes in defoliation differs markedly between cultivars. For example, a comparison of different cultivars under rotational and continuous stocking by sheep in New Zealand (Brock, 1988) showed that a small-leaved cultivar (cv. Tahora) down sized sufficiently to survive the continuous stocking and clover content increased (Table 3). In contrast, a large-leaved cultivar (cv. Kopu) that was continuously stocked had a lower number of leaves per growing point, causing stolon mass and clover content to decline. Thus, selection of the right cultivar is important and depends on the grazing system (Brock and Hay, 1996; Brock and Tilbrook, 2000; Brock, Hyslop and Widdup, 2003). This concurs with the inverse relationship between leaf size and persistence of white clover cultivars on the current recommended list for Northern Ireland (Figure 5).

The physiological process that enables white clover to compensate for changes

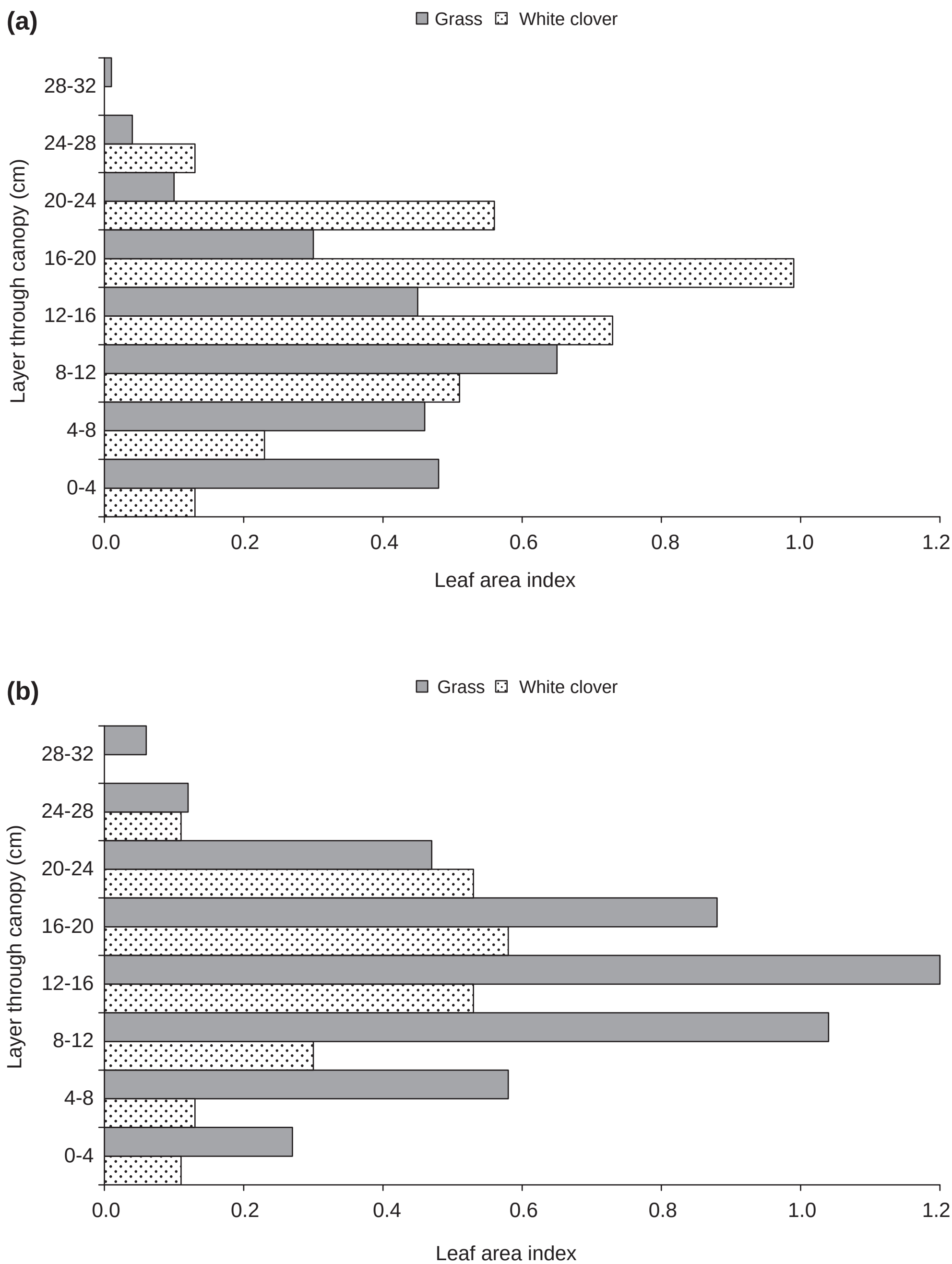

Figure 3. Leaf area index of grass and white clover in mixture, 50 days after defoliation, in 4 cm layers through the canopy from ground level, with (a) no N fertilizer and (b) N fertiliser input of 100 kg/ha at the beginning of regrowth (Laidlaw and Withers, 1997).

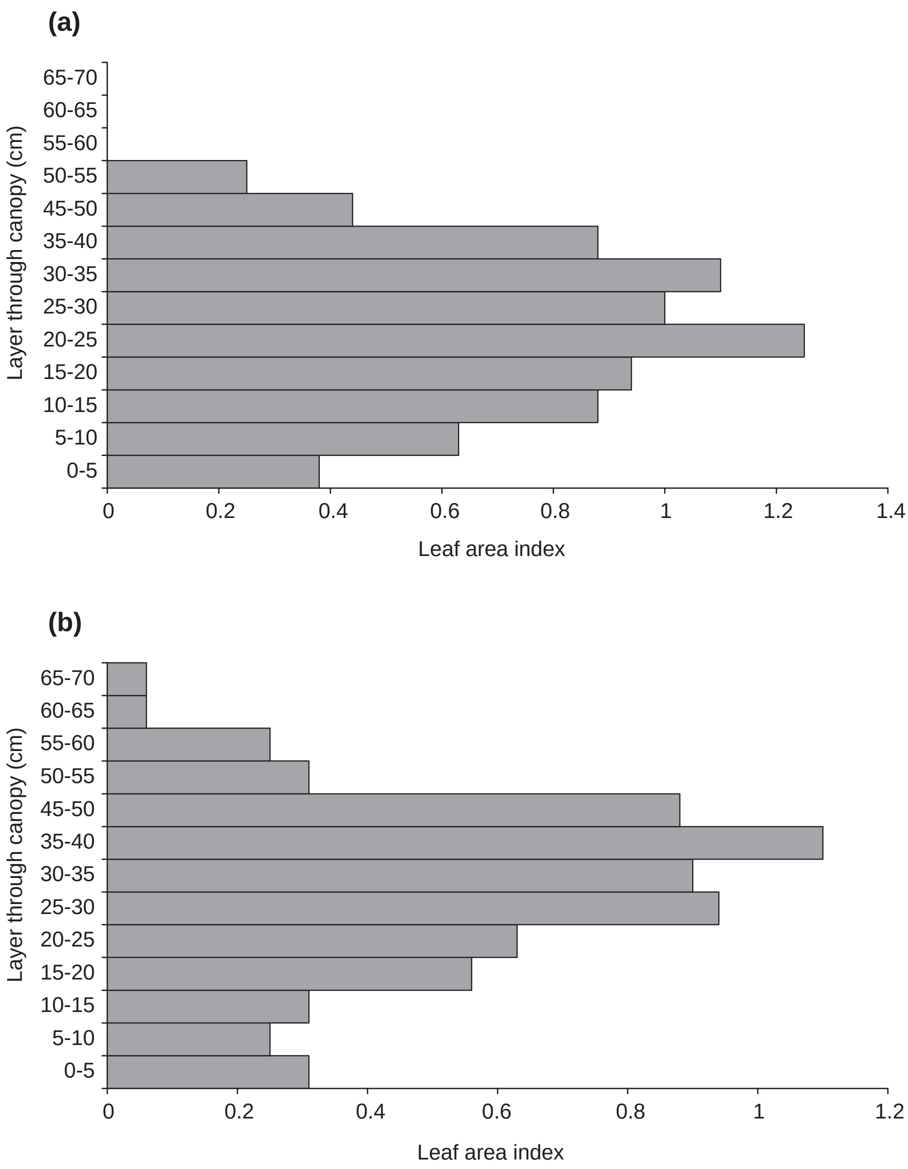

Figure 4. Leaf area index of (a) vegetative and (b) reproductive red clover in 4 cm layers through the canopy from ground level, 79 days after sowing (Joggi et al., 1983).

in defoliation is related to the red:far red ratio of sunlight. Stolons readily branch under full sunlight such as in a very open sward. In the later stages of sward regrowth, mainly far-red light reaches the stolons, reducing the red:far red ratio to 0.1 to 0.3 which inhibits branching (Robin *et al.*, 1994). After defoliation, daylight again reaches stolon growing points and these are activated to form new stolon branches. In this way, stolon density is increased on repeated close grazing. This mechanism of increasing the sites of new leaf production also provides a much more rapid increase in LAI in the early stages of regrowth than could be achieved solely by leaf appearance on existing stolon growing points, which continues at more or less a fixed rate after defoliation.

White clover grows best under conditions that allow sufficient time between defoliations for the development of sufficient LAI for optimal interception of solar radiation and therefore growth. Thus, white clover content is usually greater in swards under rotational than continuous stocking (Curll and Wilkins, 1983). Furthermore, continuous stocking at a very high grazing pressure reduces stolon branching and therefore LAI formation due to a reduction in carbohydrate concentration in stolons (Jones and Davies, 1988) which can result in a rapid decline in white clover content (Orr *et al.*, 1990). Conversely, if swards are grazed infrequently or are maintained at high herbage mass, stolon growing point density also declines because residual grass herbage shades the stolons and reduces branching, which inhibits white clover concentration (Steen and Laidlaw, 1995).

Red clover: Cultivars of red clover are usually classified by ploidy level and flowering date. Early flowering cultivars are widely grown and give two similar conservation cuts and subsequent lower-yield cut(s). Late flowering cultivars give a greater proportion of their yield at the first cut and have been considered as more grazing tolerant and persistent than early flowering cultivars (since their growing points are more numerous). Tetraploid cultivars have been viewed as more persistent and disease resistant than diploid varieties; although with modern varieties this may not hold true (Frame *et al.*, 1998).

Red clover is less able to compensate to changes in defoliation than white clover so yield and persistence decrease with increased defoliation frequency. For example, increasing the number of defoliations from 3 to 6 during the growing season in the UK reduced yield by 30% (Sheldrick, Lavender and Tewson, 1986). Under frequent close defoliation, red clover is unable to maintain LAI and plant numbers decline rapidly (Taylor and Quesenberry, 1996).

Red clover remobilises carbohydrates and N stored in its crown and taproots for regrowth. After defoliation, the phytochrome mechanism (already discussed for branching of white clover stolons) allows activation of buds at the base of the crown

Table 3. Effect of rotational grazing (RG) and continuous stocking (CS) by sheep on plant characteristics of four white clover cultivars in grass/clover swards[1]

System	Cultivar[2]	Leaf area (cm^2)	Leaves per growing point	Stolon size (g/m)	Growing points/m^2	Clover content (%)
RG	Tahora	2.09	2.90	0.48	3 750	13.3
	Huia	2.75	2.87	0.63	2 750	11.0
	Kopu	5.58	2.88	0.88	1 530	19.5
CS	Tahora	1.30	1.72	0.46	10 480	20.6
	Huia	1.15	1.71	0.56	4 720	13.1
	Kopu	1.66	1.42	0.61	1 530	7.3
s.e.		0.35	0.14	0.08	110	2.8

[1] Brock, 1988.
[2] Leaf size: Tahora = small, Huia = medium, Kopu = large.

shoots in response to changes in red:far red light. In the early stages of regrowth, bud growth is driven by stored assimilates and the first leaves produced are small so light interception and regrowth are low. As the LAI increases, carbohydrates and N are again replenished in the crown and taproots (Joggi *et al.*, 1983), provided the companion grass does not prevent red clover from claiming its share of available light. Reserves are normally accumulated in crowns and taproots during the growing season to be gradually depleted over winter (Halling, 1988). Taking more than one harvest in autumn reduces these reserves, particularly in early-flowering cultivars. This has an adverse effect on persistence and reduces yield and competitive ability at the first harvest in the following spring.

Red clover is more vulnerable to grazing than white clover due to its upright growth habit and solitary crown. Continuous stocking reduces its persistence due to removal of leaf area and growing points as well as crown damage by hoof trampling which hastens invasion by pathogens. Even with some form of lax rotational grazing, the persistence of red clover is limited to 2 or 3 years (Laidlaw, 1979; Cosgrove and Brougham, 1985; Hay, 1985; Hay and Hunt, 1989; Sheath and Hodgson, 1989; Kelly, Stockdale and Mason, 2005).

Improved grazing tolerance is now a major breeding objective for red clover (Frame *et al.*, 1998; Abberton and Marshall, 2005). In Australia, a semi-prostrate cultivar (cv. Astred), which reproduces by seed and vegetatively by stolons, has shown persistence under grazing (Smith and Bishop, 1993). In New Zealand, spreading types have shown increased persistence over crown types under fertile and moist conditions (Hyslop *et al.*, 1996; Orr and Wedderburn,

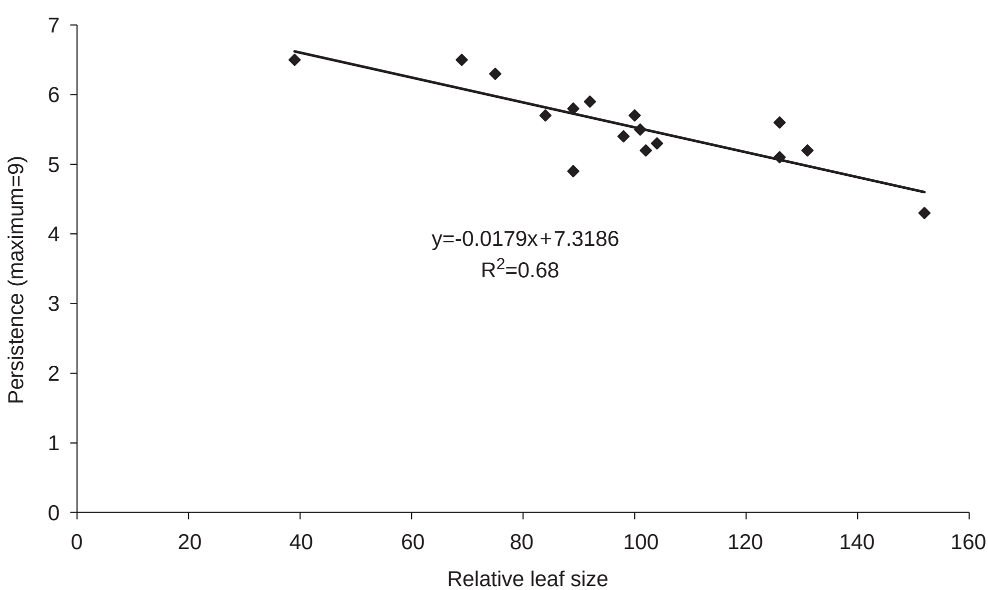

Figure 5. Relationship between leaf size (% relative to cv. Grassland Huia) and grazing persistence of white clover cultivars grown in grass/clover swards under a low N fertilizer regime (Department of Agriculture and Rural Development, 2008).

1996; Hyslop, 1999). The cultivar Astred was compared with a crown-type cultivar (cv. Pawera) under grazing frequencies of 4, 6 and 8 weeks and post-grazing heights of 5 cm and 10 cm (Hay and Ryan, 1989; Brock *et al.*, 2003). Astred had more plants remaining after 2 years under all grazing management options (Table 4).

Recently, breeding for grazing tolerance in red clover has led to new cultivars in New Zealand (Claydon, Rumball and Miller, 2003; Rumball, Keogh and Miller, 2003). Such cultivars warrant further investigation in Ireland. The expectation is that prostrate and spreading cultivars will be more grazing tolerant, but possibly lower yielding, than crown-type cultivars with erect growth forms that are typically grown for conservation. However, early provisional results from variety comparisons in Northern Ireland show some of these stoloniferous cultivars to be as high yielding in the first two harvest years as some conservation types under cutting (Department of Agriculture and Rural Development, 2008).

Nitrogen fertilizer

Nitrogen fertilizer does not adversely affect white clover growth directly but it stimulates grass growth which increases its competitiveness towards white clover. Laidlaw and Withers (1997) showed that with no N fertilizer leaves of white clover occupied a high proportion of the uppermost LAI of the canopy over a short vertical distance (Figure 3). However, with N fertiliser input of 100 kg/ha the contribution of grass LAI to the uppermost layer of the canopy increased, rather than overtopping leaves of white clover, and the share of light available to white clover declined. This results in a reduction in photosynthesis by white clover. Consequently, young stolon branches do not survive and branching is inhibited due to a declining red:far-red ratio (e.g., Figure 2, Laidlaw and Stewart, 1987). This, combined with increased grass growth, results in a decline in white clover content in the sward in response to N fertilizer.

Nitrogen fertilizer has little impact on the production of a red clover monoculture, although it may increase the weed grass component and reduce the red clover content of the stand (Frame, Harkess and Hunt, 1976). In grass/red clover swards, the effect of applying N fertilizer on the legume component is similar to that for grass/white clover swards (Frame, 1990; O’Kiely, O’Riordan and Black, 2006).

Table 4. Effects of grazing frequency (4, 6 and 8 weeks) and post-grazing height (5 and 10 cm) on persistence[1] of red clover over 18 months in Southland, New Zealand[2]

Season	Cultivar[3]	4 weeks		6 weeks		8 weeks		s.e.
		5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	
Mid-winter	Pawera	83	86	90	84	86	77	4.6
	Astred	68	78	78	90	69	87	
Summer	Pawera	67	57	74	64	61	53	6.3
	Astred	51	77	69	73	65	76	
Spring	Pawera	13	48	30	43	39	34	6.3
	Astred	26	59	52	58	47	66	

[1] Proportion of parent plants that survived.
[2] Hay and Ryan, 1989.
[3] Pawera = crown type, Astred = creeping type.

Management implications

White clover/grass swards

For white clover to make its target contribution to pasture production it needs to make a significant contribution to the upper layers of the sward canopy as early in each season as possible. To achieve this, grass growth in spring needs to be controlled so white clover can intercept its share of light for photosynthesis and to stimulate the branching of stolons at the base of the sward.

The population of functional white clover stolon growing points (i.e. those which produce harvestable leaves) follows an annual cycle rising from a low population in spring to a maximum in about late July and thereafter declining steadily through autumn into winter as older stolons die and are not replaced. In early spring, carbohydrate reserves in the stolon are at their lowest (Hay *et al.*, 1989), which means that white clover is at its most vulnerable to competition from grass. Thus, grass needs to be controlled in early-mid spring (by frequent grazing and minimizing N fertilizer application) so that daylight reaches the stolons to stimulate branching and the grass canopy is controlled to allow white clover leaves to photosynthesise and build up stolon reserves (Laidlaw, Teuber and Withers, 1992). In late autumn and winter, care is needed to avoid damage and burial of stolons during grazing, which can lead to an increase in winter-kill (Grant and Marriot, 1989; Patterson, Laidlaw and McBride, 1995).

Management should ensure that a balance is struck between grazing being sufficiently intense for light to reach stolons to stimulate branching and grazing intervals sufficiently long for leaves of white clover to claim their share of LAI in the upper canopy layer. To achieve the latter, it is important that the right choice of cultivar has been made (Table 3). Even in swards continuously stocked by sheep, white clover content can remain relatively stable from year-to-year by the use of small-leaved cultivars with a high stolon density and control of sward surface height to avoid overgrazing (Davies, Fothergill and Jones, 1991; Laidlaw, Withers and Toal, 1995; Teuber and Laidlaw, 1995). The principle of allowing sufficient time during regrowth intervals for leaves of white clover to contribute to the upper layer of the canopy also applies in a silage system (Roberts, Frame and Leaver, 1989).

During grazing the transfer of legume N to grass provides a competitive advantage to grass. Some transfer takes place irrespective of grazing due to death and decay of roots and stolons. In addition, N in herbage consumed but not utilized by the animal is returned to the sward in excreta (Ledgard, 1991). Legumes, such as white clover, receive no net gain from N fertilizer because they merely replace fixed atmospheric N with this external source of N (Armstrong *et al.*, 1999). Only the grass benefits from this additional N. Thus, a further source of pressure is exerted on white clover. Nevertheless, large-leaved cultivars can be competitive towards grass (Camlin, 1981). These complex interactions between white clover and grass make a flexible approach to management essential (Frame and Laidlaw, 1998).

Red clover/grass swards

The morphology and physiology of red clover dictates that it is primarily a forage species for conservation. It grows best between infrequent cuts which minimise damage to growing points and allow sufficient time for it to intercept light. To aid ensilage, red clover is best grown with grass (O'Kiely and Black, 2008). Unlike white clover, the canopy characteristics of red clover enable it to compete with grass during the first two regrowth intervals each year. Also, N transfer as a percentage of the total N in red clover is low compared with white clover under cutting (Frame *et al.*, 1998). This is an advantage to red clover because its contribution to the strength of grass competition is relatively low. Although there is usually a gradual increase in grass contribution year-on-year, this is due more to red clover declining independently of the grass than due to grass yield increasing.

Red clover is a short term perennial but there have been instances when it is cut three to four times per year for it to remain productive beyond its third harvest year. This is less likely if it is grazed in autumn. For the potential production of current cultivars to be realized in Ireland, management should include long regrowth intervals, e.g. 3 to 5 harvests per year. Also, its growth and competitive ability towards grass is reduced by grazing due to: damage to the crown by treading, the potential for selective grazing as the sward is open and increased availability of N to grass from excreta. Thus, the main purpose of including red clover in a seed mix for grazing is to improve yield and quality in the early life of the sward. While in the future red clover may be routinely used as a dual purpose forage, until prostrate or stoloniferous cultivars have been proven to be tolerant of grazing red clover should be confined mainly to conservation swards.

Knowledge of responses of growing point density and of production per growing point to management and environmental factors is of practical importance. Quantified information on these can form the basis of models of crop growth (Hay and Porter, 2006). These models can be incorporated into decision or management support systems such as in a grass/white clover model as part of the CloverCheck management aid system in Northern Ireland (Laidlaw, Moore and Dale, 2007). Detailed quantification of responses of red clover axes and segment production to a range of relevant management and environmental conditions in monoculture and mixture could form a starting point for such a model for red clover.

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