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MANAGING WHITE CLOVER IN MIXED SWARDS PRINCIPLES AND PRACTICE

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SUMMARY

The key to sustainable productivity from grass/white clover swards is the maintenance of a satisfactory clover content. This is not always easy given the dynamics of the grass/white clover association and the interaction of the components, particularly in light of the N fluxes. Nevertheless, considerable advances by researchers have been made, especially over the last 10-15 years, and management guidelines increasingly elucidated. The research findings leading up to these are examined and discussed below for both grazing and conservation forms of utilization. Emphasis is given to the vital role of the perennating stolon network and its reaction to the different interacting components (defoliation, trampling, excretal return) of the grazing process; the effects of cutting intensity (severity and frequency) are also considered, as is the advantage of a conservation cut in rejuvenating severely grazed swards. While as yet limited in number in Europe, systems studies exploiting the high nutritive value of clover have proved practicable and economically viable for sheep, dairy and beef cattle production. Clover varietal types and companion grasses are also discussed in relation to their influence on clover persistence as are the effects of different fertilizer nutrients. Environmental concerns are briefly touched upon, particularly in relation to minimising N losses, still a challenging topic for researchers.

It is concluded that a flexible approach to management is necessary, i.e. applying specific management techniques or factors at specific times in response to seasonal effects or to the effects of previous management. Arguably farmers accustomed to the straightforward use of N-fertilized grass swards require decision support from advisory services; they in turn need support from researchers who have validated practical systems of animal production primarily based upon grass/white clover swards. It is predicted that their use will increase in the near future for various reasons including the political moves towards extensification, the requirement for increasingly environmentally-friendly farming systems and consumer demand for production systems perceived as being 'natural'.

Key words: Grass/white clover swards, grazing, conservation, herbage quality, animal performance, fertilizers, seasonal effects.

INTRODUCTION

Although reliance on white clover in European grassland has declined over the second half of this century, political and economic influences during the past twenty years or so have stimulated research interest in forage legumes generally and white clover in particular. White clover is considered, potentially, to play a key role in the development and maintenance of sustainable, low-input and low-cost animal production systems, which are politically, environmentally and economically desirable (Frame *et al.*, 1998). White clover's attributes are qualitatively akin to those of most other forage legumes including its ability to fix high rates of atmospheric N and its high nutritive and feeding value. However, unlike many of the other widely-grown temperate forage legumes, such as lucerne and red clover, white clover has the potential to maintain its contribution, and value, to a sward indefinitely and under a range of managements.

In practice, white clover often fails to achieve its potential. The main limitations are its variable contribution both within a year (seasonal) and from year-to-year, the latter often being unpredictable and resulting in uncertain persistence; concerns about its propensity to cause bloat in grazing animals is a further disincentive to it being used widely.

A principle cause of white clover's unpredictable contribution is its association with grass. For example, although grass is a competitor to white clover, the legume makes a high proportion of its N available to grass, which the latter uses to good effect to increase its competitiveness towards clover. In addition, white clover does not always respond similarly to grass when the environment of the sward changes - an example being response to severe treading where stolon branching and survival may be more severely affected than tiller initiation and growth in the companion grass.

The challenge of the grassland researcher working on white clover over the past two decades has been to explain white clover's variability and attempt to reduce it by management and breeding. This article reviews some of the main findings from this research, especially in relation to their relevance to management of long-term grass/clover swards.

GRAZING

Due to its creeping, stoloniferous growth habit white clover is considered to be well suited to grazing. Although it has evolved and spread widely throughout temperate zones of the world by colonising natural pastures, modern varieties have been bred to suit specific grazing situations, even in intensive farming systems (Caradus and Woodfield, 1997); their world checklist noted 319 named white clovers, but the seed of many are unavailable or in short supply.

Grazing is a complex method of harvesting forage. It not only involves the animal defoliating the vegetation, but also exertion of pressure and sometimes damage by hooves on the plant units, and deposition of excreta resulting in nutrient return which has a beneficial effect on herbage growth; however, the excreta also cause fouling of the pasture, thus limiting subsequent defoliation due to rejection by the grazing animal (Fales *et al.*, 1996). The specific consequences of each of these components of grazing are difficult to quantify and their interaction heightens the complexity of grazing as a system of harvesting herbage, especially when taking account of the differential response of grass and white clover to these interacting components.

Trampling

Trampling by hooves is integral to the grazing process and can have significant effects, both direct and indirect, on clover contribution in the mixed sward. Individual plants and the stolon network may be physically damaged, and under severe trampling (poaching) even destroyed. Severe poaching is visually obvious but the subclinical effects of trampling are less evident. Plant damage is most severe on heavy-textured clay and silt soils, particularly in wet conditions (Wilkins and Garwood, 1985).

Nonetheless, clover has the capability to recover from poaching since there can be regeneration of displaced plants and/or plant generation from buried stolen fragments (Vertès *et al.*, 1988). On occasion trampling damage may suppress the grass component more than clover, thus reducing shading of the clover, while in another scenario, the clover is partially protected (cushioned) by the grass canopy, with both effects aiding clover persistence (Harris, 1987).

The indirect compactive effects of trampling —increased soil bulk density, reduced soil porosity and water infiltration, less soil aeration, increased gas diffusion, restricted nutrient uptake— adversely affect the minority clover component, with its reliance on shallow nodal rooting, new plant initiation and less root competitive ability, more than grass (Caradus 1990; Vidrih and Hopkins, 1996). However, following trampling damage to clover in autumn, recovery can be rapid if the winter is mild since stolon fragments can develop into separate plants and earthworm activity aids adventitious root development (Vertès, 1989). In contrast, grazing in a wet winter hinders earthworm activity thus delaying recovery of a soil structure beneficial to clover root development (Cluzeau *et al.*, 1992).

Clearly, management should be geared to minimize trampling damage, for example, by maintaining effective soil drainage systems; by encouraging dense swards through grazing management and balanced fertilizer use; by reducing stock traffic through planned layout of fields and tracks.

Excretal return

Excretal return, also integral to the grazing process, strongly influences the botanical composition of a grazed sward through nutrient cycling. Urinary N is of major importance since about three-quarters of the excreted N is in the urine, which is deposited in patches and these patches therefore receive a high concentration of N (Table 1). This N is readily available, particularly to the grass, and while some N is lost through volatilization and leaching, the remaining N boosts the grass component at the expense of the clover. There is a decrease in the density of clover growing points, reduced stolon survival and diminished stolon branching (Marriott *et al.*, 1987,1991); however, these adverse effects are not apparent in autumn since both grass and clover components grow slowly then, with neither achieving a competitive advantage. The K-rich urine and P-rich faeces which offer benefit to clover (though also to grass) are overridden by the adverse N effects, though faecal patches *per se*, where grass is smothered out, are potential sites for clover stolon colonization. In the faecal patches and surrounding areas rejected by cattle, clover stolon elongation rate is faster but branching rate slower compared with well grazed areas, effects mainly due to shading from accumulated ungrazed grass (Teuber and Laidlaw, 1996).

TABLE 1

Nitrogen returned annually in faeces and urine in a nitrogen-fertilized perennial ryegrass and perennial ryegrass/white clover sward grazed with heifers (Laidlaw and Vertès, 1991)

Nitrógeno devuelto en heces y orina en pastos de raigrás inglés fertilizado con nitrógeno y de raigrás inglés-trébol blanco utilizados por novillas en pastoreo

	Ryegrass	**Ryegrass/white clover**
N applied (kg ha^{-1})	250	-
N fixed (kg ha^{-1})	-	120
Faeces (kg ha^{-1})	6900	6200
N (g kg^{-1})	3.2	4.6
N returned (kg ha^{-1})	22	28
Urine (l ha^{-1})	13500	18500
N(g kg^{-1})	7.0	7.9
N returned (kg ha^{-1})	94	147

Effect of grazing system and intensity

Generally white clover contribution in mixed swards, i.e. its growth relative to accompanying grasses, is lower under grazing than cutting (Evans *et al.*, 1992). Within the range of grazing systems under which grass/clover swards may be managed, the optimum system for white clover depends upon the criteria used to define 'optimum'. For example white clover contribution to herbage mass is usually higher under rotational than continuous grazing, especially in the early years of a reseeded mixed sward (Curll and Wilkins, 1983; McAdam, 1986; Reyneri *et al.*, 1996) but clover in rotationally-grazed swards may be less capable of withstanding stresses, such as drought (Brock and Hay, 1993; Fig. 1). As will be discussed later, there is a case for maintaining white clover levels below the maximum possible where it is necessary to reduce adverse environmental effects caused by N loss from the system.

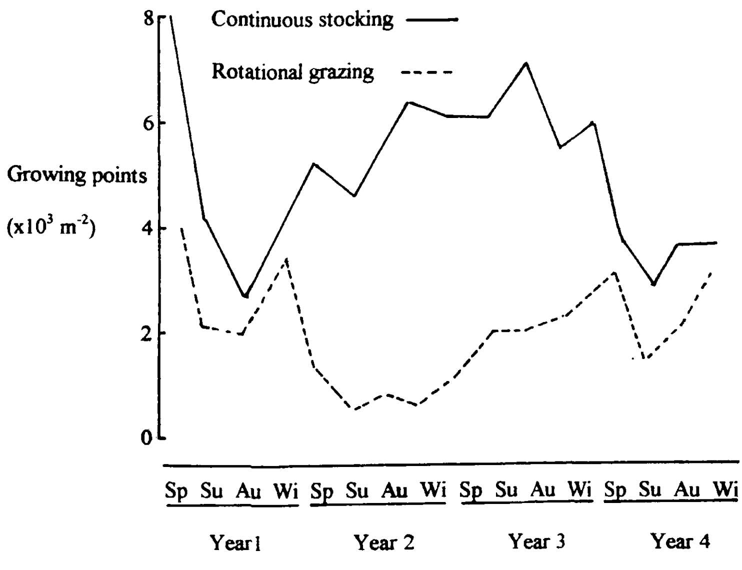

FIGURE 1

Stolon growing point population density of white clover in rotationally grazed and continuously stocked swards in New Zealand over four years (A drought occurred in spring of Year 2) (Brock and Hay, 1993).

Densidad de la población de los puntos de crecimiento de los estolones de pastos utilizados en pastoreo rotacional y continuo en Nueva Zelanda durante cuatro años (Hubo sequía en la primavera del 2º año)

In grass/white clover swards continuously stocked with cattle, clover content may remain relatively stable from year to year (Laidlaw *et al.*, 1995) or gradually decline if the initial content of clover is high (Gibb and Baker, 1989). In these swards rejected areas act as sites of uninterrupted sward growth which give white clover an opportunity to recover from severe defoliation (Teuber and Laidlaw, 1995).

With sheep grazing, white clover decline can be rapid, especially under continuous stocking (Widdup and Turner, 1983; Curll *et al.*, 1985; Orr *et al.*, 1990). Growing point density increases in the early stages of continuous stocking by sheep as branching is encouraged due to favourable light environment at the base of the sward. However, repeated defoliation of white clover at very short intervals reduces stolon branching and the content of water soluble carbohydrates in the stolon (Jones and Davies, 1988). Moreover, removal of stolon apices when defoliation is severe also reduces branching in white clover (Brink, 1996) and so intensive long-term continuous stocking will inevitably lead to poor white clover production. However, white clover performance can be satisfactorily maintained in mixed swards continuously stocked with sheep by growing small-leaved clovers with compatible companion grasses and controlling sward height (Davies *et al.*, 1995; Gooding *et al.*, 1996).

Rotational grazing offers white clover the opportunity to produce progressively larger leaves in the period of uninterrupted regrowth and so during summer, rotationally-grazed swards may contain more clover than those continuously stocked. However, in rotationally grazed swards with cattle, especially if stocked sufficiently lightly to maintain high daily liveweight gains, heavy residual herbage mass may reduce white clover branching at critical times, e.g. in early summer, resulting ultimately in low clover contribution (Stewart, 1988).

Sustained undergrazing is usually detrimental to clover as it will eventually result in reduced branch numbers, those which die not being replaced because of inhibited branching due to the increase in far red relative to red light at the base of the sward (Thompson, 1993). In the early stages of undergrazing advantage may accrue to clover as it can grow uninterruptedly and increase its leaf size. Consequently, in understocked swards continuously stocked with cattle, white clover may contribute more to sward production than in the higher-stocked swards in the early years of utilization; however, in later years, growing point density declines faster than in the higher-stocked swards (Steen and Laidlaw, 1995). Understocking in rotationally-grazed swards with beef cattle, managed to ensure a high daily liveweight gain, may have been responsible for the rapid decline in clover content after the third production year in the trial reported by Stewart (1988). Declining growing-point density was responsible for the low clover contribution in subsequent years (Laidlaw and Stewart, 1987).

Effect of species of animal

Sheep grazing generally reduces clover stolon and leaf dimensions, i.e. thinner, shorter internodes, shorter petioles and smaller laminae compared with cattle grazing or cutting (Briseño de la Hoz and Wilman, 1981). In comparisons between sheep- and cattle-grazed swards, white clover content was higher in the latter (Wright *et al*, 1992), and subsequently weaned lambs performed better on the sward previously grazed with cattle than with sheep. A similar effect on clover content has been found in comparisons between sheep- and goat-grazed swards (e.g. Penning *et al.*, 1996), and in another trial, lambs gained weight faster on swards previously grazed by goats than by sheep due to the higher clover content of the goat-grazed swards (del Pozo *et al.*, 1996).

There is continued debate about the extent to which differences in clover content are due to differential selection by grazing animals. In free-choice experiments in which animals had access to monocultures of white clover and grass, sheep and cattle chose a diet with approximately 70% clover whereas goats chose one with about 50% (Penning *et al.*, 1998). Grazing mixed swards, selection of clover by sheep seems to occur only at the extremities of clover content; otherwise clover content in their diet reflects the clover content of the surface (grazed) layer (Milne *et al.*, 1982). Using the mathematical procedure of Ridout and Robson (1991) to determine the degree of selection exercised by goats and sheep grazing mixed swards, del Pozo *et al.* (1997) found that the proportion of clover in the diet of sheep was similar to that in the top 2 cm of the sward, unlike the goats' diet which had generally a lower clover content than that of the top 2 cm of the sward. It seems that goats graze less deeply into the canopy than sheep, possibly being inhibited from grazing deeper due to the clover lamina canopy forming a barrier.

Bloat prevention

The spectre of bloat in cattle when grazing grass/white clover swards is often raised by farmers. The complex of plant and animal factors causing it has not yet been fully elucidated. However, bloat has not proved to be a significant risk in systems-type work with various classes of stock (Stewart and Haycock, 1984; Bax and Schils, 1993; Frankow-Lindberg *et al.*, 1996). There seems to be some advantage with continuous stocking since there is less variation in the type and quality of the herbage available than with rotational grazing provided grazing pressure and sward surface height are well controlled. In north-west France where rotational grazing is practised, the rest interval is 5-6 weeks rather than 3-4 weeks in order to provide more mature herbage which lessens the risk of bloat (Pflimlin, 1993); the main risk arises from stock entering lush, rested swards from swards which have been well grazed down. Several bloat preventative and control measures are available, e.g. provision of additional fibre (hay or straw) to the diet; use of an anti-foaming agent such as poloxalene incorporated into drinking water, into block licks or as a concentrate supplement; use of mineral or vegetable oil drenches.

SEASONAL EFFECTS OF MANAGEMENT

As white clover is invariably grown with a companion grass, its growth cycle is influenced by the relative competitiveness of the companion towards clover at various times of the year. Under mild winters in north-western Europe, white clover stolons continue to produce branch buds, provided the canopy is not overtopped by grass (Patterson *et al.*, 1995). However, the potential for branches to arise from nodes produced from autumn through to early spring declines progressively, compared with nodes produced during the summer (Teuber, 1993; Fig. 2). In addition to the production of branches, rate of clover growth is determined by the rate of production of leaves and leaf size. Temperature limits the rate of leaf appearance (Davies and Evans, 1982) and mean

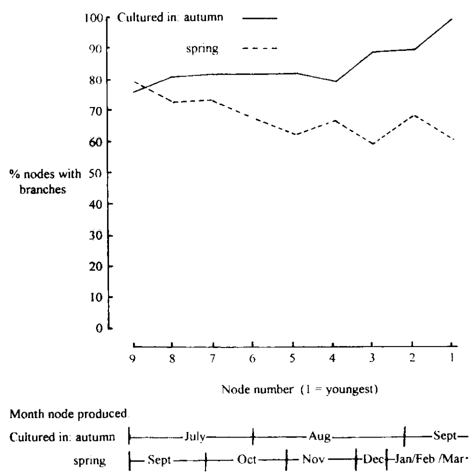

FIGURE 2

Potential for branching at consecutive nodes along stolons in spring (March) and autumn (September). 'Leader' stolons removed from a continuously-stocked perennial ryegrass/ white clover sward and cultured for 3-5 weeks under optimum conditions in a glasshouse (Teuber, 1993)

Potencial de ramificación de los sucesivos nudos de los estolones en primavera (marzo) y en otoño (septiembre). Estolones 'leader' se tomaron de un pasto de raigrás inglés/trébol blanco utilizado en pastoreo continuo y se cultivaron durante 3-5 semanas en condiciones óptimas en un invernadero leaf mass under regular defoliation increases from early spring until June, declining in mass from summer through to winter (Wilman and Asiegbu, 1982). At less than 10ºC the growth rate of grass is faster than that of white clover and so in early spring the content of white clover in a mixed sward is low. In regularly defoliated swards (e.g. monthly) many of the reproductive tillers are decapitated following late spring defoliation and grass regrowth is hindered; as a consequence, white clover stolons proliferate by branching, leaf growth per stolon increases and so clover contribution to herbage growth usually increases rapidly. For the remainder of the summer and early autumn, clover contribution remains more or less stable (at least in the absence of severe drought), declining as clover growth rate is more severely affected by decreasing temperature in late autumn than that of grass.

Defoliating swards to a short height (2-3 cm) in winter by cutting to simulate sheep grazing compared with swards defoliated to about 5 cm in late autumn, resulted in improved white clover contribution in spring due to higher stolon branching rate and a higher potential photosynthetic rate in clover, effects most likely due to reduced grass cover (Laidlaw *et al.,* 1992; Table 2).

TABLE 2

Correlation between herbage mass over winter, varied by management in autumn, and white clover characteristics measured in early spring (Laidlaw *et al.*, 1992)

Correlación entre la masa de hierba en el invierno, modificada por variación del manejo en otoño, y las características del trébol blanco medidas a principios de primavera

Characteristic	Correlation coefficient
Stolon density	-0.60*
Stolon length	+0.45NS
Petiole weight	+0.93***
Potential photosynthesis	-0.84***

Variation in grazing intensity during the gr azing season has a small but potentially important effect on clover development and persistence. Maintaining a low sward surface height in continuously-stocked grass/clover swards in spring and early summer can result in an increase in stolon density (Gibb *et al.,* 1989; Teuber and Laidlaw, 1995). This is likely to be due to a decrease in above-ground competition by grass towards white clover, especially since it is at a time when white clover is likely to be particularly vulnerable. In spring, carbohydrate content of clover stolons is at its lowest (Hay *et al.*, 1989), axillary buds are at their least viable (Newton *et al.*, 1990) and, due to low air temperatures (less than 10ºC), white clover is less able to compete against grass for the upper layers of the mixed sward canopy (Woledge *et al.*, 1990). These factors may also account for the long-term benefits which can be achieved by continuously stocking grass/clover swards with sheep in spring followed by rotational grazing for the rest of the season (Hay and Baxter, 1984). Clover content in swards rotationally grazed with cattle in the normal grazing season responds positively to a treatment of grazing intermittently with sheep from November to March, mainly due to an increase in stolon growing-point density (Laidlaw and Stewart, 1987). The removal of clover herbage in autumn has an adverse effect on carbohydrate status of stolons, thereby reducing their ability to withstand harsh winters, and so this management strategy may be harmful in more northerly environments (Frankow-Lindberg *et al.*, 1997).

The depression of white clover content by continuous stocking with sheep can be alleviated by 'resting' the sward for a conservation cut (Curll and Wilkins, 1985; Barthram and Grant, 1995; Gooding *et al.*, 1996). Introducing a conservation cut in continuously-stocked swards is more beneficial to clover the later in the summer it is imposed and is more effective with larger-leaved than smaller-leaved clover types (Gooding *et al.*, 1996; Table 3). The thinning effect of the conservation cut on the grass tillering is considered to be important in increasing stolon density (Gooding and Frame, 1997). Additional continued benefit after the conservation cut is due to the production of larger leaves which continues for a short period after grazing resumes (Davies, 1992).

TABLE 3

Effect of white clover leaf size category and timing of a conservation cut in swards continuously stocked with sheep on white clover cover at end of second year of treatments (Gooding *et al.*, 1996)

Efecto del tamaño de la hoja y de la época del corte para conservación en pastos utilizados en pastoreo continuo sobre la cobertura del trébol al final del segundo año de los tratamientos

	Leaf size category			
	Very large	**Large**	**Medium**	**Low**
No rest	20.6	41.1	34.5	96.3
April-late May	8.3	19.3	18.6	84.8
Late May-end June	13.7	45.4	34.0	98.9
Early July-mid Aug	41.1	71.4	59.6	97.0
s.e.d. = 9.20				

Alternating managements may also reduce the risk of so-called 'clover crashes', i.e. sudden declines in clover contribution. These are considered most likely to occur in swards which have contained a high content of clover. The size of the clover plant units fall below a threshold caused by a break-up of complex stolon networks in early spring (Brock *et al.*, 1988), and competition between individuals within the clover population drastically reduces numbers (Fothergill *et al.*, 1996). External factors such as environmental stress or treading (Vertès *et al.*, 1988) can cause these complex units to break up; however, there may also be intrinsic factors which contribute to fragmentation of these complex stolon networks. By anticipating the approach of these very small units being formed, managements can be introduced, e.g. a switch from grazing to a pre-conservation rest period, which will reverse the progress of clover towards this intense intra-species competition.

In conclusion there is no definitive single grazing system for white clover. However, by fixing objectives for the grass/clover sward to meet, one or a combination of the components of systems described here can be chosen and implemented to meet these objectives. This implies that a more flexible management approach is needed than for that for nitrogen-fertilized grass swards. Thus farmers require decision support by advisory services and they in turn require support from researchers who have developed and validated practical systems. This approach has been successful in the UK (Bax and Browne, 1995) and Sweden (Frankow-Lindberg *et al.*, 1996), albeit on a limited scale.

CONSERVATION

Traditionally and correctly white clover has been regarded as a species highly suitable for grazing. However, evidence has accumulated in recent years showing that it has a valuable role in swards cut for conservation. Early evidence (Frame and Newbould, 1986; Frame and Paterson, 1987) came from small-plot experimentation but the role was later confirmed in farm systems work (Bax and Thomas, 1992; Bax and Browne, 1995) when perennial ryegrass/clover swards with no applied fertilizer N gave *circa* 80% of the yields from grass swards receiving 350 kg/ha N annually (Table 4); first-cut yields were broadly similar for both sward types. A similar conclusion was drawn by Søegaard (1991) from Danish work using N rates of 250-400 kg ha^{-1} N, work which also showed that grass/clover swards receiving half the maximum N rate applied to grass swards produced equivalent yields.

TABLE 4

Silage yields (t DM ha^{-1}) from annual 3-cut system over four years grass plus 350 kg ha^{-1} N (GN) annually versus plus white clover (CG) (Bax and Browne, 1995)

Producción (t/ha MS) de 3 cortes por año para ensilar durante cuatro años en una pradera de gramínea con una aplicación anual de 350 kg ha $^{-1}$ de N (GN) vs. una pradera de gramínea-trébol blanco sin nitrógeno (CG).

Year	Sward	1st cut	2nd cut	3rd cut	Total	(Relative)
1	GN	4.7	3.5	3.8	12.5	(100)
	GC	3.9	3.0	3.0	9.9	(79)
2	GN	4.8	3.5	3.2	11.5	(100)
	GC	4.8	2.1	2.4	9.3	(81)
3	GN	5.6	3.6	2.7	11.9	(100)
	GC	5.9	2.4	3.1	11.4	(96)
4	GN	3.8	3.6	3.5	10.5	(100)
	GC	4.0	2.7	2.2	8.9	(85)

In heavily-grazed swards the introduction of a conservation cut, particularly in late summer when clover growth is most vigorous and there is peak stolon development (Laidlaw and Vertès, 1993),encourages clover contribution to the sward (Barthram and Grant, 1995; Gooding *et al.,* 1996). A benefit from the cutting of a conservation crop is the removal of a considerable amount of nitrogen from the soil pool, *circa* 30 kg N per tonne of herbage DM, a removal which decreases grass competition to the clover by lowering the available N supply.

Closeness of cutting: It is well recognised that repetitive close cutting of swards, whether grass-only or grass/clover, results in higher yield than lax cutting, though adequate recovery periods are needed between defoliations. In the case of grass, it is mainly because of better utilization of the standing crop. For clover the benefit is indirect, resulting from improved light at the base of the sward. This leads to increased stolon branching, more growing points and the encouragement of photosynthetically-efficient leaves, efficient because of being initiated in good rather than poor light conditions (Dennis and Woledge, 1987). A high stubble height (10 cm) at monthly cutting intervals caused a severe reduction in clover content and nearly eliminated it from the sward by the third year, (Acuña and Wilman, 1993). Though white clover had larger leaves and thicker stolons in tall compared with short stubbles, it had fewer stolon nodes, fewer branch-bearing nodes and shorter stolon length per unit area (Wilman and Acuña, 1993).

In practice, the cutting height for silage has to be sufficiently low to achieve good utilization efficiency and yield yet not so low that soil contamination of the cut crop is a hazard to subsequent fermentation. A cutting height of about 5 cm above ground level is an acceptable compromise provided field surfaces are fairly level. Lowering the cutting height also results in an increase in the length of stolon and the number of stolon nodes per unit area and the positive effects of close cutting on clover growth and development outweigh the negative effects, namely, reduced clover leaflet size and weight, shorter petioles and stolon internodes, and reduced stolon diameter (Wilman and Acuña, 1993). Frequent close defoliation reduces stolon branching because of a reduction in total available carbohydrate (Jones and Davies, 1988).

Frequency of cutting

Within silage cutting systems, total herbage production from mixed swards increases as the length of the interval between defoliations increases up to six weeks or so with little or no effect on the ratio of white clover to grass (Frame and Newbould, 1986). Increased rest interval promotes the growth of existing grass tillers at the expense of tiller initiation from basal buds and so the improved light conditions at the base of the sward result in longer clover petioles, increased leaf weight, stolon length and diameter (Wilman and Asiegbu, 1982). However, with longer rest intervals than the norm for silage harvesting the white clover content is likely to decrease. This results from a reduction in stolon growing points, although the stolons are larger; also, although clover leaves are larger, a high proportion is removed by cutting. The effect of increasing the rest intervals between defoliations is also dependent on other factors such as growth characteristics of the companion grasses, clover variety and season of year. For example, large-leaved clovers are more suited to conservation than small-leaved varieties (Swift *et al.*, 1992).

Effects of rest interval are greater in the early than late part of the season, and delaying the primary harvest of the season can reduce white clover content considerably (Frame, 1987). In general, nitrogen application whether in spring only or repetitively during the season adversely affects white clover contribution at most practical frequencies of cutting though the effects may be more adverse with long than short rest intervals (Fisher and Wilman, 1985); however, this effect is not consistent (Frame and Newbould, 1986).

SWARD COMPOSITION

Effect of white clover varieties

Among clover varieties, small-leaved types demonstrate more marked phenotypic plasticity than larger-leaved types. Consequently, they can adapt more readily to the demands made on them by continuous stocking; by reducing their leaf size when continuously grazed by sheep, a higher proportion of leaf tissue escapes grazing (Davies and Jones, 1987). In a New Zealand trial over a five-year period, the small-leaved cv. Kopu increased its stolon population density three-fold when stocked continuously compared with rotational grazing while the larger-leaved cv. Tahora only slightly increased its stolon density; the more frequent defoliation of stolons under continuous stocking resulted in the small leaved-type maintaining its leaf area index whereas that of the larger-leaved Tahora was reduced to one-third (Brock and Hay, 1993). A similar pattern in stolon numbers has been reported from Wales between the small-leaved cv. Gwenda and medium-leaved selection Ac 3785 when compared under cutting and continuous stocking by sheep (Evans *et al.*, 1998). However, Ac 3785 and cv. Gwenda had similar stolon weights under grazing, suggesting that plasticity can also be exhibited by a medium-leaved type.

Although white clover varieties are evaluated routinely for their suitability for grazing, via frequent mowing to simulate grazing, this method has been questioned for making recommendations about their suitability for sheep grazing (Swift *et al.*, 1992; Davies *et al.*, 1995). For example, Swift *et al.* (1992) showed that the ranking of white clover cultivars could be more or less reversed when tested under cutting (5-6 cuts per annum) compared with continuous stocking with sheep (Table 5). Even clover ground cover in the grazed plots and plots mown 17 times in the growing season did not correspond closely. Therefore, care needs to be exercised when selecting white clover varieties for specialist grazing use. However, it is generally safe to assume that the small-leaved types are most suited to sheep grazing, especially continuous stocking and the large-leaved types to rotational grazing and/or cutting. In practice, a blend of two or three clovers of differing leaf size is used in seeds mixtures to allow for flexibility of utilization. In New Zealand, one kg ha^{-1} of a small-leaved clover is commonly added in dairy pasture seeds mixtures since its well anchored stolons and low position in the canopy enable it to escape grazing and so contribute to the amount of N fixed (J.F.L. Charlton, pers. com.).

TABLE 5

Comparison between white clover yields (t ha^{-1}) and ranking of a range of cultivars when cut 5 to 6 per annum as per National List trials or continuously stocked with sheep, grown in combination with perennial ryegrass (mean of 3 years) (Swift et al., 1992)

Comparación de las producciones del trébol blanco (t ha^{-1}) de diversas mezclas de variedades de trébol con raigrás inglés, cortadas de 5 a 6 veces al año, como en los ensayos de Valor Agronómico para la Lista Nacional, o utilizadas por ganado ovino en pastoreo contínuo (media de 3 años)

		Cutting		Grazing	
Variety	**Leaf size**	**Yield**	**Rank**	**Yield**	**Rank**
Milkanova	Large	3.48	1	1.26	3
Menna	Medium	2.97	2	1.20	5
Huia	Medium	2.83	3	1.22	4
S184	Small	2.69	4	2.04	2
Kent	Small	1.93	5	2.31	1

Companion grasses

Compatibility of grasses with white clover depends on morphological and physiological characteristics of the grass and of the white clover, together with the interaction of the association with the management imposed and with the climatic, edaphic and biotic environment under which the association is growing.

As a general rule, among the most widely grown temperate grasses in Europe, meadow fescue is the most compatible while cocksfoot and tall fescue are the least with perennial ryegrass and timothy being intermediate (Frame *et al.*, 1998). However, within a species some cultivars may be less aggressive towards white clover than others. For example, some modern varieties of cocksfoot are more compatible with white clover than older types (Moloney, 1994) and in perennial ryegrass, late-heading cultivars are generally less compatible with white clover than earlier-maturing types (Gooding *et al.*, 1996).

While clover usually makes a higher contribution to swards containing grasses which have a low bulk density at the base of the canopy, such as tetraploid perennial ryegrasses, compared with the denser diploid cultivars (Frame and Boyd, 1986), even under sheep grazing (Fothergill and Davies, 1993). White clover's inability to compete successfully in a dense sward probably accounts for its poor performance in swards containing creeping bent *(Agrostis stolonifera)* or Yorkshire fog *(Holcus lanatus)*; however, the relatively high proportion of red light filtered out of daylight passing through the canopy of these two species, thus inhibiting branching of white clover stolons, has also been suggested as a cause (Thompson and Harper, 1988), as is Yorkshire fog's strong root growth and ability to form spreading clumps (Watt, 1978).

The principle of co-adaptation is being applied to perennial ryegrass and white clover breeding in an attempt to breed cultivars of both components from ecotypes which were naturally co-existent. The aim is to produce high mutual compatibility combined with high performance in mixture (Rhodes, 1991).

FERTILIZER USE

In the mixed sward white clover is the most sensitive component to a limited supply of nutrients such as P and K (Dunlop and Hart, 1987). This is due to the lower root mass of clover compared with grasses, especially in the upper soil layers where nutrients are concentrated, and to disadvantageous root structure differences (Caradus, 1990). These root differences also put clover at a disadvantage for water uptake (Thomas, 1984). In grazed swards recycling of the nutrients ingested in the herbage takes place through excretal return. However, distribution of the excreta is uneven and so moderate applications of P and K are necessary to compensate for this. The situation is clearer cut with the removal of conservation crops where replenishment of the nutrients is required in proportion to the DM yield removed (approximately 3 kg P and 30 kg K per tonne of DM).

An adequate soil pH, at least 5.8 for mineral soils and 5.5. for peat, is necessary for satisfactory clover growth. Apart from countering soil acidity, lime application supplies calcium which is needed, *inter alia,* for encouraging infection of roots and formation of root nodules by *Rhizobium.* Excessive liming has to be avoided since it decreases P availability (Rangeley and Newbould, 1985) and can cause deficiency of trace elements needed for growth, e.g. boron, manganese, zinc (Mengel and Kirkby, 1987); conversely, excessive acidity can reduce available potassium, molybdenum, sulphur and copper. Also, on very acid soils, exchangeable aluminium becomes toxic to white clover, limiting calcium and phosphorus uptake and retarding root growth.

The effect of applied fertilizer N on the grass/white clover sward is well documented. Typically, annual total herbage is increased as a result of increased grass yield, an increase which is greater than the resultant decrease in clover yield (e.g. Frame and Boyd, 1987a). The reason for clover decline is not yet fully understood but is likely to be a combination of factors including reduced photosynthesis (Faurie *et al.,* 1996) and a reduction in growing-point density because of diminished assimilate allocation and stolon branching (Laidlaw and Withers, 1989); increased competition for nutrient uptake by the roots of N-stimulated grass growth is another possibility.

Most evidence on the effects of repetitive applied N on herbage yield comes from cutting trials with varying frequencies of defoliation but, while there is a scarcity of grazing trials, the decline in white clover is intensified in grazing conditions partly because of the excretal N return. Yield response on grass/clover swards to N at 8-10 kg DM per kg N applied is about half that on all-grass swards (Frame and Newbould, 1986). At low rates of fertilizer N, a negative response may occur because the loss in white clover yield is not offset by a sufficient gain in grass yield (McEwen and Johnston, 1985). Considering the annual rate of fertilizer N needed on all-grass swards to match the yield from grass/clover swards, an average of 172 (range, 124-278) kg ha^{-1} N is cited from British experiments (Royal Society, 1983).

The tactical application of fertilizer N during the season is a method of increasing herbage production via the grass component with least adverse effect on the clover. Application in spring is the most common and although there is an adverse effect on clover performance, this is usually temporary (e.g. Laidlaw, 1980). Clover recovery will depend to a large degree on the extent of the stolon network (and subsequent management) though it has been suggested that annual clover yields increase linearly as stolon length in spring increases from about 20 m m^{-2} to 80-100 m m^{-2} (Rhodes *et al.*, 1994). Table 6 shows the effect of spring and/or autumn N application on clover contents in a mixed sward; the relatively high levels are typical of cutting rather than grazing trials.

TABLE 6

Effect of spring and/or autumn fertilizer N application on white clover contents (% on a DM basis) in perennial ryegrass/white clover swards (mean of 3 years) (Frame and Boyd, 1987b)

Efecto de la aplicación de fertilizante nitrogenado en primarera y/o en otoño sobre el contenido en trébol blanco (% sobre la producción en MS) de una pradera de raigrás inglés/trébol blanco (media de 3 años)

Spring N (kg ha^{-1})	Autumn N (kg ha^{-1})			
	0	25	50	75
0	48	48	41	45
25	43	36	40	36
50	38	33	33	31
75	34	27	29	27

Slurries

Animal slurries are being used more rationally than before in farm manurial programmes particularly as a source of N and K. Scorch damage and smothering are more of a hazard to clover with its horizontally-orientated leaves than to grass, though the effects can be ameliorated by rainfall soon after application of the organic manure (Wightman *et al.*, 1996; 1997). Nevertheless, on mixed swards comparison of fertilizer N rates with dilute slurry or urine at similar N rates have resulted in higher clover contents with the organic manures (e.g. Nesheim *et al.*, 1990). This effect has not been fully explained. The positive effect on clover of slurry P and K may be a factor though attempts were made to equalize P and K applications in the comparisons. Again, the fertilizer N equivalents of the organic manures used may have been underestimated because some of the organic N component in the manures may have been mineralized.

MANAGEMENT TO MINIMISE N LOSSES

From studies in sheep-grazed swards with low (*circa* 15% in the first year to 5% in the third year) clover contents, Orr *et al.* (1990) found that sufficient N was cycling in the system to sustain sheep production equivalent to about 80% of a high N system; the period of decline in clover content took place in winter. These results have been supported by other studies with continuously-grazed swards in which low clover contents (5 - 10% on a dry matter basis) were able to sustain relatively high levels of animal production e.g. for fattening lambs (Chestnutt, 1992) or steers (Steen and Laidlaw, 1995). Although the proportion of clover in the diet of the grazing animals in these studies was 2 to 3 times the content in the whole sward (estimated by tissue turnover methods (Binnie and Chestnutt, 1994; Laidlaw and Steen, 1989) this could not fully account for the higher than expected production from these swards. Therefore a combination of rapid cycling in the system with low losses due to grass being in deficit for N and so rapidly taking up mineral N might explain the highly economical use of N in such systems.

Based on this principle, Jarvis *et al.* (1996) have predicted a possible scenario if a typical dairy farm in south-west England changed from relatively high N input to reliance on low clover content (fixation rate of 72 kg N ha^{-1}). They considered that it was possible to maintain a level of output similar to a system with a high clover content and 80% that of the high N system with much reduced loss of N from the system (Table 7). If this is shown to be widely applicable in grazed grass/clover swards, the challenge is to maintain the whole system in steady state. This will require clover to be manipulated

TABLE 7

Comparison of N inputs and outputs (kg ha^{-1}) from three types of dairy farms (currently typical, high clover and low clover) in England (Jarvis *et al.*, 1996)

Comparación de las entradas y salidas de N (kg ha^{-1}) en tres tipos de fincas de vacuno lechero (típica, alto contenido en trébol y bajo contenido en trébol) en Inglaterra

Source		Typical farm	High clover	Low clover
In:	Fertilizer	250	0	0
	Atmosphere	25	25	25
	Fixation	10	144	72
	Concentrates	52	41	41
Out:	Milk and live weight	67	54	54
	Leaching	56	28	16
	Denitrification	55	27	15
	NH_3 Volatilization	49	34	31
Unaccounted:		109	78	23

at times using the combination of management techniques outlined above so that its desired level can be maintained. Of course it will not always be possible to exercise the level of control required to achieve targets exactly, not least due to seasonal variation in clover content. Also the targets are likely to be well below the optimum for individual animal performance, as the high clover contents required to achieve maximum animal production invariably result in high rates of mineral N being voided by the animals. Target levels will probably be approximately 15-25% on a dry matter basis in swards about to be grazed in a rotation and 10-15% in continuously stocked swards although target contents of mixed grass/clover swards with very low N loss rates have yet to be derived experimentally.

HERBAGE QUALITY

In comparison with N-fertilized grass, grass/white clover herbage has usually higher contents of protein, pectin, lignin and minerals but lower cellulose, hemicellulose and water soluble carbohydrate (Thomson, 1986; Søegaard, 1994). At equivalent growth stages the white clover component has higher cell contents especially of the more digestible N and other soluble compounds, but low cell wall contents, particularly of the hemicellulose fraction (Thomson *et al.*, 1985). However, the digestibilities of clover flowerheads and flowerhead stalks are lower than those of grass leaves and stems (and also of clover leaves and petioles), differences which explain why the digestibility of mixed herbage may be lower than that of grass herbage from grazed swards in summer (Wilman and Altimini, 1984; Soegaard, 1994). The differences may not be great in well grazed, continuously-stocked swards and, for example, perennial ryegrass/white clover swards had higher organic matter digestibility (1.7 to 5.8 percentage units) than ryegrass swards receiving 350 kg ha^{-1} N (Frame *et al.*, 1992); the mixed herbage also had greater P, K and Ca concentrations though lower N, Mg and Na concentrations, albeit in clover-rich swards, the N concentrations were sometimes higher in the N-fertilized herbage. The mean annual quality of the herbage from the two swards is shown in Table 8.

TABLE 8

Mean annual quality of herbage from N-fertilized grass (GN) and from grass/clover (GC) swards (Frame *et al.*, 1992)

Calidad anual media de la hierba de praderas de gramínea (GN) y de gramínea/trébol (GC)

Sward	Clover %	OMD	N and minerals g (kg DM)$^{-1}$					
			N	P	K	Ca	Mg	Na
GN	-	70.9	28.0	3.7	22.8	5.0	2.8	1.96
GC	19	73.3	27.1	4.0	24.3	6.5	2.8	1.00
GN	-	68.2	27.3	3.0	18.1	6.3	3.3	2.76
GC	44	71.4	33.9	4.0	24.9	8.6	2.8	1.50
GN	-	72.9	34.3	4.2	28.6	4.6	2.7	1.83
GC	14	73.2	27.9	4.4	29.7	5.9	2.7	1.16
GN	-	67.4	28.7	3.8	21.6	5.6	3.0	2.84
GC	35	70.5	33.1	4.1	30.5	6.6	2.7	1.22

In spite of clover's inherently high N concentration the first silage cut of a grass/white clover sward generally has a lower crude protein content than an N-fertilized grass sward (Bax and Schils, 1993); this is partly a consequence of the slower clover growth in early spring and thus a lower contribution in the mixed herbage. Clover-rich material used to be regarded as difficult to ensile but this difficulty was perhaps overstated. Clover has a higher buffering capacity than grass, i.e. more resistant to the required lowering of pH in the silo. Wilting is necessary to concentrate the dry matter and sugars in the cut material but should be no longer than 24 hours otherwise respiration losses continue and wilting to beyond 30-35 % DM is not advisable since there will be loss of nutritious leaf. Short chopping aids the release of sugars for fermentation and also makes compaction easier. If the above conditions are met and there is dry weather, additive use may not be necessary, though various types from acids to inoculants, provided they are of proven effectiveness, have proved of benefit (Bax and Browne, 1995). The overall quality of the silage will be determined to a large extent by the stage of growth of the dominant grass component of the mixed sward, with cutting before or at early car emergence being necessary to ensure high quality silage for productive dairy cows.

ANIMAL PERFORMANCE

It is well documented that in comparisons of white clover forage, in whatever form, and grass, voluntary intake of clover is substantially higher with physical, chemical and plant anatomical factors all playing a part. In addition, ingested nutrients may be utilized more efficiently (Beever *et al.,* 1985) and more efficient use made of metabolizable energy (Cammell *et al.,* 1986). This intake advantage is manifest in increased animal production (e.g. Thomson *et al.,* 1985) but the situation is less clear-cut in comparisons of grass/clover swards versus N-fertilized grass swards and a challenge for researchers is to obtain as much of these advantages from the mixed sward situation. Animal production advantage to the mixed sward is least with dairy cows (Bax and Schils, 1993), intermediate with fattening beef cattle (Clark, 1988) and greatest with lambs (Vipond and Swift, 1992). The results may be influenced by a number of factors including the amount of clover in the sward, the productive state of the stock, different techniques of experimentation and different grazing patterns of cattle and sheep. Nevertheless, systems of animal production based on grass/white clover swards have proved reliable and viable *per se* (Stewart and Haycock, 1984) and in comparisons with N-fertilized grass swards using dairy cows (Bax and Browne, 1995) or ewes and lambs (Vipond *et al.,* 1993,1997).

CONCLUSIONS

The complexity of the interaction between grass and clover necessitates a flexible approach to management and so managing grass/clover swards to achieve their potential requires more skill than that needed to exploit grass-fertilizer nitrogen systems. In Europe the use of grass/clover swards is not currently as widespread as might be expected given the research effort of the past 10-15 years and the advantageous individual and overall animal performance results recorded. It will take some time before farmers become accustomed to the necessary management to realize the potential of such swards since N-fertilized grass swards have been the norm for two generations.

Nevertheless, management guidelines to exploit grass/white clover swards are available (e.g. Frame, 1992) and it is predicted that their use will increase in the near future. This is particularly in view of the extensification policies of many governments and the public desire for environmentally-acceptable and more 'natural' systems of animal production rather than those based on high inputs of N fertilizer. Additional effort is required to translate research findings into management, advisory and decision support packages so that farmers have access to reliable, scientifically-based advice which is 'user friendly'. The scientific base is already there but the challenge is for research and extension workers to cooperate and devise technology transfer strategies which give the farmer not only the necessary information but also training and eventual confidence in the use of grass/white clover swards.

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MANEJO DEL TRÉBOL BLANCO EN PRADERAS MIXTAS - PRINCIPIOS Y PRÁCTICA

RESUMEN

La clave para una productividad sostenible de praderas mixtas de gramíneas con trébol blanco es el mantenimiento de un contenido satisfactorio en trébol. Esto no es siempre fácil dada la dinámica de la asociación gramíneas/trébol blanco y la interacción de los componentes, debido principalmente a los flujos del nitrógeno. Sin embargo, los investigadores han hecho avances importantes, sobre todo a lo largo de los últimos 10-15 años, que resultaron en normas de manejo cada vez más claras. En este artículo se examinan los hallazgos científicos que han llevado a la situación actual, tanto en las praderas de siega como en las de pastoreo. Se pone un énfasis especial en el papel vital de la persistencia del entramado de estolones de la pradera y en su reacción a los componentes interactuantes en el proceso de pastoreo (defoliación, pisoteo, retorno de excrementos); se consideran también los efectos de la intensidad del corte (severidad y frecuencia), así como la conveniencia de un corte para rejuvenecer praderas pastadas. Aunque todavía en escaso número en Europa, los estudios de sistemas para explotar el alto valor nutritivo del trébol han demostrado su viabilidad práctica y económica en ovino, vacuno de carne y vacuno de leche. Se analiza el papel de las variedades de trébol y de sus gramíneas acompañantes en la persistencia del trébol, así como el efecto de los diferentes nutrientes. Se abordan ligeramente aspectos medioambientales, especialmente en relación con la minimización de las pérdidas de N, todavía un reto para los investigadores.

Se concluye que es necesario adoptar normas flexibles de manejo. Por ejemplo, aplicación de técnicas específicas de manejo en momentos determinados como respuesta a efectos estacionales o a efectos de un manejo previo. Los agricultores acostumbrados al manejo de praderas de gramíneas con altas dosis de nitrógeno necesitan apoyo de los servicios de divulgación en su toma de decisiones, a la vez que necesitan apoyo de los investigadores que hayan validado sistemas prácticos de producción animal basados fundamentalmente en praderas de gramíneas/trébol blanco. Se predice que su uso aumentará en el próximo futuro por varias razones, que incluyen las tendencias políticas hacia la extensificación, la necesidad sistemas de producción más respectuosos con el medio ambiente, y la demanda de los consumidores de sistemas de producción que se perciban 'naturales'.

Palabras clave: Praderas de gramíneas y trébol blanco, pastoreo, conservación, calidad de la hierba, producción animal, fertilizantes, efectos estacionales.