INTEGRATION OF GOATS INTO SHEEP AND CATTLE GRAZING SYSTEMS AS A PERMANENT WEED CONTROL TOOL

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Errata

Table 5.4, pp. xii and 90: see ~~figures~~ Figure 5.3

P.5, ln.22: (Tilman, 1987, 1988; Begon *et al.*, 1996).

P.6, ln.16: Tainton *et al.* (1996)

P.7, ln.7; p.8, ln.15 and 16: Popay (1980)

P.8, ln.3 from the bottom: is very limited

P.8, ln.15: fertilisers (Thompson, 1974; Lambert *et al.*, 1986)

P.9, ln.3 from the bottom: Penning *et al.*, 1997

P.10, ln.10: ~~Mitchell et al., 1987;~~

P.12, ln.19: Delow *et al.* (1988)

P.23, ln.18: (Kent and Coker, 1992; Braun-Blanquet, 1932)

P.39, ln.15: (it was nil in winter~~, as seen in Section 0~~)

P.39, ln.15: ~~(further results on consumption of individual components are presented in Section 3.3.4)~~

P.40, last sentence: [measurements are in centimeters]

P.45, ln.15: Parsons *et al.* (1994a)

P.48, ln.10: consumed ~~it~~ them

P.53, ln.2: ~~where~~ were

P.54, ln.7: ~~Host~~ Holst

P.54, ln.13: (range 7-41%)

P.59, ln.6: ~~fist~~ first

P.73, ln.11: McDonald *et al.* (1995)

P.79, ln.12: ~~(Cowie, 1972)~~

P.82, ln. 4 and 5: (0.13 x 0.77 m)

P.85, ln.15: ~~*BS = bare soil*~~ BS = bare soil

P.105, last line: left~~-one~~.

P.110, ln.8: i.e. wet (Edmond, 1962; 1970)

P.111, ln.7: ~~they~~ the

P.113, ln.8: the sward

P.116, ln.1: ~~irrespectively~~ irrespective

P.116, ln.12: Parsons *et al.* (1994a)

P.116, ln.13: Parsons *et al.* (1994b)

P.118, ln.1: ~~invasions than a cattle one?~~

P.128, ln.13: permanent basis (Statistics New Zealand, 2000)

P.130, ln.4 from the bottom: it has also been shown

P.136, ln.13: ~~(Section 0)~~

P.136, last line: Panetta and Wardle ~~(1995)~~ (1992)

P.138, ln.19: tips of the stolons

P.140, ln8: (Bourdôt *et al.*, 1994a)

P.144, ln.3: (Valentine and Matthew, 1999; McKenzie et al., 1999)

P.144, ln.6 from the bottom: ~~are~~ is largely

P.144, ln.7: ~~(Section 0)~~

P.145, ln16: (Bourdôt *et al.*, 1994b)

P.145, ln.20: (Preston, 2000). (For further reading see Sindel, 2000.)

P.147, ln.10: ~~becomes~~ become immaterial

P.149, ln.11: conducted by Radcliffe and Moorhouse (1988) and Radcliffe *et al.* (1991)

P.155, ln.2: same for perennials (Bridges, 1995)

P.161, ln.13: McCutcheon *et al.* (1986)

P.165, ln.20: ~~(Section 0)~~

P.169, ln.13: (f) which is likely

P.179, ln.7: points

P.182, ln.3 from the bottom: Thorhallsdottir *et al.*, 1990

P.188, ln.16: ~~Publisihng~~ Publishing

P.189, ln.2: ~~*Senecio jacobaea*~~ Senecio jacobaea

P.189, ln.15: (1994a)

P.189, ln.18: (1994b) [...] ~~thislte~~ thistle

P.190, ln.4: ~~Onopordum illyricum~~ *Onopordum illyricum*

P.190, ln.11: ~~*principals*~~ *principles*

P.193, ln.7: ~~Butter Worths~~ Butterworths

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P.198, ln.1: fertiliser

P.199: Parsons, A. J., Newman, J. A. [...] (1994a)

P.199: Parsons, A. J., Thornley, J.H.M. [...] (1994b)

P.202: Sakanoue, S. [...] (1995)

P.204, ln4: ~~Southerland~~ Sutherland

P.204, ln14: ~~gaots~~ goats

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Key

P. and p. = page; pp. = pages; ln. = line. Underlined characters signify inserted text; crossed out characters are replaced by underlined ones in the same line.

ABSTRACT

This project evaluated the integration of goats into sheep and cattle grazing systems as a permanent herbaceous weed control tool. Foraging behaviour of goats grazing pasture with no access to browse was monitored in Experiment 1. A selection index was used to determine degrees of effort for selection or avoidance of plant species. Although most of the grazing time was spent on herbage species, no effort was made to select them, whereas moderate to strong efforts were made to select weeds. Selection index varied with season of the year. Goats preferred taller vegetation and grazed above 10 cm from the ground whenever possible, though they took 70% of their bites from below the top of the sward, regardless of organ selected. Experiment 2 consisted of feeding known numbers of weed and herbage seeds to goats and recovering them to assess destruction and viability. On average, 92% of the viable seeds were destroyed, with up to 72 hours for complete excretion. The effects of goat and cattle grazing on the structure and competitiveness of swards against weed invasions were studied in Experiment 3. A pasture competitiveness index (PCI) was calculated using structural attributes of a sward resulting from goat and cattle grazing alone and in combinations, under hard and lax grazing severities. The sward was denser, leafier, more uniform, and covered the soil more thoroughly (greater PCI) with increasing participation of goats in the treatments, especially because of severe treading damage caused by cattle contrasting with no damage from goats. The PCI explained 93% of the variation in weed seedling density. The effect of pasture surrounding thistle rosettes on their consumption by goats was investigated in Experiment 4. Thistle rosettes that were exposed by clipping the adjacent sward were severely defoliated by goats, while rosettes surrounded by the sward were only nibbled or not eaten at all. Grazing management, economics, and drawbacks of using goats for herbaceous weed control are discussed. Integration of goats into grazing systems can result in a more desirable botanical composition, more uniform and competitive sward, reduced weed control costs, greater herbage utilisation, and better pasture quality.

Keywords: weed ecology, grazing ecology, weed control, biological weed control, weed management, grazing management, mixed grazing, goat, cattle, sheep.

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To family and friends in Brazil

from whom we had to be away

for four long years

in order to do this

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CHAPTER 1

GENERAL INTRODUCTION

Botanical composition is one of the most important characteristics of any grazing system. The presence and abundance of certain plant species in the pasture are closely related to the quantity, quality, and seasonality of its forage production (i.e. feed supply). These three elements determine both the potential and limitations of the system in meeting animal nutritional demands. Thus, ultimately, changes in botanical composition can affect animal performance, either positively or negatively.

There are several ways to promote desirable changes in the botanical composition of a pasture. In general, these are agronomic techniques designed to address problems related to soil fertility, aeration, water deficit, plant competition, pests, diseases, etc. Grazing management is one such technique and it has the advantage of using a tool that is already available, namely the grazing animal.

Grazing animals differ not only in their diet, but also in the way they obtain it and they cannot feed without causing damage to the plant communities. When well understood and properly manipulated, such damage can be beneficial and result in increased productivity (Popay and Field, 1996).

It has been demonstrated experimentally that goats can cause a significant impact on established weed populations. However, in most studies (Chapter 2) goats have been used as a temporary control measure, i.e. they were brought in, they caused a desired level of damage to an established population of a target weed species, and were then removed from the system. A pasture weed can be killed by transient but severe mechanical damage to its aerial parts, depending on its life cycle and regrowth capacity. However, for many species this is not expected to be an effective control measure, especially if used in isolation. Even if all established plants are killed, weeds are likely to continue to be a problem, unless the conditions that lead them to become established are changed to prevent new recruitment of seeds from the soil seed bank.

The present study explores the possible advantages of integrating goats into grazing systems as a permanent weed control tool instead of a transient one. It is concerned with interrupting the life cycle of weeds and preventing them from becoming established instead of simply attacking established populations without necessarily considering the factors that allow them to become a problem. Its primary hypothesis is that *the permanence of goats in the grazing system can make it less vulnerable to weed invasions*. This would be brought about (a) by their selective grazing, which places weeds at a competitive disadvantage against pasture plants; (b) by preventing flowering and seed formation; (c) by destroying viable seeds that are ingested, thus not allowing seeds to enter the soil seed bank; and (d) by favouring a sward structure that is more competitive against weeds. Factors (a) and (b) have been the subject of many studies in the past and are covered in Chapter 2. However, there is insufficient information about Factor (c), and Factor (d) is a new proposition, thus these are treated as secondary hypotheses to be tested in this study.

The above factors are intimately related to the foraging behaviour of goats, but nearly all information available on this has been derived from experiments where animals had access to at least one woody species, thus little is known about their foraging behaviour in the absence of browse. In New Zealand, goats have traditionally been seen as a weed control option for hill country farms, where scrub weeds are a major problem.

However, goats are also known to control some herbaceous weeds (e.g. many thistle species) and if the hypotheses above are confirmed, there would be further reasons for integrating them into systems such dairy, bull beef, sheep and beef intensive finishing, and mixed finishing farms.

Thus, the specific objectives of this study are:

- to understand the foraging behaviour of goats grazing a plant community comprised of a mixture of grasses, legumes, and herbaceous weeds without access to browse;
- to determine the extent of destruction and viability of weed seeds after passage through the digestive tract of goats;
- to determine the influence of goat and cattle grazing on sward structure and its overall competitiveness against weed emergence and establishment.

These were accomplished through a linked series of experiments and are reported in Chapters 3, 4, and 5, respectively. The experiment reported in Chapter 6 tests the hypothesis that goats will not reject thistle rosettes (as it is currently believed) if the rosettes are sufficiently exposed in the sward. This resulted from field observations carried out in Experiment 1 (Chapter 3).

Finally, the results and discussions specific to each of the four experiments are brought together and discussed as a whole in Chapter 7.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

This review is focused on studies that have used goats for weed control in grazing systems in general. It shows how goats have been managed for this purpose, what weeds they have controlled, and some problems related to goat husbandry that can limit their use for weed control. However, it is difficult to understand how goats can be used effectively to control pasture weeds without understanding how weeds become established in pastures and without considering that goats are not merely "weed eaters", contrary to the popular belief (Yerex, 1986). Thus, these points will also be covered in this chapter, though only to the extent necessary for the understanding of the main topic.

A grazing system is henceforth considered any animal production enterprise that depends largely on the production and utilisation of pastures and, unless indicated otherwise, the term "pasture" will be used for grasslands in general (i.e. both native and cultivated).

2.2. WEED ESTABLISHMENT IN PASTURES

The establishment of weeds in pastures is related to a process known as plant succession, an ecological theory which became widely known after studies carried out by Clements (1916). Its main points were (a) that throughout the development of any vegetation, the same area becomes successively occupied by different plant communities and (b) that vegetation changes progress to a stable state—the climax vegetation (Weaver and Clements, 1938). It also stated that constant or recurrent disturbances to the vegetation prevent it from reaching the climax, thus producing a subclimax vegetation. While these views have certainly helped advance the knowledge of vegetation dynamics, they are now superseded to some extent, especially for considering vegetation changes in one direction only (Chapman and Reiss, 1992). Subsequent contributions and new theories attempting to explain vegetation processes related to plant succession (e.g. MacArthur and Wilson, 1967; Grime, 1979; Tilman, 1982) have resulted in intense debates, most notably between J.P. Grime and G.D. Tilman (Grace, 1990). Yet, no consensus has been reached amongst ecologists as to the causes of successional patterns. Nevertheless, there seems to exist enough agreement to allow some generalisations, at least for the purpose of understanding weed invasions in pastures.

Succession is currently classified according to the vegetation history as primary or secondary (Tilman, 1988; Begon *et al.*, 1996) and to the source of vegetation changes as autogenic or allogenic (Begon *et al.*, 1996). Primary succession starts with the colonisation of bare substrates with no previous vegetation history (e.g. rocks, landslips, sand dunes etc.) and continues with the subsequent transformations in the substrate itself and sequence of species. Secondary succession, on the other hand, occurs where the vegetation was partly or completely removed, but where well-developed soil and plant propagules remain (Tilman, 1988; Begon *et al.*, 1996). Autogenic succession is driven by internal changes such as gradual transformations of the substrate caused by plant growth and decay which, in turn, tend to result in changes in the vegetation (e.g. botanical composition, plant density, etc.). In contrast, allogenic succession is driven by external influences such as droughts, floods, fire, machinery and others (Begon *et al.*, 1996).

Thus, pasture can be considered as subclimax vegetation that is prevented from advancing further towards more complex communities (e.g. forest) by the pressure exercised by grazing animals or by a combination of this and abiotic factors such as soil depth and moisture (Gray *et al.*, 1987; Briske, 1996). Changes in the botanical composition of pastures are normally related to secondary succession (except in the case of landslips) and result from both autogenic and allogenic factors. Even stable communities are subject to botanical fluctuations (Archer and Smeins, 1991), i.e. reversible changes in species dominance in a sward (Rabotnov, 1974). However, if changes continue in one direction instead of fluctuating, succession will lead to either progression or retrogression. Progression is characterised by increased plant density, productivity, and species diversity, while retrogression is the opposite (Archer and Smeins, 1991), a bi-directional concept which was not allowed for in the model proposed by Clements (1916), discussed earlier.

When stable, a pasture can form a dense canopy that covers the ground and remains productive for a long time, provided adequate grazing pressure and growing conditions (i.e. nutrients, water, and soil aeration) are maintained (Tainton, 1996). Pasture plants have evolved under heavy herbivory pressure, thus they are capable of surviving frequent and sometimes severe defoliation and treading (Briske, 1996). However, factors such as treading on wet soil, droughts, fire, dung patches, camping sites, overgrazing, erosion, etc., can offset the vegetation balance and break its resistance against invasions (Gray *et al.*, 1987). These are known as disturbances (Harper, 1977). Disturbances that create gaps in the plant canopy are of special importance for the establishment of pasture weeds, especially if the soil becomes exposed (Panetta and Wardle, 1992; Beskow *et al.*, 1994). This is because some weed seeds require light that is unfiltered by the canopy to germinate, i.e. with high red:far-red ratio (Medd and Lovett, 1978; Cresswell and Grime, 1981; Popay and Kelly, 1986; Beskow, 1995), or at least for their seedlings to become established (Salisbury and Ross, 1992).

Additionally, the temperature amplitude is greater in the gaps than under the canopy (Harper, 1977) and fluctuations in temperature are known to stimulate germination of some weed species and even to substitute for light requirements, in some cases (Thompson *et al.*, 1977).

If the pasture is capable of closing the gaps before weed seedlings emerge or while they are small and more vulnerable to competition, then the weeds have little chance to establish themselves (Popay, 1981). If, on the other hand, the gaps are too large or the pasture is not dense or vigorous enough to close the gaps quickly, weeds are likely to become established. Nevertheless, seedlings of some pasture weeds, such as ragwort (*Senecio jacobaea*), are capable of surviving without any growth for up 6 months under a pasture canopy that has closed up after their emergence (Beskow, 1995).

Even if gaps become available and growing conditions are favourable, weeds cannot establish if there are no propagules in the soil (i.e. any reproductive or vegetative organ capable of developing into new plants), especially seeds. Weed seeds can remain viable in the soil for many years through different kinds of dormancy mechanisms (Harper, 1977; Roberts, 1982), which make their establishment possible even if there has not been any recent seed ingress into the area.

Despite the invasive characteristic of many species of pasture weeds (i.e. the capacity to occupy open gaps quickly), they are not confined to a particular stage in plant succession (Scott, 2000). Their different strategies (Grime, 1979) allow them to persist in a wide range of environmental conditions (Holzner, 1982). However, as individual species, they are often more limited as to the type of environment in which they can thrive. Some weeds such as broad-leaved dock (*Rumex obtusifolius*), for instance, are typical of moist soils (Webb *et al.*, 1988), while others such as nodding thistle (*Carduus nutans*) are usually found in dry areas (Popay and Thompson, 1979). Nevertheless, most weeds are adapted to cope with major changes in resource availability (e.g. light, moisture, and nutrients) throughout their lives (Tilman, 1988; Mortimer, 1990). This attribute when coupled with morphological changes is known as phenotypic plasticity (Bradshaw, 1965) and the species that possess it have major competitive advantage against those with fixed morphology (Tilman, 1988).

Weed strategies are discussed further in Chapter 7, but it should be pointed out at this stage that species attributes such as duration of life cycle (Zimdahl, 1999), tolerance to grazing (Briske, 1996; Friend and Kemp, 2000), defensive mechanisms (Briske, 1996), and form of reproduction (Mortimer, 1990) are very important for the establishment and survival of weeds in pastures, as well as for planning their control, irrespective of the method adopted (Roberts, 1982).

A number of studies have consistently demonstrated that the establishment of weeds in pastures can be minimised through the choice of pasture species and cultivars (Ivens, 1979), through grazing management (Hartley *et al.*, 1978), use of herbicides (Ivens, 1982), fertilisers (Thompson, 1974), control of insect pests (Popay, 1981), or through combinations of these (Popay, 1981; Popay *et al.*, 1990; Rahman *et al.*, 1993). With the exception of herbicides, all these alternatives are actually methods of making pastures more competitive against weeds and this is an important concept underlying this thesis, as outlined in Chapter 1.

2.3. FEEDING BEHAVIOUR OF GOATS

Goats were one of the first animals to be domesticated (Mowlem, 1988), yet our knowledge of their feeding behaviour very limited. In a review of several aspects of goats feeding on pasture, McCall and Lambert (1987) pointed out that knowledge of the influence of pasture conditions on goat production was scant. In reviewing the feeding behaviour of goats, Narjisse (1991) argued that the database specific to goats was fragmentary and that the knowledge of fundamental foraging relationships of goats and the environment was empirical and controversial. This situation has hardly changed since then, probably because very few studies on feeding behaviour of goats have been conducted in the last 10 years.

There has been some disagreement as to whether goats should be considered grazers or browsers (Cory, 1927; Norton, 1985). In their original habitat, the Himalaya and neighbouring Middle East and Asian regions, goats are essentially cliff dwellers, some living on treeless hills and others on wooded ones. On the wooded hills they consume a wide variety of forbs and leaves from shrubs and trees, but are seen more often on grass, whenever it is available. However, during dry seasons, when grass becomes scarce and tree leaves are still abundant, browsing becomes more common (Schaller, 1977). Marked seasonal differences in time spent browsing versus time spent grazing have also been detected in other free-ranging goats, such as feral goats in a New Zealand reserve, where both browse and grasses were always available (Stronge *et al.*, 1997). This capacity to adapt to different diets with seasonal and geographical variations led Lu (1988) to suggest that they would be better described as "mixed-feeding opportunists", thus being neither exclusively grazers nor exclusively browsers. (This view is also shared by Narjisse, 1991.) Thus, the terms "feeding" or "foraging behaviour" are used in this thesis instead of grazing behaviour to include both browsing and grazing, where appropriate.

A number of studies have recorded or estimated the relative amount of plant species selected by goats and some have used that to draw conclusions about preferences (e.g. Penning, 1997; Malechek and Leinweber, 1972; Orihuela and Solano, 1999). Yet, few studies have related the amount of each plant species selected by goats to the availability of the same species in the vegetation (Clark *et al.*, 1982; Mitchell *et al.*, 1987; Ganskopp *et al.*, 1997). Strictly, preference can only be determined if all components are available to animals without restriction (Hodgson, 1990; Newman *et al.*, 1995). Thus, care should be exercised with interpretation of diet selection studies because other factors such as access to species and risks (e.g. predation, cliffs etc.) may influence the diet selection process (Laca and Demment, 1996).

The upper lip of the goat is complete and muscular and lacks the dividing philtrum found in sheep. According to Smith and Sherman (1994), this favours the grasping and tearing of browse, while the philtrum in the sheep favours consumption of grasses close to the ground. Goats are able to select specific plant organs such as small flowers within a spiny bush (Schaller, 1977), while sheep are not known to do this. Amongst the domestic ungulates, goats are unique in using a bipedal stance to access vegetation overhead (Wood, 1987; Lu, 1988) and to climb trees in search of food, if the trunk and branch structure allow (Garcia and Gall, 1981; Erasmus, 2000). They are also known to travel greater distances than cattle and sheep in the same environment (Cory, 1927; Arnold and Dudzinski, 1978).

General claims that the digestive processes of goats are more efficient than those of cattle and sheep do not seem to be supported by experimental evidence, as discussed in a review on the nutrition of goats (AFRC, 1998). However, this same review noted that if the digestibility of the organic matter on offer is lower than 60% and animals are not supplemented with nitrogen, goats are likely to be more efficient in digesting it than sheep because of their higher concentration of rumen ammonia.

2.4. USE OF GOATS FOR WEED CONTROL

Most of the research on the use of goats for weed control in pastures has been done in New Zealand and Australia. According to Crouchley (1983), the use of goats for weed control in New Zealand started in 1906, when they were introduced on farms for the control of blackberry (*Rubus fruticosus*) from feral populations that had been in the country since 1773 (Yerex, 1986). The earliest scientific reports are papers published in the *New Zealand Journal of Agriculture* by Scott (1924), Fawcett (1925), Wright (1927), and Guthrie-Smith (1929) on the use of goats for the control of blackberry, gorse (*Ulex europaeus*), and bracken (*Pteridium esculentum*). Despite these reports lacking the rigour of modern science (Bunge, 1998; Chalmers, 1999), they do show that the use of goats specifically for the control of pasture weeds is an alternative that has been considered by scientists and farmers for a long time.

In Australia, scientific studies seem to have started in 1975 in New South Wales (NSW) (Holst, 1980) and have been concentrated mainly in that state, especially on thistles, which are amongst the most important weeds in temperate Australian pastures (Sindel, 1997).

2.4.1. How goats control weeds

According to Holst (1980), goats control weeds by (a) preventing flowering and subsequent seed dispersal; (b) preferential grazing, thus placing a weed at a competitive disadvantage; (c) causing mechanical damage, either by ring-barking (woody species) or destroying the plant because of its structural weakness; or (d) a combination of these.

It may be possible to prevent seed dispersal even if weeds manage to set seeds, provided all seed-heads are eaten by goats before seed rain takes place and seeds are destroyed during digestion (this is studied in Chapter 4). Additionally, a weed can be at a competitive disadvantage even if it is not a species preferred by goats (e.g. through grazing management techniques that reduce animal choice). These points will be discussed in depth in Chapters 4, 5, 6, and 7, in light of the results obtained in the current study.

2.4.2. Previous weed control studies

Most studies have used either goats and sheep, or goats alone, and very few have had goat and cattle or goat, cattle, and sheep treatments, as discussed in the following sections.

2.4.2.1. Goats alone

Torrano *et al.* (1999) compared the effectiveness of goats versus herbicides (MCPA and clopyralid) for the control of Illyrian thistle (*Onopordum illyricum*) in NSW. Both methods reduced the number of seed-heads significantly (up to 80% when combined) and plant numbers by up to 90%. Plants that survived goat grazing produced fewer seed-heads per plant compared to untreated thistles, while plants treated with herbicides produced more viable seeds. This was attributed to sprayed thistles having lower competition from surrounding plants compared to thistles eaten by goats (note, however, that sprayed thistles should have been killed by the herbicides, which suggests that the application rate was too low). The authors recommended one goat per hectare for each 3% ground cover of Illyrian thistle for total control with goats alone.

Goats have also been used on their own for the control of blackberry in NSW with success (Dellow, 1988). Stocking rates varied from 7 to 12 goats per hectare of densely infested blackberry country. Goats penetrated large and dense blackberry bushes (more than 2 m high) by pushing tracks into the centre of the bushes. Plants of less then 1 m high were completely defoliated in 6 months (the duration of the trial) and those higher than this were reduced to small individual bushes, resembling large mushrooms, with leaves on top where goats could not reach.

A comprehensive diet selection study was carried out by Fajesmin *et al.* (1996) to determine the potential of goats for the control of woody species in the sagebrush steppe in Oregon, USA. The main species of interest were sagebrush (*Artemisia tridentata*) and juniper (*Juniperus occidentalis*), but these constituted only a small proportion of the diet of the goats (less than 1%), especially when there was abundant herbaceous forage. Thus, it was concluded that goats have little potential to control these two species, especially if alternative feed options are available.

2.4.2.2. Goats and sheep

Perhaps the most well known study of weed control by goats was the one carried out in a hill country pasture at the Ballantrae Research Station of DSIR Grasslands Division (now AgResearch Grasslands), in Woodville, New Zealand (Lambert *et al.*, 1981; Rolston *et al.*, 1981; Rolston *et al.*, 1983; Clark and Lambert, 1989). Treatments consisted of four combinations of sheep and goats (ranging from pure sheep to pure goats) set-stocked, and one sheep treatment, mob-stocked. Treatments containing goats had a major impact on gorse, manuka (*Leptospermum scoparium*), rushes (mainly *Juncus pallidus,* but also *J. australis, J. gregiflorus,* and *J. sarophorus*), Scotch thistle (*Cirsium vulgare*), marsh thistle (*C. palustre*), Californian thistle (*Cirsium arvense*), barberry (*Berberis glaucocarpa*) and blackberry. Some plants were killed, while others were reduced in size and vigour. Goats were also more effective in controlling the formation of mature flower-heads than sheep. Goats spent a large proportion of their feeding time on banks and kerbs, which were rarely visited by sheep. This is consistent with observations of sheep and goats in their original habitats (Schaller, 1977). Set-stocked sheep resulted in poor or no weed control. Mob-stocked sheep had some impact on weeds, but the authors pointed out that the method would not be practicable in a commercial situation (Lambert *et al.*, 1981), probably because of losses in animal performance.

Radcliffe (1983; 1984; 1985; 1987; 1990) studied the effect of animal species (goats and sheep), pre-conditioning (cutting and burning), and grazing method (set-stocking, rotational grazing, and mob-stocking) on the control of gorse on rolling downlands, at North Loburn, New Zealand. Goats (alone or mixed with sheep) were effective in reducing mature gorse cover (up to 2 m high) to negligible levels in 2 years, while sheep alone at equivalent stocking rate were ineffective. Grazing method had no effect on gorse control in goat-only treatments, but rotational grazing was more effective than set-stocking when goats were grazed with sheep. Burnt gorse regrowth was satisfactorily contained by goats at high stocking rates (35 goats/ha).

Combinations of sheep and goats were also used in a study carried out at Mosgiel, New Zealand (Cossens *et al.*,1989), for the control of matagouri (*Discaria toumatou*), which is a small, piny tree species, and purple fuzzweed (*Vittadinia triloba*), a 20-30 cm tall herbaceous perennial weed. Increased reduction in matagouri cover was obtained with increasing percentage of goats in the treatments (all treatments used burning followed by superphosphate topdressing, and legume oversowing before grazing started). However, both animal species refused to forage on purple fuzzweed, thus had no direct effect on its control.

McGregor *et al.* (1990) studied the effect of goats and sheep on control of cotton thistle (*Onopordium acanthium*) and artichoke thistle (*Cynara cardunculus*) in southern Victoria, Australia. Goats reduced the height and vigour of tall and medium thistles and depressed flowering, but had little effect on the height and vigour of short plants. Sheep did not affect the height nor the vigour of thistles, but they did consume artichoke regrowth that resulted from goat grazing. Cotton thistle had its life prolonged into summer as a result of goat grazing. This was found favourable from the nutritional point of view, because of its higher quality compared to senescent pasture. However, it also provided opportunity for thistles to flower again if not subjected to further goat grazing.

Combinations of goats and sheep were also used by Campbell and Holst (1990) in a study of the control of Illyrian thistle in NSW, Australia. The authors were primarily concerned with the prevention of flowering. Goats consumed all Illyrian thistle flower-heads in summer before seeds were produced, though this did not result in reduced seedling density in the subsequent autumn, contrary to what was expected. This indicated that the soil seed bank had viable Illyrian thistle seeds close to the surface from previous years, as was shown later by Allan and Holst (1996). Sheep were not effective in preventing thistles from producing large quantities of viable seeds. Campbell and Holst (1990) considered that the stocking rate of goats must be adjusted to the biomass of weeds available for complete flower-head consumption (this is discussed in detail in Chapter 7). Similar results and conclusions were reached by Holst and Allan (1996) and Stanley *et al.* (2000) with Illyrian, nodding, and variegated (*Silybum marianum*) thistles also grazed by sheep and goats.

2.4.2.3. Goats and cattle

Studies combining cattle and goats for weed control seem to be very rare, though anecdotal reports do exist (e.g. Anonymous, 1988). Thompson and Power (1993) studied the effects of adding goats to a beef cattle system, but no information was given on weeds (their findings are discussed in Chapters 5 and 7).

Provenza *et al.* (1983) used a mixed grazing of goats and cattle to modify the growth form of blackbrush (*Coleogyne ramosissima*), a densely branched, spinescent shrub found in nearly monospecific stands in large areas of south-western USA, which is poorly utilised by cattle. Goat browsing in winter (stocked at various intensities) provided increased spring twig production and quality for the cattle. Though the utilisation of blackbrush by cattle increased with the addition of goats, no significant differences in cattle weight responses were found, contrary to what was expected by the authors.

2.4.2.4. Goats with sheep and cattle

Limited information is available on relative and combined impacts of sheep, cattle, and goats on pasture weeds. Wood (1987) compared the potential of each of these animals for the control of several weed species in Vermont, USA, by monitoring their diet and assessing vegetation changes. Overall, goats were found to have a much greater impact on weeds than sheep and cattle. Unlike the other species, goats destroyed small trees and shrubs by debarking them, were not deterred by thorny vegetation, and browsed much higher by standing on their hind legs. Grass cover increased in response to brush destruction by goats.

2.4.3. Possible drawbacks

Despite the advantages presented by goats for weed control, it should be noted that they also present some potential drawbacks. These include: (a) having the same intestinal worms as sheep (Smith and Sherman, 1994); (b) some goats can be difficult to confine within paddocks (DOC, 1998); (c) they can damage conservation or shelter trees, especially by debarking them (Rolston *et al.*, 1983); and (d) they can suffer from foot problems, particularly scald, but also footrot (Smith and Sherman, 1994).

Although these problems can become very serious, researchers and farmers have come up with strategies that can either eliminate or minimise them. These are discussed in Chapter 7.

2.5. SUMMARY

Below are the main points of this review:

(i) The establishment of weeds in pastures is attributable to the existence of favourable ecological conditions, most of which can be minimised through pasture management, particularly through methods that promote a dense and vigorous sward.

(ii) Goats have some anatomical, behavioural, and physiological differences that allow them to utilise plant species not normally eaten by other livestock.

(iii) Goats can be managed effectively to control a number of woody and herbaceous weeds.

(iv) Studies have concentrated on attacking established populations of pasture weeds. Limited information is available on whether goats can help prevent the emergence and establishment of weeds in pastures.

CHAPTER 3

FORAGING BEHAVIOUR OF FREE-RANGING GOATS GRAZING A DIVERSE HERBACEOUS PLANT COMMUNITY

3.1. INTRODUCTION

The success of integrating goats into sheep and cattle grazing systems for maximising the utilisation of plant resources and minimising weed problems will largely depend on the diet that goats will select (Chapter 7). The more weeds they eat, the greater the expected impact on the suppression of weed populations (Holst, 1980), and the lesser the competition with other stock for grass and clover.

However, our knowledge of foraging behaviour of goats has many gaps (Chapters 1 and 2). Studies of diet selection by goats are almost exclusively based on vegetation comprising mixtures of herbaceous and woody plant species (e.g. Clark *et al.*, 1982; Malechek and Provenza, 1983; Radcliffe, 1987; Kronberg and Malechek, 1997). Merchant (1996) seems to have done the only goat diet-selection study (UK) looking at an herbaceous weed (*Juncus effusus*) in the absence of shrubs and trees.

Herbaceous weeds are a significant problem in many grazing systems in New Zealand, especially on dairy farms (Bôurdot *et al.*, 1994), sheep and beef intensive finishing, and mixed finishing farms (New Zealand Meat & Wool Boards' Economic Service, 1998). In these systems woody weeds are usually not present, so the time that goats would normally invest in browsing such vegetation must necessarily be directed to grasses and forbs (herbaceous legumes and weeds), if a similar daily intake is to be maintained. The foraging behaviour of goats in these conditions remains largely unknown.

The objective of the study reported in this chapter was to determine the diet selected by free-ranging goats in an environment where only herbaceous plants were available. It was designed to answer the following specific questions:

(i) *What is the relative contribution of weeds, grasses, and clover to the diet of goats when they are allowed to graze such a mixed vegetation freely?*

(ii) *Will this diet be affected by season of the year?*

(iii) *Will goats obtain their diet randomly or is there a pattern of selection and avoidance in such conditions?*

(iv) *What plant organs will be eaten?*

(v) *Will goats eat thistle rosettes, or are thistles only consumed when they are in the reproductive stage, as it is claimed?*

(vi) *Assuming goats will eat grasses in spring and summer, what is the importance of grass seed-heads to the total amount of grasses consumed during this time of the year?*

(vii) *Will goats harvest the top of the pasture only, as it is normally claimed, or are other strata also explored?*

3.2. MATERIALS AND METHODS

The foraging behaviour of a group of free-ranging Angora does was monitored on a commercial farm from December 1997 to November 1998.

3.2.1. The farm

The farm is a small Angora stud of 16 ha, located in Feilding (Manawatu). The land was bought in 1985 and goat breeding started in the same year by mating Angora bucks with feral does. It is an easy hill country farm, with approximately 15% of the land formed by easy slopes, 80% by medium slopes, and 5% by steep slopes.

Paddocks ranged from 1 to 5 ha and were divided by permanent internal fences (five electric wires) and conventional boundary fences (no electric wires). The farm has no problems with animals escaping through fences. None of the paddocks has enough flat area to allow hay production, which limits the number of stock that can be carried through winter and results in under-grazing during summer, according to the farmer.

During this study, the farm carried 40 does, 35 kids, 18 wethers, 6 bucks, and 10 steers, but used to carry 80 does from 1985 until February 1997 (9 months before the current study began). Animals are rotationally grazed during the whole year, except during kidding in September, when does are set stocked for a few weeks. Goats and cattle are grazed separately (cattle following goats), except in the largest paddock during summer, when they are often grazed together.

Pastures were established more than 20 years ago and have a history of very low and infrequent fertilizer (phosphate) application. When the property was bought, winged thistle (*Carduus tenuiflorus*) was widespread throughout the whole farm and was very dense in some paddocks. Barley grass (*Hordeum* sp.) is the only weed the farmers are not able to control through grazing management, so they rely on herbicides to control it (patches are spot sprayed). Scrub weeds have never been seen on the property

Other aspects of the farm and its management are conventional in New Zealand, according to the general practices described by Yerex (1986; 1991) for goat farming.

3.2.2. Measurements and observations

3.2.2.1. Foraging behaviour

Foraging behaviour was monitored by observing 10 does out of a group of 40, for 10 minutes each, twice a month (first and third weeks of each month), for 12 months. The criteria for selecting the animals for observation was based on their position within the flock during normal grazing activity, as follows: centre most (Animal 1); northern most (Animal 2); north-eastern most (Animal 3); eastern most (Animal 4); south-eastern most (Animal 5); southern most (Animal 6); south-western most (Animal 7); western most (Animal 8); north-western most (Animal 9); centre most (Animal 10). The flock was usually highly mobile and there was typically two hours between the first and the last animal being observed. Thus, to prevent the same animal from being monitored more than once in the same day, distinct characteristics of each animal were recorded each time. If there was doubt about this, the animal closest to the next position that had clearly not been observed was then chosen. This procedure ensured a random selection of animals on each occasion.

All observations were carried out in the afternoon, following the recommendations by Greaves *et al.* (1991), who found that the odds of observing a goat grazing in a New Zealand hill country pasture during the afternoon were twice that of observing a goat grazing in the morning.

A verbal description technique (Martin and Bateson, 1993) was adopted by dictating 10-minute sampling intervals of pre-defined animal activities into a miniature tape-recorder. Data was later coded by playing back the tape and timing each activity. Activities were expressed in percentage time (see details below).

Animal states (Martin and Bateson, 1993) were recorded as either grazing or not grazing. Non-grazing activities were recorded as walking (when animals walked without taking any bites, otherwise it was recorded as grazing), standing, grooming, or sitting. Percentage time of non-grazing activities was relative to total observation time. When animals were grazing, the following variables were recorded: (a) plant species; (b) plant organ (stem, leaf, flower, or seed-head); (c) physiological status of the organ (i.e. green or dead); (d) bite height (i.e. prehension bite height), and (e) local vegetation height. Percentage time of grazing activities was relative to grazing time. Plant organ and physiological status combined formed a component (e.g. dead stem, green leaf etc.). Bite height and local vegetation height were based on a scale from 1 to 9 relative to animal body parts, as shown in Plate 3.1.

The corresponding values in centimetres were obtained by measuring a random sample of 10 animals from the same group. Local vegetation height was the absolute top surface of the vegetation within a radius of approximately 50 cm around a feeding station (defined in Section 3.2.2.4).

After a two-week habituation period, animals allowed the observer to stay very close to them (up to 2 m), suffering no apparent distress or interference. Observations, however, were made 3 m away from the animals with the naked eye and perpendicular to their walking movement. Binoculars were used to identify the plant species or the organ, when in doubt. Grasses were not identified to specific level, but all other species were positively identified.

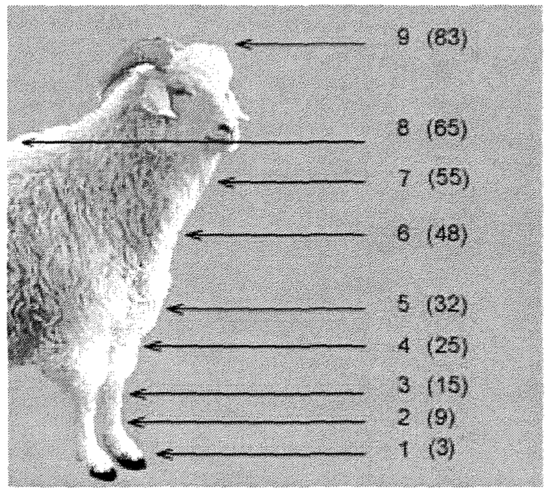


Plate 3.1 Scale (1-9) relative to the body of the goats used during all observations for determining prehension bite height and local vegetation height. Values in parentheses denote corresponding heights in centimetres above ground level.

3.2.2.2. Botanical composition

Botanical composition of the sward was determined by assessing the percentage cover (Greg-Smith, 1964) of the area that had actually been explored by the goats during the two hours of observations (typically 0.5-1.0 ha). A 1 x 1 m quadrat was divided into four sub-units of 0.5 x 0.5 m, so that any of the species present could fit into the sub-units at any stage of development. Twenty quadrat samples were assessed along two intersecting transect lines, crossing the area from corner to corner, making 80 sub-samples per session (i.e. ten quadrat samples per transect, with four sub-samples per quadrat). The interval between quadrats (typically 8-14 m, depending on the shape of the area) was 1/10 of each transect length. Percentage cover was visually appraised using a scale from 1 to 10, 1 being attributed to a species that covered up to 10% of the ground, and 10 to one that covered 91-100% (Kent and Coker, 1992).

Leaf surface height (measured at the top surface of the grass and clover leaf canopy) and vegetation height (measured at the top surface of the vegetation) were recorded in each quadrat sub-unit with a sward stick (Frame, 1993). Additionally, the presence or absence of green or dead leaves, stems, flowers, and seed-heads was recorded for each species.

3.2.2.3. Selection Index

A selection index (SI) was obtained to provide a measure of the effort made by goats to select or avoid each species. This index reflects the relationship between time spent per species and the proportion of that species in the botanical composition. It was calculated based on the logistic model (for details see McCullagh and Nelder, 1983), as follows:

$$\mathrm{SI} = \mathrm{Ln}\,\frac{\mathrm{P\,time}/(1-\mathrm{P\,time})}{\mathrm{P\,cover}/(1-\mathrm{P\,cover})} \tag{3.1}$$

where:

Ln	=	natural logarithm
P time	=	proportion of time harvesting and handling species, i.e. percentage time (Section 3.2.2.1) divided by 100
P cover	=	proportion of species in the vegetation cover, i.e. percentage cover (Section 3.2.2.2) divided by 100

The SI values were divided into seven classes according to their distance from zero, based on regular intervals of time and cover proportions, as shown in Table 3.1. Positive values were considered an effort for selection; negative ones, an effort for avoidance; and zero denoted neutrality, i.e. no effort for selection, nor avoidance.

Table 3.1 Classes of efforts made by goats for selection (positive SI) and avoidance (negative SI) based on regular intervals of time and cover proportions. Neutral selection (N) for SI = 0.00; minor selection (MNS), SI from +0.01 to +1.36; moderate selection (MDS), SI from +1.37 to +3.23; strong selection (SS), SI ≥ +3.24; minor avoidance (MNA), SI from -0.01 to -1.36, moderate avoidance (MDA), SI from -1.37 to -3.23, and strong avoidance (SA), SI ≤ -3.24.

Time/cover [1]	...	0.17/0.84	...	0.34/0.67	...	0.50/0.50	...	0.67/0.34	...	0.84/0.17	...
SI [2]		-3.24		-1.37		0.00		+1.37		+3.24	
Class	SA		MdA		MnA	N	MnS		MdS		SS

[1] Time = proportion of time harvesting and handling species; cover = proportion of species in the vegetation cover. [2] For definition, see Equation 3.1.

3.2.2.4. *Feeding areas*

To assist with interpretation of foraging behaviour, the feeding areas explored by goats were classified as feeding patch, feeding station, and feeding or non-feeding trails. A feeding patch was a horizontal section of the vegetation visited by the mouths of the goats from which the same type of food was collected. These are illustrated by the shaded areas in Figure 3.1 on the horizontal plane and by short horizontal lines on the vertical one. Note that feeding patches can overlap (denoted by the black areas).

Goats were considered to have changed feeding patch when at least one of the following conditions was satisfied: (a) goats changed species; (b) goats changed organ being harvested; (c) goats changed bite height; (d) while walking and grazing, the local vegetation height changed; or (e) goats walked without feeding. Thus, a feeding patch can be seen as an imaginary horizontally displayed "tray" of variable size and shape, containing only one type of feed.

The area surrounding consecutive feeding patches was called the feeding trail. This was the horizontal projection of the total vegetation volume explored by goats while grazing (denoted by the two rectangular areas in Figure 3.1). Two consecutive feeding trails were separated by a non-feeding trail, which was simply an irregular line that animals walked without harvesting anything on the way (walks were normally in search for new feeding patches).

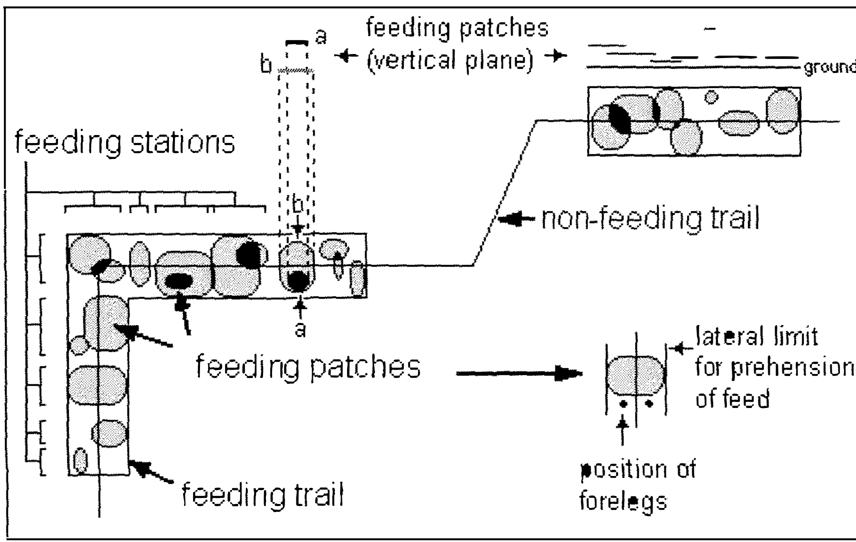


Figure 3.1 Horizontal and vertical projections of feeding areas explored by goats.

A feeding station (Ruyle and Dwyer, 1985) was any place within a feeding trail where animals grazed without moving their forelegs. Consequently a feeding trail was comprised of one or more feeding stations, and each feeding station, by one or more feeding patches.

3.2.2.5. Bite height index

A bite height index (BHI) was calculated by dividing bite height by the local vegetation height in order to determine whether the feeding patch was at the top of the vegetation (BHI = 1.0) or lower (BHI < 1.0). Each feeding patch generated one BHI.

3.2.3. Statistical analyses

Variances of percentage time grazing were not homogeneous for comparisons between species. As transformations did not improve homogeneity significantly, the Kruskal-Wallis one-way analysis of variance by ranks (Daniel, 1990) was performed using the SAS NPAR1WAY Procedure, with X^2 (Chi-square) approximation (SAS, 1996). Multiple comparisons of mean percentage time between species within seasons, and between seasons within species were carried out using the following nonparametric procedure (Daniel, 1990):

$$\left|\bar{R}_i - \bar{R}_j\right| \leq z\left(1-\left[\alpha/k(k-1)\right]\right)\sqrt{k(N+1)/6} \tag{3.2}$$

The left side of Equation 3.2 is the difference between any two ranks (R) of percentage time being compared. These were the Wilcoxon mean sum of ranks, obtained through the same NPAR1WAY Procedure mentioned above. The right side is the test statistic, which is a function of the number of samples (k), the number of observations (N), the experimentwise error rate (α), and the standard normal curve z value. Rank differences which were larger than this test statistic were declared significant (P=0.05).

Percentage time spent on herbage plants (grasses and white clover) versus percentage time spent on weeds in general (i.e. on all weed species) was analysed through the Wilcoxon two-sample test with normal approximation, using the same SAS NPAR1WAY Procedure.

SI values were skewed and transformations did not significantly improve normality. Thus, for testing the null hypothesis that the true SI was zero, the centred Wilcoxon sign rank test was used by means of the SAS UNIVARIATE Procedure (SAS, 1996). This is a distribution-free statistic, so it was not affected by the skewness of the data (Daniel, 1990).

To test the hypotheses that the species harvested were independent of (a) bite height, (b) vegetation height, and (c) plant components, the X^2 test of independence was performed through the SAS FREQ Procedure (SAS, 1996).

3.3. RESULTS

Variations in percentage time, percentage cover, and SI were relatively small between months within seasons, but were large between seasons. For this reason, the results are presented on a seasonal basis and only the most relevant monthly events are commented on. Summer was considered the period from early December to late February; autumn, from early March to late May; winter, from early June to late August; and spring, from early September to late November. Data are presented in the same chronological order in which the observations were made (i.e. from summer of 1997 to spring of 1998).

3.3.1. Botanical composition

Table 3.2 lists the plant species found on the farm. Most of these species were regularly distributed in all paddocks, but daisy, dandelion, lotus, soft brome, and nettle were only found very infrequently. Scotch and winged thistles were distributed in clusters. While Scotch thistle was present in all paddocks, winged thistle was only found in two paddocks.

There were marked fluctuations in relative contributions of each species to the botanical composition throughout the year (Figure 3.2, p.30). Both Scotch and winged thistles (Figure 3.2b and d, respectively) presented a similar pattern of percentage cover, with peaks in summer and no considerable cover in winter (nil for winged thistle). White clover (Figure 3.2c) also behaved similarly, but its maximum cover was recorded in spring and its minimum, in autumn.

Table 3.2 Plant species present in at least one sample, from December 1997 to November 1998.

Family	Species
Asteraceae	catsear (*Hypochaeris radicata*) daisy (*Bellis perennis*)[1] dandelion (*Taraxacum officinale*)[1] Scotch thistle (*Cirsium vulgare*) winged thistle (*Carduus tenuiflorus*)
Fabaceae	white clover (*Trifolium repens*) lotus (*Lotus pedunculatus*)[1]
Juncaceae	rushes (*Juncus* sp.)
Plantaginaceae	narrow-leaved plantain (*Plantago lanceolata*)
Poaceae	annual poa (*Poa annua*) barley grass (*Hordeum* sp.) browntop (*Agrostis capillaris*) cocksfoot (*Dactylis glomerata*) crested dogstail (*Cynosorus cristatus*) perennial ryegrass (*Lolium perenne*) prairie grass (*Bromus willdenowii*) soft brome (*Bromus hordeaceus*)[1] sweet vernal (*Anthoxanthum odoratum*) Yorkshire fog (*Holcus lanatus*)
Polygonaceae	broad-leaved dock (*Rumex obtusifolius*)
Ranunculaceae	creeping buttercup (*Ranunculus repens*)
Urticaceae	nettle (*Urtica urens*)[1]

[1] Traces of cover only.

Broad-leaved dock, narrow-leaved plantain, and catsear all presented a summer minimum and a spring maximum cover, with a steady increase from summer to spring (Figure 3.2f, g, and h, respectively). Additionally, they had similar percentage cover values. Rushes had the most uniform cover, close to 5.1% for the whole year, and this was unlike any other species (Figure 3.2e). The closest pattern was that of creeping buttercup (Figure 3.2i), in that both displayed a winter maximum. Grasses were the dominant cover (Figure 3.2a), with an autumn maximum and a spring minimum. This group encompasses all the species listed under Poaceae in Table 3.2, but the dominant grass species was browntop (*Agrostis capillaris*), at all times. Figure 3.2(j) summarises all weeds and herbage plants. The overall weed cover was maximum in summer, with similar value in spring, and minimum in autumn, with a similar cover in winter.

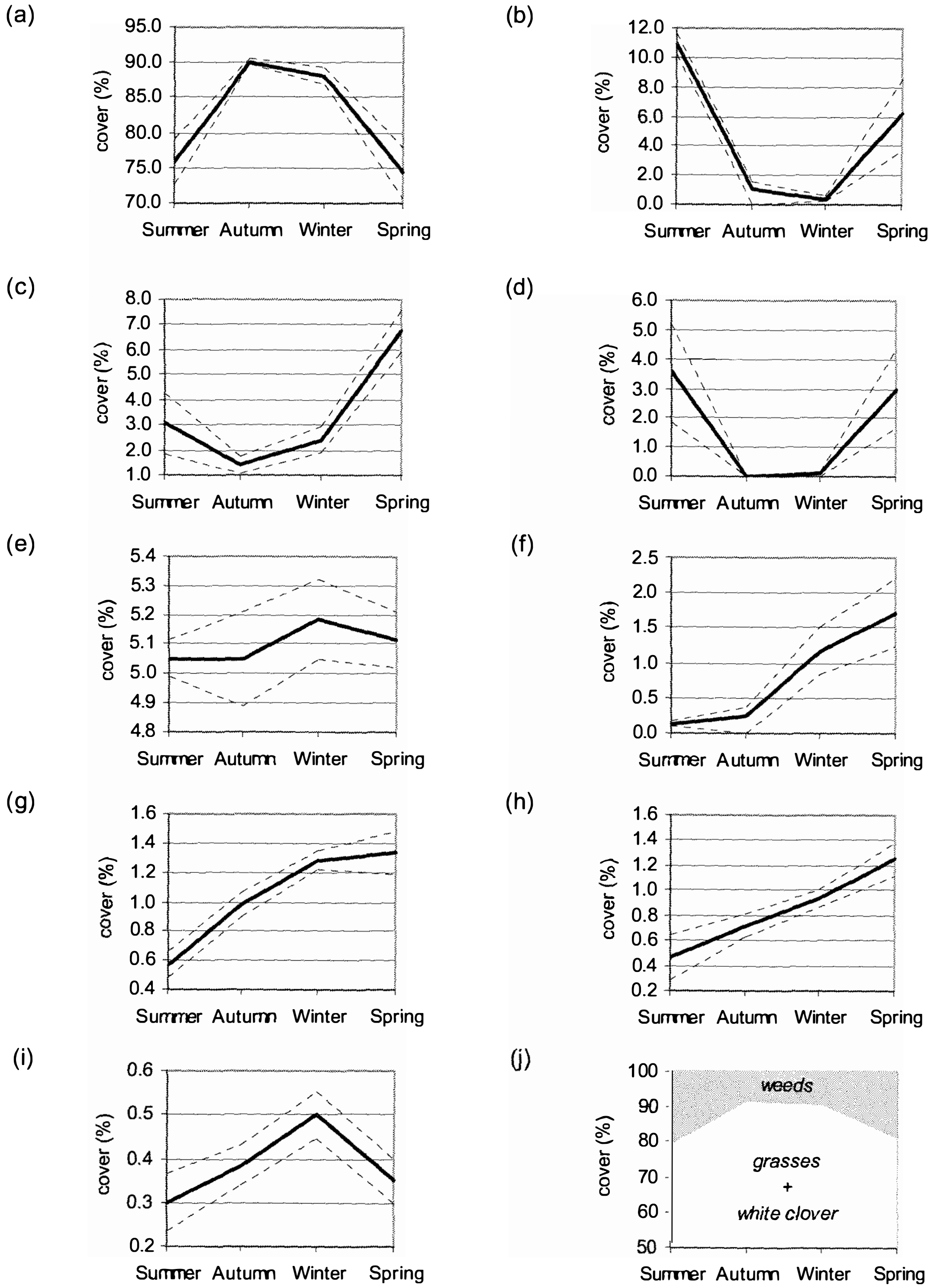


Figure 3.2 Botanical composition of pasture grazed by goats, from December 1997 to November 1998. Lines are mean percentage cover (—) ±SEM (--). (a) grasses; (b) Scotch thistle; (c) white clover; (d) winged thistle; (e) rushes; (f) broad-leaved dock; (g) narrow-leaved plantain; (h) catsear; (i) creeping buttercup; (j) weeds total (i.e. all, except a and c), and herbage (i.e. not weeds) total (a and c).

Flowering, in general, started in early spring and extended till late summer. The first species to flower was narrow-leaved plantain in early September, followed by creeping buttercup in October, and the remainder of the species in November. All species reached their peak of flowering (number of inflorescences per unit of area) in November and December. However, very few plants of broad-leaved dock and rushes were seen in flower.

3.3.2. Selection of individual plant species

The amount of time that goats spent grazing herbage plants was consistently higher than the time spent on weeds ($P<0.0001$). This general pattern is illustrated in Figure 3.3(a) by comparing the seasonal means of percentage time spent on each of the plant groups. Note also that the proportion of time spent on weeds was maximal in summer, minimum in autumn, and intermediate in winter and spring. The general composition of the vegetation cover for the same period is shown in Figure 3.3(b) for comparison. The relationship between percentage time and percentage cover is addressed in Section 3.3.3.

Table 3.3 provides detailed information on percentage time spent grazing by goats per plant species. There was a significant seasonal effect ($P=0.05$) on percentage time for all species, except for catsear. This effect was also significant ($P=0.05$) when the species were grouped into herbage total and weed total.

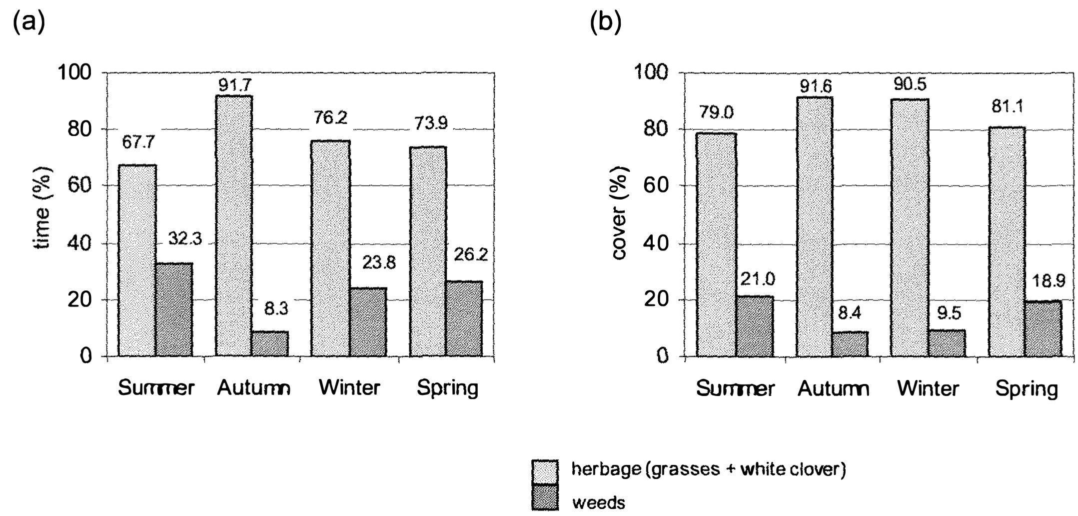


Figure 3.3 (a) Percentage time spent by free-ranging goats grazing on herbaceous weeds and herbage plants (grasses and white clover), and (b) general botanical composition (percentage cover) of the pasture, from December 1997 to November 1998.

Despite the annual fluctuations in time spent on grasses (66.6-90.2%) and on white clover (1.1-2.0%), goats spent a constant proportion of 98% on grasses and 2% on white clover, if only the total time spent on herbage plants is considered. This can be calculated from Table 3.3 by dividing time spent on grasses by the total time spent on herbage plants (likewise for white clover). The only minor exception to this happened in winter, when the proportions were 97.4 and 2.6%, respectively.

Of the time dedicated to weeds, the greatest amount was spent on Scotch thistle in summer (20.0%) and spring (13.6%), and on rushes in winter (15.2%). An intermediate proportion of time was dedicated to winged thistle in summer (6.2%) and spring (6.7%), and to broad-leaved dock in winter (7.7%). Goats spent a small proportion of their time (3.9% and less) on the other species if considered separately, but together they accounted for up to 8.4% of the time (autumn).

Table 3.3 Percentage time spent in the afternoon by free-ranging goats on grazing and non-grazing events, from December 1997 to November 1998. Figures above the double line represent the percentage of grazing time spent on those species, whereas below the double line are percentage of all activities. Values in italics are mean Wilcoxon ranks of percentage time for multiple comparisons within columns (values below percentage time) and within rows (values on its right).

Species	Season				Year Mean
	Summer	Autumn	Winter	Spring	
grasses	**66.6** *86*	**90.2** *187*	**74.2** *107*	**72.4** *102*	**75.9**
	497	*511*	*504*	*510*	*2021*
white clover	**1.1** *95*	**1.5** *128*	**2.0** *138*	**1.5** *121*	**1.5**
	209	*270*	*274*	*230*	*982*
Herbage total	**67.7** *85*	**91.7** *185*	**76.2** *108*	**73.8** *104*	**77.4**
creeping buttercup	**1.1** *127*	**1.8** *148*	**0.0** *104*	**0.0** *103*	**0.8**
	222	*262*	*171*	*151*	*799*
catsear	**3.9** NS	**1.2** *NS*	**0.7** *NS*	**1.1** *NS*	**1.8**
	256	*259*	*230*	*242*	*986*
broad-leaved dock	**0.0** *86*	**1.1** *105*	**7.7** *166*	**3.0** *126*	**2.9**
	179	*217*	*330*	*235*	*961*
narrow-leaved plantain	**0.6** *100*	**2.5** *165*	**0.2** *87*	**1.5** *130*	**1.2**
	219	*334*	*191*	*255*	*985*
rushes	**0.0** *91*	**0.1** *93*	**15.2** *196*	**0.3** *102*	**3.9**
	179	*173*	*400*	*174*	*928*
Scotch thistle	**20.0** *172*	**1.6** *90*	**0.0** *67*	**13.6** *153*	**8.8**
	394	*240*	*168*	*352*	*1155*
winged thistle	**6.2** *143*	**0.0** *93*	**0.0** *93*	**6.7** *153*	**3.2**
	281	*169*	*168*	*286*	*908*
Weed total	**32.3** *156*	**8.3** *56*	**23.8** *133*	**26.2** *138*	**22.6**
Grazing total	**77.8**	**82.2**	**84.8**	**86.4**	**82.8**
Non-grazing event	Summer	Autumn	Winter	Spring	Year
walking	12.5	12.2	12.2	9.7	11.6
grooming (scratching)	1.9	0.1	0.5	1.0	0.9
standing	6.0	5.5	2.6	2.7	4.2
sitting	1.7	0.0	0.0	0.2	0.5
Non-grazing total	22.2	17.8	15.2	13.6	17.2

Differences between ranks (numbers in italics) are significant (P=0.05) when greater than 88 within season, than 50 within year, or than 34 within species. Differences between ranks of herbage total and between ranks of weed total are significant (P=0.05) when greater than 34. Herbage and weed totals are significantly different (*P*<0.0001) within seasons and within year. NS = not significant (*P*>0.05). For mean percentage time, n=24.

Goats grazed during most of the time they were monitored (on average, 82.3%) and most of the non-grazing time was spent walking, particularly in search for food (on average, 11.6%). Time spent walking was surprisingly consistent in summer (12.5%), autumn (12.2%), and in winter (12.2%), but was lower in spring (9.7%).

3.3.3. Selection index

Selection indexes were statistically different from zero ($P<0.05$) during most parts of the year. However, many of these were still relatively close to zero, according to the classification system explained in Table 3.1, thus only representing a minor selection or avoidance effort (see Table 3.4).

Goats made a strong effort to select catsear in summer and broad-leaved dock in winter. Similarly, a moderate effort was made to select creeping buttercup in summer, rushes in winter, narrow-leaved plantain in summer, and broad-leaved dock in autumn (in decreasing order of importance). No effort or only a minor effort was made to select other species at other times.

Conversely, goats made a strong effort to avoid rushes in autumn, creeping buttercup in winter, rushes in spring, and narrow-leaved plantain in winter. A minor effort was made to avoid white clover in summer and winter, and a moderate one in spring. None of the species was avoided in summer, except for broad-leaved dock and rushes, which were not eaten at all during this time of the year. Note that these two species were the only ones not seen in flower (Section 3.3.1).

Table 3.4 The degree of goat effort in selecting (positive values) or for avoiding (negative values) plant species indicated by selection index (SI) with *p*-values (probability of true SI being zero) in parentheses.

Species	Summer	Autumn	Winter	Spring
grasses	-0.46 (0.0025) minor[1]	+0.01 (0.9305) neutral	-0.94 (0.0001) minor	-0.10 (0.6467) neutral
white clover	-1.04 (0.0001) minor	+0.06 (0.2254) neutral	-0.19 (0.0475) minor	-1.56 (0.0001) moderate
Total herbage	-0.58 (0.0001) minor	+0.02 (0.8901) neutral	-0.09 (0.0001) minor	-0.42 (0.0013) minor
creeping buttercup	+1.38 (0.0389) moderate	+1.56 (0.1869) neutral	nil[2] - -	nil[2] - -
catsear	+3.24 (0.0375) strong	+0.52 (0.2775) neutral	-0.29 (0.0345) minor	-0.13 (0.0517) neutral
broad-leaved dock	nil[2] - -	+1.49 (0.0130) moderate	+3.28 (0.0001) strong	+0.57 (0.2085) neutral
narrow-leaved plantain	+0.06 (0.0389) minor	+1.39 (0.0001) moderate	-3.27 (0.0001) strong	+0.12 (0.0855) neutral
rushes	nil[2] - -	-3.97 (0.0001) strong	+1.39 (0.0001) moderate	-3.40 (0.0001) strong
Scotch thistle	+0.71 (0.0010) minor	+0.41 (0.1078) neutral	nil[2] - -	+0.88 (0.0073) minor
winged thistle	+0.59 (0.4506) neutral	nil[3] - -	nil[3] - -	+0.85 (0.5056) neutral
Total weeds	+0.58 (0.0005) minor	-0.02 (0.9189) neutral	+1.40 (0.0001) moderate	+0.42 (0.0023) minor

[1] For definition, see Table 3.1. [2] Species was present, but was not eaten. [3] Species was not present. SI values that did not differ from zero statistically (i.e. $P>0.05$) were classed as "neutral" (see Section 3.2.3). For each SI, n=24.

3.3.4. Selection of individual plant components

Percentage cover does not provide a measure of the relative contribution of each plant component to the total vegetation cover. For this reason, the consumption of individual components was analysed by comparing the number of visits per component to the total number of visits (3607).

Table 3.5 shows the number of times (both absolute and relative) that animals visited each species in order to harvest individual components. Plant species and components were not independent ($P<0.0001$) with regards to number of visits, according to the X^2 test of independence, i.e. both species and plant components exerted a significant effect on the decision of goats to visit them. For this test, plant components had to be grouped into vegetative and reproductive categories due to the number of zeros and empty cells.

Green leaves were the most frequently visited component for all species, except for rushes, from which goats harvested green stem, and for winged thistle, which was visited mainly because of its reproductive components.

Of all visits to grasses, 2% were for harvesting dead stems and 2% for litter. This was dead plant material (predominantly trampled grass stems in late summer), lying on the base of the pasture. The consumption of such a component was not anticipated.

It should be pointed out that a portion of the grass stems (typically the top 1/3) was removed together with the seed-heads, and that this was recorded as a seed-head removal and no reference was made to the stem. So, the dead and green stem components referred to on Table 3.5 are stems without the seed-heads (i.e. they had been removed previously).

With the exception of the top portion of the grass stems removed with the seed-heads, each bite clearly prehended a single type of component. Thus, when goats harvested leaves, for instance, stems were not harvested; when they harvested flowers, leaves were not removed, even if the flower was surrounded by leaves. This was a consistent pattern, observed in all goats.

Table 3.5 Number of visits per species, partitioned into plant components. Within each cell (see box demarcated by dotted line), values are total number of visits (in bold), relative frequency of visits within species (%), and relative frequency of visits within components (%), from top to bottom, respectively.

Species	Components								Total
	litter	dead stem	green stem	dead leaf	green leaf	flower/ seed head	VEG[1]	REP[2]	
grasses	**37** 2 100	**53** 2 100	**23** 1 13	**15** 1 100	**1550** 69 65	**566** 25 61	**1678** 75 64	**566** 25 61	**2248** 100
white clover	**0**	-	**2** 1 1	**0**	**72** 54 3	**60** 45 6	**74** 55 3	**60** 45 6	**134** 100
creeping buttercup	-	-	**0**	-	**50** 80 2	**13** 20 1	**50** 80 2	**13** 20 1	**63** 100
catsear	-	-	**0**	-	**144** 75 6	**48** 25 5	**144** 75 6	**48** 25 5	**194** 100
broad-leaved dock	-	**0**	**0**	-	**199** 98 8	**5** 2 1	**199** 92 8	**5** 2 1	**204** 100
narrow-leaved plantain	-	-	**0**	-	**143** 95 6	**7** 5 1	**143** 95 5	**7** 5 1	**150** 100
rushes	-	**0**	**146** 100 82	-	-	**0**	**146** 100 6	**0**	**146** 100
Scotch thistle	-	-	**4** 1 3	-	**232** 76 10	**72** 24 8	**236** 76 9	**72** 24 8	**304** 100
winged thistle	-	-	**2** 1 1	-	**6** 4 0	**158** 96 17	**8** 4 0	**158** 96 17	**164** 100
Total	**37** 100	**53** 100	**177** 100	**15** 100	**2396** 100	**929** 100	**2678** 100	**929** 100	**3607**

[1] Total visits to vegetative components (i.e. all components, except flower and seed-head).
[2] Total visits to reproductive components (i.e. flower and seed-head).
Hyphens denote component not detected by the botanical assessment.

In many instances, the majority of the flock, and sometimes the whole flock, was seen to change their focus to the same type of target (i.e. the same component of the same species). Hence, in one moment different individuals were seen harvesting different components of different species and within 20-30 seconds they were all, or nearly all, harvesting grass seed-heads, for instance. This phenomenon did not appear to be always related to goats actually seeing the actions of their peers, though in some instances the action of one animal did cause a chain effect on the diet of the whole flock, as was the case when the first thistle plant was found in the paddock. The first animal to see the thistle would walk faster than normal towards it, thus drawing attention of others, who would, in turn, notice the plant and move towards it too.

Goats ate some reproductive Scotch thistle plants to ground level on the first visit to the plant, but this was uncommon. Typically, the same plant was revisited several times and it was eaten down gradually along with other species (this includes observations other than the recorded ones). However, when moved to a new paddock in spring and summer, goats consistently looked for flowers and seed-heads first and when they found thistles, the group would not change to other species while there was any of its reproductive components left.

In spring and summer, when species and component choices were maximal, goats tended to search for feed in the following order (most favoured listed first):

(i) Scotch thistle flower and seed-heads;
(ii) winged thistle flower and seed-heads;
(iii) grass seed-heads;
(iv) white clover flower and seed-heads;
(v) catsear flower-heads;
(vi) grass leaves;
(vii) others.

The above was consistent when they had just walked into a new paddock and when all these targets were readily available. In cases where thistles were further back into a paddock, for instance, goats tended to select their diet in the same order, but starting from (iii). When thistles were found, animals spent a considerable time on them and then resumed their search, typically following the same order again (i.e. visiting grass seed-heads after leaving thistles and so forth).

The consumption of thistle rosettes was erratic. While some rosettes (especially of Scotch thistle) were eaten to ground level, others had just the tips of their leaves removed or were not even touched. Often, the Scotch thistle rosettes that were eaten were identical in physiological stage, size, and shape to the rosettes that were left untouched. Of the 1.6% time that goats spent on Scotch thistle in autumn (Table 3.3), half of this was dedicated to rosettes. Although goats also consumed rosettes in summer and in spring, the time invested on them in these seasons was negligible (it was nil in winter, as seen in Section 0).

Of the total time dedicated to grasses in spring and summer, which was the period when seed-heads were available, 58% was spent in harvesting seed-heads (further results on consumption of individual components are presented in Section 3.3.4). However, goats were never seen to eat seed-heads of barley grass. They did consume the species in its vegetative stage, but refused it completely once it started to flower.

3.3.5. Bite height

Overall, the majority of the feeding patches (70%) explored by goats were not located at the top of the vegetation (see Section 3.2.2.4 for the definition of a feeding patch). This proportion was the same for feeding patches providing vegetative components and those providing reproductive ones (Table 3.6).

Table 3.6 Vertical location of feeding patches, partitioned into vegetative and reproductive components. Values are absolute numbers of patches (in bold) and respective component percentages.

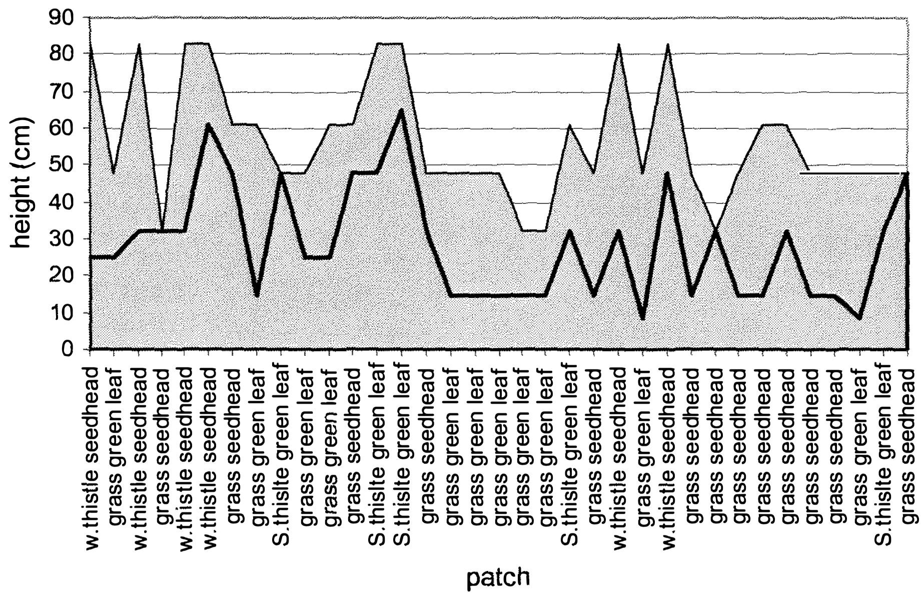
Component	Location of feeding patch		Total
	Below the top[1]	At the top	
vegetative	**1875** 70	**803** 30	**2678** 100
reproductive	**641** 69	**288** 31	**929** 100
Total	**2516** 70	**1091** 30	**3607** 100

[1] Refers to the top of local vegetation, i.e. the vegetation surrounding the goat (Section 3.2.2.1).

The mean BHI (i.e. bite height index, as defined in Section 3.2.2.5) of all feeding patches located below the top was 0.37 (median 0.30; range 0.04-0.94), i.e. the average bite below the top was taken at a height which was approximately 1/3 of the local vegetation height. When partitioned, the mean BHI of the patches providing vegetative material was 0.28 (median 0.28; range 0.04-0.94) and the reproductive one was 0.60 (median 0.63; range 0.25-0.94). So, when feeding below the top, goats harvested vegetative and reproductive components from average heights of 28 and 60% of the local vegetation height, respectively. In Figure 3.4, raw data extracts provide two representative examples of how goats explored the vegetation profile.

The seasonal averages of local vegetation heights (i.e. the vegetation surrounding the animals during the observations) were invariably greater ($P<0.001$) than the seasonal averages of the overall vegetation heights obtained from the quadrat assessments. Mean local and overall vegetation heights (±SE) were: 58 (±4) and 31 (±6) in summer; 52 (±3) and 28 (±4) in autumn; 38 (±2) and 14 (±2) in winter; 55 (±5) and 29 (±6) in spring, respectively.

(a)



(b)

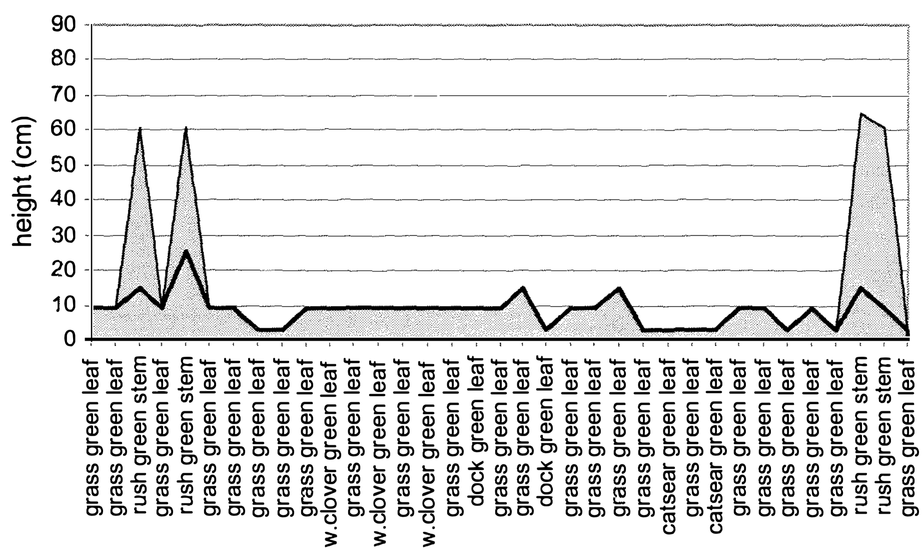


Figure 3.4 Typical examples of how goats explored the vertical profile of the vegetation in contrasting seasons: summer (a) and winter (b). The shaded area represents the vertical profile of the vegetation effectively explored by goats. The bold line denotes bite height. The horizontal axis shows species and component being harvested on each consecutive feeding patch. Non-feeding trails were omitted.

Goats grazed above 10 cm whenever this was possible and the more options they had above 10 cm, the lower the probability of grazing being at the top of the vegetation. The decision to harvest from the top or below the top of the vegetation was significantly affected ($P<0.05$) by season of the year. This is illustrated in Figure 3.4. While Figure 3.4a shows four feeding patches located on the top of the vegetation, Figure 3.4b shows 31. Goats harvested 15% of their feed from the top of the vegetation in summer; 20% in autumn; 87% in winter; and 25% in spring.

3.3.6. Other observations

Short visits to specific feeding patches were much more common than long ones. Eighty percent of the visits lasted less than 60 seconds (Figure 3.5).

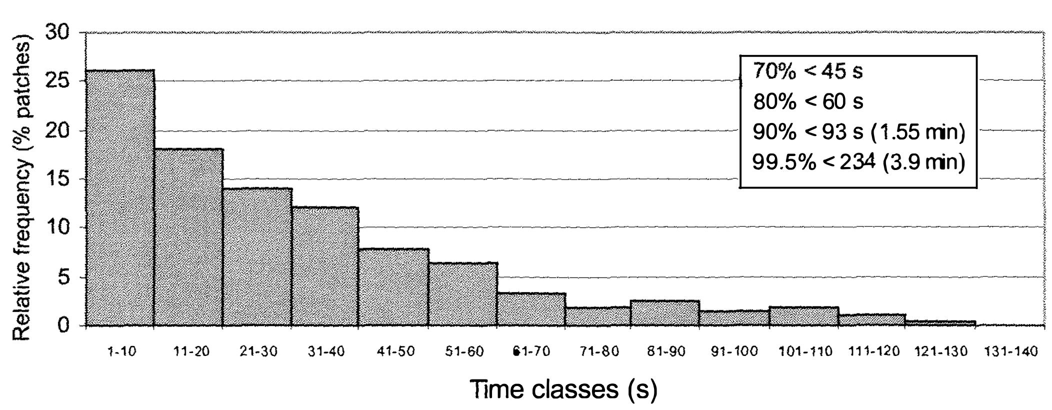


Figure 3.5 Histogram of time spent by goats per feeding patch, from December 1997 to November 1998 (n = 3607).

When changing feeding patches, goats changed their target in only 37% of the times, i.e. in 63% of the times, they changed patch but selected the same component of the same species that they had just been eating. This pattern was evident in the field, even before the results were analysed. The animals seemed to be interested in a specific target for some time (e.g. white clover flower-head), thus moved from patch to patch after that target. While walking between feeding trails (Figure 3.1, p.26) they passed by feed that had been of interest a short time before or that came to be so soon after, apparently ignoring it. This was the most common foraging strategy, but goats used other strategies as well. Table 3.7 shows a simplified description of the four foraging strategies that were identified in this study.

Table 3.7 Foraging strategies (A-D) used by goats grazing herbaceous vegetation, from December 1997 to November 1998.

	A	B	C	D
(i)	Before walking, searches for and identifies a distant feeding patch bearing the same feed.	Before walking, searches for and identifies a distant feeding patch bearing the same feed.	Starts to walk, apparently without searching.	Starts to walk, apparently without searching.
(ii)	Walks and arrives at the chosen feeding patch without stopping for other feed on the way.	While walking, comes across a different feed option and stops to harvest this instead of continuing to the previously identified feeding patch.	Searches while walking until it finds an attractive feed option, which can be either the same feed as before or a different one.	Walks, apparently without searching.
(iii)	Stops to harvest the target feed.		Stops to harvest the feed option.	Stops to harvest the same feed option as before.
(iv)	Stops eating and starts a new cycle.	Stops eating and starts a new cycle.	Stops eating and starts a new cycle.	Stops eating and starts a new cycle.

New cycle mentioned in (iv) can be any of the strategies. While in A, B, and C the animal searches by looking in various directions (walking or not), in D the only apparent searching movement is the walk itself (i.e. animal looks down and keeps the head and neck straight).

Strategies A, B, and C were used throughout the year, but to a far lesser extent in winter than D, when this was the most common foraging strategy. Strategy D was not apparent at any other time of the year.

In many instances, goats were seen to rub their horns on plants such as rushes and mature thistles while eating them. Two does were observed eating needles of radiata pine (*Pinus radiata*) collected from the ground in 3-4 needles per bite (the needles had fallen from the neighbour's trees). However, the total time spent on such needles was insignificant (only 113 seconds), and this was only seen once (winter).

One doe was once observed pulling a 3 m white clover stolon from within a tall rank pasture in summer, all the way from tip to base, then eating it once it was totally uncovered.

The flock never became dispersed during grazing. Does were usually 3-4 m apart from each other while grazing, and whenever an animal noticed that it had been left behind by 20 m or more, it walked fast (often ran) immediately towards the group. Also, whenever a person approached their group, the first one or two animals to spot the person snorted to alert their peers. When the person was a stranger they mobbed and ran away (they acted in this manner towards the observer during the habituation period only), otherwise they just lowered their heads and continued grazing.

3.4. DISCUSSION

Note that the three-dimensional concept of feeding patch put forward in this study (Section 3.2.2.4) differs from the simpler, two-dimensional one, which has become traditional in foraging theory since MacArthur and Pianka (1966). It was adopted to allow for the fact that goats can select different components (i.e. different feed) from a single plant, located at different heights (e.g. flower-heads from the top of the plant and green leaves from the bottom). Feeding and non-feeding trails (Figure 3.1, p.26) are apparently novel defmitions. However, feeding station was used in the same sense defined by Ruyle and Dwyer (1985).

3.4.1. Percentage time

Ganskopp *et al.* (1997) showed that time spent by goats per plant species can reliably represent ($P<0.01$) the relative amounts of each species in the diet. This was concluded from a study of the relationships between 12 variables commonly used for indexing selective grazing behaviour. Their aim was to identify one estimator that could be used in field conditions when it was not possible to record a range of other variables due to time or other resource constraints, which was the case in the current study. Therefore, it can be inferred from the percentage time figures shown in Table 3.3 that grasses were the main component of the summer diet, for instance, followed by Scotch thistle, winged thistle, and so on. However, it is unknown whether those figures represented the actual amounts of each species in the diet (i.e. whether the summer diet comprised of 67% grasses, 20% Scotch thistle, etc.). This would be true if time per species was indeed highly correlated with intake rate, but the latter was not measured in this study nor in the one carried out by Ganskopp *et al.* (1997), mentioned earlier. Nevertheless, such a correlation has been consistently high for sheep (Parsons *et al.*, 1994), cattle (Poli, 1998; Griffths, 1999), and even for white-tailed deer (*Odocoileus virginianus*) (Koerth and Stuth, 1991). Thus, it is probably safe to assume that the figures of percentage time spent by goats on various species closely reflected the actual proportion of each species in their diet.

3.4.2. Selection index

When time spent per species is the only variable considered, one may have the impression that goats preferred the species that they spent more time on (typically grasses). However, a completely different picture is revealed when percentage cover is taken into account and the analysis is based on the SI instead. This shows that goats made an effort, though minor, to avoid grasses in summer and in winter (see Table 3.4), and, at most, made no effort to avoid them (such was the case in autumn and spring), eating them in the same proportion that they occurred in the pasture. So goats spent more time on grasses not because they were preferred, but because of the combined effect of grasses being the dominant species in the vegetation, and goats having made no effort or only a minor effort to avoid them. As all vegetation components were edible to goats (the only exception to this was barley grass seed-heads), they were continuously faced with the need to assess whether to stop and eat what was within reach or to continue walking in order to find a preferred feed option. So, every time they decided to walk, they walked past potential sources of feed. By doing this they not only accepted to pay for the direct costs of energy and time required to reach the next feeding trail, but also for the indirect opportunity cost, represented by the feed they ignored. They apparently knew the outcome when they employed Strategies A and B described in Table 3.7, but were risking not finding anything better when they employed Strategies C and D. All these factors led to the conclusion that the consumption of grasses was primarily a matter of neutral acceptance rather than preference.

This was not the case with any of the other species, which were distributed over a small percentage of the area, thus making random encounters with them much less probable than encounters with grasses. The fact that goats grazed the species in greater proportion than their occurrence in the vegetation (denoted by positive SI) implies a positive searching strategy.

3.4.3. Rejection to eat versus difficulty in finding

When a species was present but not eaten its SI was nil, which was the case with creeping buttercup in spring, broad-leaved dock and rushes in summer, and Scotch thistle in winter (Table 3.4). (A nil SI should not to be confused with SI=0.) There are two possible explanations for this occurrence: either (a) the species was entirely rejected (i.e. goats encountered it but chose not to eat it), or (b) it was not found, either by chance or otherwise, at least during the observations.

Although the percentage cover of creeping buttercup was very small in spring, goats were able to find it in summer, when its cover was even smaller. If the vegetation had been taller in spring than in summer this could have impaired the ability of goats to find creeping buttercup. However, sward heights were similar, and indeed the vegetation was slightly taller in summer, not in spring (Section 3.3.5). Moreover, creeping buttercup plants bore many more flowers in spring than they did in summer, which made them more conspicuous in spring to the human eye. Goats, like other grazing animals, also have colour perception (Burhenauer and Fritsch, 1980). Thus, following this reasoning, it is logical to conclude that creeping buttercup was entirely rejected by goats in spring. Given the circumstances of such a rejection, it seems reasonable to predict that goats will tend to reject creeping buttercup in spring, even if the percentage cover is greater than in this study (provided other options are plentiful). Determining the cause(s) of this rejection is beyond the scope of this study, but a possible link with claims of livestock poisoning by creeping buttercup (Connor, 1977; Morales, 1989) should not be discarded.

With regard to broad-leaved dock, percentage cover was minimal in summer (even less than the spring cover of creeping buttercup). This fact alone might explain a nil SI, even if goats had made any effort to find it (whether they did is unknown). However, it is possible that goats made no effort to select it, which was the case in spring. Additionally, broad-leaved docks were not seen in flower, which probably made them less conspicuous than other species. Thus, it seems that the SI of broad-leaved dock was nil in summer because goats did not come across them during the observations. Only tentatively can one predict that broad-leaved dock will be consumed in summer to some extent if its percentage cover is greater than it was in this study, more so if the seed-heads are available. Broad-leaved dock seed-heads should have been detected in spring and summer. This was not followed up closely, but it is likely that the plants did flower in spring and that the seed-heads were consumed by goats when they were not being monitored. The same may have happened to rushes. However, this study was not designed to follow the fate of individual plants.

The most probable cause of rushes having a nil SI in summer seems to have been rejection. Although they were not seen to flower, they must have been noticed by goats as these were seen to walk past the clumps of rushes on many occasions. Additionally, the percentage cover of rushes was very uniform over the year, almost the same as in winter, when goats did consume it. Moreover, rushes were taller than the surrounding vegetation throughout the year, which would have made it possible for goats to see them at all times. Thus, it seems reasonable to predict that goats will reject rushes in summer under similar conditions.

It appears that the nil SI of Scotch thistle recorded in winter also resulted from rejection. At this time of the year all plants were seedlings and rosettes, accounting for 0.4% of the vegetation cover. Overall this is a small value, but it should be noted that this figure is an average resulting from quadrats that detected a greater cover along with others that detected nil.

While the Scotch thistle seedlings were small and may have gone unnoticed, the rosettes were larger (20-30 cm) and must have been noticed, as goats were observed walking past and grazing around them. However, even the grass immediately around the rosettes was not grazed. This seems to be related to the rosettes that were not touched or that were eaten only superficially in other seasons, as mentioned in Section 3.3.4. The fact that some rosettes were left untouched while apparently identical ones in the vicinity were eaten down to ground level suggests this was a reflection of the influence of the surrounding pasture, and not of any innate attribute of individual rosettes. An experiment was designed to test this hypothesis and is reported in Chapter 6. All that can be concluded at this stage is that the consumption of Scotch thistle rosettes by goats was erratic.

Perhaps a combination of vegetation mass and height would have better expressed the availability of plant material to goats than percentage cover alone because of considerable local and seasonal variations in the physical characteristics of the various species present (e.g. height, leafiness, size, shape, mass of seed-heads, etc). However, a destructive technique was ruled out because of the limited abundance of some of the species. Despite the point quadrat technique being considered a more reliable option for the assessment of percentage cover than visual appraisal (Grant, 1993), it could not be used in this study due to the nature of the vegetation (heights up to 80 cm in summer), and the limited daylight time left for the botanical assessments, especially in winter. Thus, given the constraints, the visual appraisal was a satisfactory option.

3.4.4. Random versus non-random foraging behaviour

To date researchers have considered that an animal grazes randomly (often erroneously called "random diet selection") when the proportion of a species in its diet equals the proportion of that species in the pasture (e.g. Edwards *et al.*, 1996; Penning *et al.*, 1997). If the neutral SI are considered together with those which only reflected a minor effort for selection or avoidance (Table 3.4), it can be seen that the diet of goats in spring, for instance, closely reflected the proportion of each species in the vegetation (i.e. six of the nine SI indicated no real difference between the proportions of the species in the diet and in the vegetation for that season). However, spring was the season when goats were most actively employing Strategy A (Table 3.7), which is not random behaviour. Moreover, it was the time when they most clearly followed the pattern in search for components as described in Section 3.3.4 (p.35). When goats were allowed to enter a paddock which had a variety of species (more so if flowering plants were available), they followed a systematic order such as the one described earlier. If only the first minutes after their entrance into the paddock had been considered, selection would have been maximal, but in this study observations were carried out for at least 2 hours after they had just been introduced to a new paddock. As time passed they progressively widened their diet in terms of number of species harvested up to the point when the choices started to become depleted and they were forced to eat plants and organs that they had not eaten at the beginning. Had the order of events not been recorded, the information available would have only been the final proportion of time per species to be compared with the percentage cover figures. Having found most of the spring SI close to neutrality, there would be little evidence to rule out randomness in their foraging. However, in 63% of the times that goats changed patch, they selected the same component of the same species that they had just been eating (Section 3.3.6). This combined with the strategies described in Section 3.3.4 (p.38) and Section 3.3.6 (see Table 3.7, p.43) indicate that goats did not forage randomly.

The expression "random selection" seems inappropriate if one accepts "selection" as the deliberate action of gathering (picking) something out of a whole, as adopted in this study. "Random foraging" or "animals foraging randomly" would be better terms. However, as illustrated above, randomness should not be assumed simply because the proportion of a given species in the diet equalled the proportion of that species on offer at the end of a grazing period. Instead, animals should be monitored during the grazing process and the order of events recorded. Conversely, the fact that a selection index is different from neutrality does not necessarily mean that the animal foraged non-randomly, as it may result from a random grazing of a non-uniform canopy (Hodgson, 1990). However, this is probably more applicable to cattle due to the way they prehend the feed. Goats demonstrated a clear pattern of searching for components, and also were not seen to take bites containing mixtures of species. Thus, the methodology used for monitoring diet selection in this study was appropriate for goats, but it would not be reliable for monitoring any animal that prehends more than one plant species or type of organ in a single bite (e.g. cattle).

3.5. SUMMARY

The answers to the questions specified in Section 3.1 are summarised below to help clarify the main points:

(i) *What is the relative contribution of weeds, grasses, and clover to the diet of goats when they are allowed to graze such a mixed vegetation freely?*

This was specifically answered in Table 3.3. In general, grasses were the main component of the diet (75.9%). Weeds accounted for 22.6% and white clover 1.5% of their overall diet. However, this diet was largely influenced by the proportion of the various species in the vegetation cover. Grasses were harvested in the same proportion that they occurred in the pasture, while all other species were positively selected during at least one season of the year. Predictions should not be made based on diet figures alone.

(ii) *Will this diet be affected by season of the year?*

It was significantly affected by seasons. Based on the various SI obtained, a seasonal difference in the diet of goats would be expected even if the relative species contribution to the vegetation cover remained constant.

(iii) *Will goats obtain their diet randomly or is there a pattern of selection and avoidance in such conditions?*

Goats did not obtain their diet randomly at any time of the year; instead, they clearly employed systematic strategies to search for specific targets. Suggestions were made for care to be exercised when interpreting neutral selection indexes (i.e. randomness should not be assumed simply on the basis of a neutral SI).

(iv) *What plant organs will be eaten?*

In general, all organs of all species were consumed. The marked exception was barley grass seed-heads, which were completely rejected.

(v) *Will goats eat thistle rosettes, or are thistles only consumed when they are in the reproductive stage, as it is claimed?*

Goats did consume some Scotch thistle rosettes, but avoided identical ones in the vicinity. A hypothesis was formulated stating that goats rejected most rosettes because of the vegetation immediately around them and not because of any innate characteristic of the plants. This generated a new experiment, which is reported in Chapter 6.

(vi) *Assuming goats will eat grasses in spring and summer, what is the importance of grass seed-heads to the total amount of grasses*

consumed during this time of the year?

Of their total time spent on grasses when seed-heads where available (i.e. spring and summer), goats spent 58% on seed-heads. Implications of this finding are discussed in Chapter 7 (Section 7.2.1.2).

(vii) Will goats harvest the top of the pasture only, as it is normally claimed, or are other strata also explored?

Goats tended to frequent areas where the local vegetation was taller than the overall average. However, the majority of the feeding patches (70%) were located below the top of the vegetation. Additionally, when components were partitioned into vegetative and reproductive, the same proportion was found (i.e. 30% from the top and 70% below the top). This contradicts previous claims that goats consistently harvest the top of the vegetation. Goats grazed above 10 cm whenever this was possible and the more options they had above 10 cm, the lower the probability of grazing being at the top of the vegetation.

CHAPTER 4

RECOVERY AND VIABILITY OF SEEDS INGESTED BY GOATS

4.1. INTRODUCTION

The results presented in the previous chapter showed that goats ate seed-heads of all species available to them, except those of barley grass. While the consumption of thistle seed-heads by goats has been well documented (see Chapter 2), little was known about the other species before Experiment 1 was conducted (Chapter 3).

Limited information is available about the fate of seeds after they are ingested by goats, especially for species found in New Zealand pastures. Host and Allan (1996) recovered less than 1% of the viable seeds of nodding and Illyrian thistles fed to goats and 10% of Scotch broom (*Cytisus scoparius*); Pierce (1990) reported a recovery of less than 0.5% of saffron thistle (*Carthamus lanatus*) seeds; Lacey *et al.* (1992) recovered 31% of the seeds of leafy spurge (*Euphorbia esula)*; Simao Neto and Jones (1987) recovered an average of 20% of the seeds of several tropical grasses (range 9-28%) and legumes (range (7-41%) found in Australian pastures (all the figures above are percentage of viable seeds fed to goats).

As seed-heads of most pasture weeds are generally not consumed by cattle and sheep, any reduction in the number of viable weed seeds following ingestion by goats should help in the control of weeds, particularly of annual and biennial species, whose populations depend on seeds being deposited in the soil for their survival. On the other hand, if some seeds remain viable after passage through the digestive tract, goats would potentially act as vectors for their dispersal. This would have management implications, particularly when moving animals to areas free of a given weed.

Therefore, the general objective of the experiment reported in this chapter was to produce additional information on the recovery and viability of weed seeds after passage through the digestive tract of goats, especially for species of importance in New Zealand pastures.

An experiment was designed to answer the following questions:

(i) Are all the seeds ingested by goats destroyed in the digestion process?

(ii) If not, are the recovered seeds viable?

(iii) If viable, are they dormant or non-dormant?

(iv) Will passage through the digestive tract change the dormancy status?

(v) How long will it take for seeds to pass through the digestive tract?

(vi) If seeds do pass in a viable state, will they germinate in intact faecal pellets?

4.2. MATERIALS AND METHODS

The experiment consisted of feeding known numbers of seeds of weed and forage species to goats, sorting through the faeces to recover the ones that were not destroyed, and assessing the extent of the destruction and changes in viability. The experiment was repeated three times, over three consecutive weeks, from 7-28 September 1998.

4.2.1. The seeds

Seeds of six weed and two pasture species were obtained from various sources (Table 4.1), all of them collected in the summer of 1997-98. Broad-leaved dock, Californian thistle, gorse, and Scotch thistle were cleaned and dried at the Massey University Seed Technology Centre (henceforth referred to as MUSTC). The other species were received as pure seeds. All seeds were stored in a cool room at 5°C until September 1998, when the experiment commenced.

The germination of these seeds was assessed immediately before the feeding trial and after recovery from faeces (Section 4.2.5) at the MUSTC, according to the International Seed Testing Association rules (ISTA, 1996). A general description of the methods used is provided in Table 4.2.

Seeds were dusted with fungicide (captan) before the germination test, for both the pre- and the post-ingestion tests.

Additionally, the 1000-seed weight of each species was determined by counting and weighing eight replicates of 100 seeds each (ISTA, 1996). This was used to obtain batches of 1000 seeds to be fed to goats (Section 4.2.3).

Table 4.1 List of species of seeds used in the experiment and their history.

Species	Origin	Previous storage[1]
broad-leaved dock (*Rumex obtusifolius*)	mature seeds, collected from seed-heads on roadsides close to Palmerston North city	none
Californian thistle (*Cirsium arvense*)	mature seeds, collected from seed-heads on roadsides and pastures in the Manawatu region	none
gorse (*Ulex europaeus*)	mature seeds, collected from plants found on the Manawatu river banks complemented with seeds collected from the soil seed bank underneath plants (once cleaned, the two were mixed and homogenised)	none
narrow-leaved plantain (*Plantago lanceolata*)	commercial seeds obtained from a dealer in South Island (mainly sold to organic farmers)	unknown; probably in bags at controlled temperature and humidity
Scotch thistle (*Cirsium vulgare*)	mature seeds, collected from seed-heads from roadsides in Woodville	none
variegated thistle (*Silybum marianum*)	commercial seeds obtained from a dealer in South Island	unknown; probably in bags at controlled temperature and humidity
perennial ryegrass (*Lolium perenne*)	commercial seeds (Massey University Seed Technology Centre)	in paper bags at 5°C for approximately 6 months
white clover (*Trifolium repens*)	commercial seeds (Massey University Seed Technology Centre)	in paper bags at 5°C for approximately 6 months

1 Before arriving at the Massey University Seed Technology Centre.

Table 4.2 Germination methods used for testing seeds before and after ingestion by goats.

Species	Temp. (°C)	First count (days)	Second count (days)	Treatment to break dormancy
broad-leaved dock	20-30[1]	5	14	none
Californian thistle	20-30	7	21	none
gorse	20-30	7	21	none
gorse	20-30	7	21	scarification[2]
narrow-leaved plantain	20-30	5	14	none
Scotch thistle	20-30	7	21	none
variegated thistle	20-30	7	21	none
perennial ryegrass	20-30	5	14	none
white clover	20	4	10	none
white clover	20	4	10	prechill

The substrate used for all seeds was top of paper (ISTA, 1996).
[1] Alternating temperatures in dark and in light, respectively.
[2] By means of piercing.

4.2.2. The animals

Six 2-year-old wether goats belonging to the AgResearch Flock House Agricultural Centre were selected at random from a herd of approximately 2000 goats (Boer-Angora cross), then drenched for worms and taken to the Massey University Animal Physiology Unit (the trial site). They were put individually into metabolism crates (indoors), offered lucerne chaff and water *ad libitum*, and observed for two weeks before the commencement of the trial to ensure habituation with the new feed and environment, as well as to allow for any seeds ingested in the field to be eliminated. Goats averaged 22 kg live weight (±SE 1.1 kg) at the end of the habituation period.

The lucerne chaff was sampled daily prior to being fed to animals (50 g from each meal of 700-900 g), and screened at the MUSTC for seed contamination. This was done to ensure the feed did not contain any of the species listed in Table 4.1.

4.2.3. Feeding the seeds

Four goats were given a single feed of 8000 seeds each, containing 1000 seeds (estimated number; see Section 4.2.1) from each of the eight plant species. This resulted in a volume equivalent to a handful of seeds (38.64 g), which were thoroughly mixed with 50 g of molasses and offered to animals in individual bowls. This process was carried out early in the morning on the fist day of each of the three weeks and was carefully monitored to ensure that all seeds were ingested. Goats ingested *c.* 96000 seeds during the study (i.e. *c.*1000 seeds x 8 plant species x 4 goats x 3 weeks).

4.2.4. Faeces collection

Faeces were collected at 24, 48, 72, 96, 120, and 144 h after ingestion from screen trays placed permanently underneath each crate, then thoroughly homogenised by hand within plastic bags and weighed. (The homogenisation was made easy by the consistency of the faeces, which was naturally dry and in pellets.) Two samples of 25% of the total weight were taken, one for seed recovery and the other for testing whether the seeds would germinate from intact faecal pellets (details in Section 4.2.6). Because the pellets were dry and hard, the samples destined for seed recovery were soaked in water and left in an open container overnight so they could be easily broken up the next day.

4.2.5. Recovery of seeds from faeces

The soaked faecal samples were washed in running water through a fine screen (0.5 mm mesh) to reduce the faecal volume and help expose the seeds. During the recovery process, seeds were identified, retrieved, and kept in water.

When no more seeds could be found, the resulting washed material (a pale mass of almost pure fibre) was spread in thin layers (5 mm thick) on top of sterile potting mix within plastic pots and kept moist through daily, manual irrigation in a glasshouse with controlled temperature set to 20°C. This was done to ensure that seeds that were missed in the recovery process would germinate and be counted as seedlings. These seedlings were identified, counted, and removed once a month. Pots were monitored for 3 months, from September to December 1998. All the recovered seeds had their germination tested using the procedures described in Section 4.2.1.

4.2.6. Seedling emergence from intact faecal pellets

Faecal samples (Section 4.2.4) were placed in pots as described in Section 4.2.5 for washed material (except layers were 1 cm thick) to determine whether the seeds would be able to germinate from intact faecal pellets. Moisture and temperature were maintained as described in the previous section. Pots were monitored for 5 months, from September 1998 to February 1999 (the end of the trial). Because seeds might have germinated but not emerged from the faecal pellets, results are presented as percentage seedling emergence (Harper, 1977) rather than percentage germination (see next section).

4.2.7. Derived variables and statistical analyses

Derived variables to quantify seed recovery (total and viable seeds) and germination from intact faecal pellets were calculated as follows:

$$PTSR = \frac{TNSW + NSDLW}{NSI} \times 100 \tag{4.1}$$

where:

PTSR = percentage of total seeds recovered
TNSW = total number of seeds found in the washed faecal material

(Section 4.2.5)

NSDLW	=	number of seedlings emerged in the glasshouse from the washed faecal material (Section 4.2.5)
NSI	=	total number of seeds ingested, i.e. *c.* 1000 seeds (Section 4.2.3)

$$PVSR = \frac{NVSW + NSDLW}{NVSI} \times 100 \tag{4.2}$$

where:

PVSR	=	percentage of viable seeds recovered
NVSW	=	number of viable seeds found in the washed faecal material (Section 4.2.5)
NVSI	=	number of viable seeds ingested, i.e. how many of the ingested seeds were expected to be viable before passing through the gut (see equation below)

$$NVSI = 1000 \times VI \tag{4.3}$$

where:

VI	=	viability index, i.e. number of viable seeds divided by total number of seeds, obtained from the seed tests carried out before ingestion (Section 4.2.1)

The percentage of seedlings emerged from intact faecal pellets (*PSFP*) was calculated as:

$$PSFP = \frac{NSDLFP}{NVSFP} \times 100 \tag{4.4}$$

where:

NSDLFP	=	number of seedlings emerged from intact faecal pellets

NVSFP	=	number of viable seed in intact faecal pellets	=	*NVSW* (on a per kg basis; see Section 4.2.4)

The relative efficiency of the seed recovery technique (*RESR*) was obtained in the following way:

$$RESR = \frac{TNSW}{TNSW + NSDLW} \times 100 \qquad (4.6)$$

The percentages of recovered seeds (both *PTSR* and *PVSR*) were log-transformed and the means were analysed through the SAS ANOVA Procedure (SAS, 1996) in a randomised complete block design. The effects of the model were species (eight), animal (four goats, regarded as complete "blocks"), week (three independent runs of the same experiment), and species versus animal interaction. This analysis was done both on *PTSR* and *PVSR.*

For testing the null hypothesis that the mean seed destruction (i.e. 1 − *PTSR*/100) was zero (i.e. that no destruction occurred), the centred Wilcoxon sign rank test was used through the SAS UNIVARIATE Procedure (SAS, 1996).

The mean percentages of viable seeds and the mean percentages of hard seeds were tested for location through the Wilcoxon rank-sum test using the SAS NPAR1WAY procedure (SAS, 1996) for comparisons of pre- and post-ingestion treatments.

4.3. RESULTS

4.3.1. Reliability and efficiency

The species did present some variability in their 1000-seed weight, as shown in Table 4.3. Nevertheless, the 95% confidence intervals indicate that the amounts of seeds offered to animals were close to the desired number (i.e. 1000).

Table 4.3 Mean weight (g) of 1000 seeds used to obtain the seed rations offered to goats, followed by the standard error (SE) and 95% confidence interval (CI) for each species.

Species	Mean (1000-seed weight)	SE	CI (No. of seeds)
broad-leaved dock	1.8323	0.038213	934-1066
Californian thistle	0.8840	0.008495	969-1031
gorse	6.2298	0.019332	990-1010
narrow-leaved plantain	2.3245	0.057962	921-1079
perennial ryegrass	2.6718	0.025349	970-1030
Scotch thistle	2.6573	0.024874	970-1030
variegated thistle	19.4150	0.077082	987-1013
white clover	0.6318	0.003544	982-1018

The seed recovery technique allowed the detection of most (83.4-100.0%) of the seeds that passed through the digestive tract (Table 4.4).

Table 4.4 Relative efficiency of the seed recovery technique. (Values are mean counts and percentages.)

Species	Recovered as seed[1]	Missed and counted as seedling[2]	Total	Efficiency[3] (%)
broad-leaved dock	968	2	970	99.8
Californian thistle	279	34	313	89.1
gorse	581	0	581	100.0
narrow-leaved plantain	256	1	257	99.6
perennial ryegrass	47	9	56	83.4
Scotch thistle	178	3	181	98.3
variegated thistle	18	0	18	100.0
white clover	113	4	117	96.6
overall	2440	53	2493	97.9

[1] Mean *TNSW*. [2] Mean *NSDLW*. [3] *NSDLW* / *TNSW* x 100. See Section 4.2.7 for definitions.

4.3.2. Magnitude of seed recovery

The mean seed destruction was statistically different from zero for all the species ($P<0.0001$). There was also a significant difference ($P<0.001$) between species for mean percentage of recovered seeds, both for total and for viable seeds (i.e. destruction did depend on species). This ranged from only 0.4 and 0.6% of the seeds surviving passage through the goats for variegated thistle to 24.0 and 32.3% for broad-leaved dock, for viable and total seeds respectively (Figure 4.1). Table 4.5 shows how the percentages of viable seeds recovered were obtained.

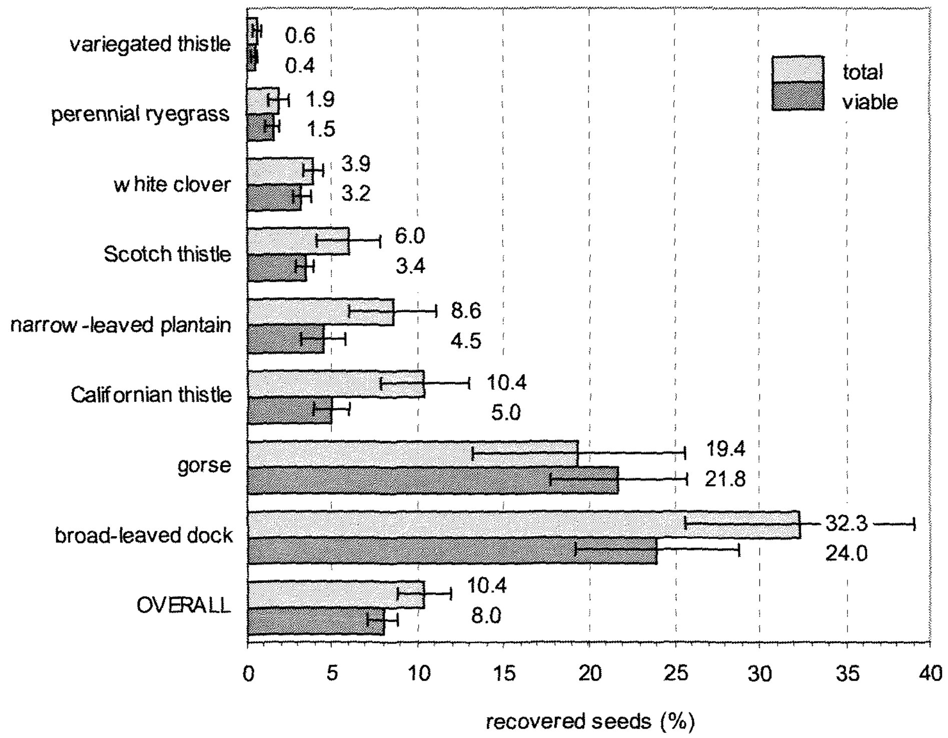


Figure 4.1 Percentage of total (*PTSR*) and viable (*PVSR*) seeds that passed through the digestive tract of goats (Section 4.2.7). Horizontal lines are ±SEM. (To obtain the mean number of seeds recovered, multiply values by 10.)

Table 4.5 Mean number and percentage of viable seeds recovered from goat faeces.

Species	Seeds[1] ingested	Viability index	Viable seeds ingested	Viable seeds recovered	Viable seeds recovered (%)
variegated thistle	1000	0.810	810	3	0.4
perennial ryegrass	1000	0.860	860	13	1.5
white clover	1000	0.990	990	32	3.2
Scotch thistle	1000	0.490	490	17	3.4
narrow-leaved plantain	1000	0.985	985	44	4.5
Californian thistle	1000	0.865	865	43	5.0
gorse	1000	0.565	565	123	21.8
broad-leaved dock	1000	0.960	960	230	24.0

[1] Expected number of seeds in the ration based on the 1000-seed weight method. For information on the 1000-seed weights, see Table 4.3.

4.3.3. Physiological changes

Table 4.6 shows a comparison of the physiological characteristics of the pre-ingestion seed lots (*c.* 96000 seeds) to the post-ingestion ones (2493 seeds, as shown in Table 4.4). In general, the percentage viability decreased when the seeds passed through the digestive system of goats ($P<0.01$). However, for variegated thistle and gorse, changes in percentage viability were not significant statistically ($P>0.05$).

The percentage of hard seeds was reduced in gorse ($P<0.05$) from 38.0% before to 24.7% after ingestion, while in white clover it actually increased substantially ($P<0.01$) from 2.0 to 53.3%.

Table 4.6 Physiological status of seeds before (PRE) and after (POST) being ingested by goats. Values are in percentage.

Species		Viable				Non-viable		
		Normal[1]	Dormant		Total	Dead	Ab-normal[3]	Total
			Hard	FU[2]				
dock (968)[4]	PRE	94.0	-	2.0	96.0	4.0	0.0	4.0
	POST	71.0	-	0.2	71.2	27.5	1.3	28.8
Californian thistle (279)	PRE	83.0	-	3.5	86.5	13.0	0.5	13.5
	POST	41.5	-	0.0	41.5	57.7	0.7	58.5
gorse (581)	PRE	7.5	38.0	11.0	56.5	43.0	0.5	43.5
	POST	17.1	24.7	21.6	63.5	36.5	0.0	36.5
plantain (256)	PRE	97.5	-	1.0	98.5	1.5	0.0	1.5
	POST	50.6	-	0.8	51.4	47.6	1.0	48.6
perennial ryegrass (47)	PRE	86.0	-	0.0	86.0	12.5	1.5	14.0
	POST	69.0	-	0.0	69.0	30.5	0.5	31.0
Scotch thistle (178)	PRE	42.0	-	7.0	49.0	50.5	0.5	51.0
	POST	27.6	-	0.0	27.6	72.3	0.1	72.4
variegated thistle (18)	PRE	79.0	-	2.0	81.0	18.0	1.0	19.0
	POST	31.3	-	27.1	58.3	41.7	0.0	41.7
white clover (113)	PRE	97.0	2.0	0.0	99.0	0.5	0.5	1.0
	POST	29.0	53.3	0.0	82.3	17.7	0.0	17.7

[1] This term applies to the seedlings. It represents the percentage of seeds that were not dormant and produced normal seedlings (ISTA, 1996). [2] FU = "fresh ungerminated" (ISTA, 1996). [3] "Damaged, deformed, or unbalanced seedlings, which would not develop into a normal plant" (ISTA, 1996). [4] Total number of seeds (n) recovered throughout the experiment (POST) and tested for germination. In the pre-ingestion tests (PRE), 200 seeds were used (ISTA, 1996). Within species, mean percentages of total viable seeds differ significantly between PRE and POST treatments ($P<0.01$), except for gorse and variegated thistle ($P>0.05$). Likewise, mean percentages of hard seeds differ significantly for both gorse ($P<0.05$) and white clover ($P<0.01$).

4.3.4. Seed passage time

Most seeds passed through the digestive system in the first 24 h, though it took up to 72 h for all the seeds to be excreted (Figure 4.2). All seeds of perennial ryegrass, variegated and Californian thistles were recovered within 48 h, while gorse, Scotch thistle, broad-leaved dock, narrow-leaved plantain, and white clover took up to 72 h to be excreted. No seeds were found after 72 h, with the exception of one seed of variegated thistle, which was found viable in a sample collected between 72-96 h.

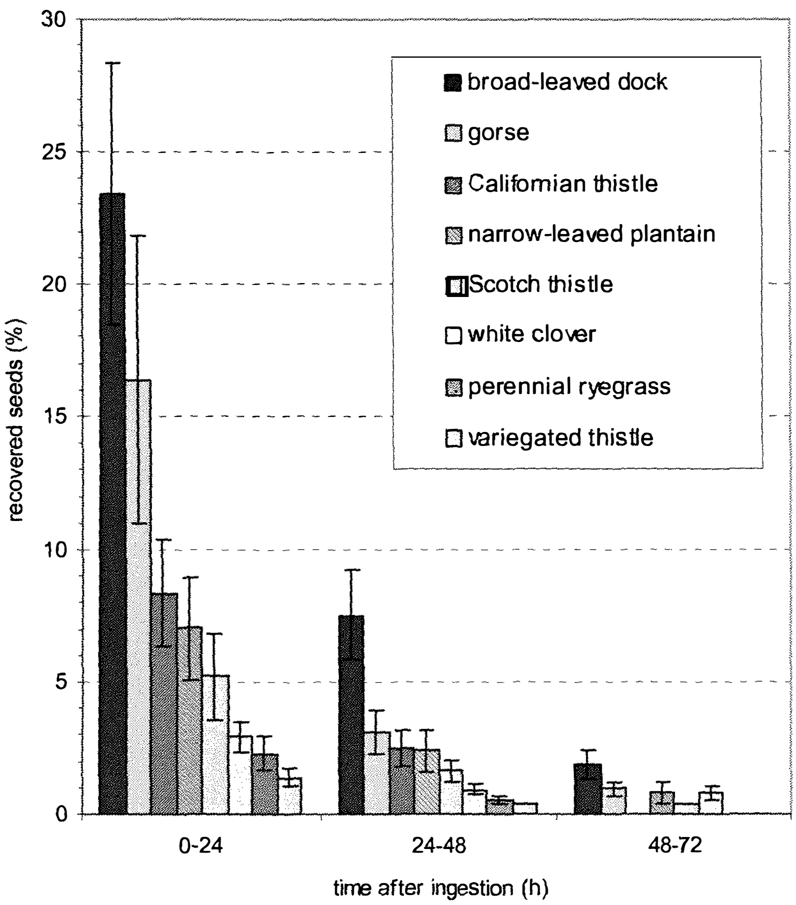


Figure 4.2 Seed recovery in time as a percentage of the total seeds ingested by goats. Vertical lines are ±SEM. Values are the same as the ones presented in Figure 4.1 (total), but spread over time.

4.3.5. Germination from intact faecal pellets

All the species were capable of germinating from intact faecal pellets. The emergence of four of them is illustrated in Plate 4.1. Table 4.7 shows the percentage seedling emergence of each species. Although variability was large, means ranged from 31.3% in white clover to as much as 100% in variegated thistle.

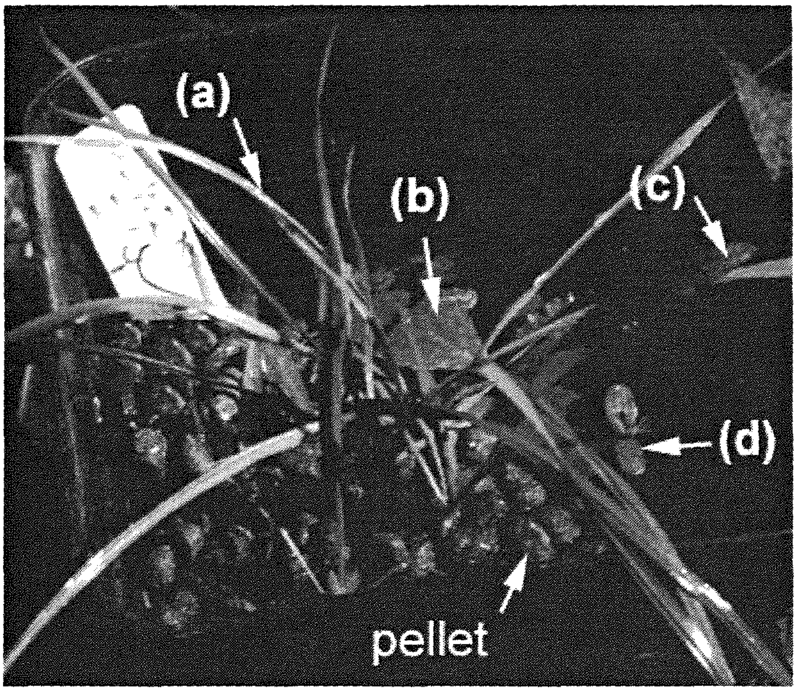


Plate 4.1 Seedlings of (a) perennial ryegrass, (b) Scotch thistle, (c) narrow-leaved plantain, and (d) gorse, developing in intact faecal pellets excreted by goats. Pellets are on top of potting mix, within a plastic pot (Section 4.2.5).

Table 4.7 Percentage of seedlings emerged from intact goat faecal pellets within 5 months of defecation.

Species	Mean	SE
broad-leaved dock	83.2	6.79
Californian thistle	41.9	10.96
gorse	77.8	5.24
narrow-leaved plantain	85.7	2.69
perennial ryegrass	46.7	22.00
Scotch thistle	75.0	11.79
variegated thistle	100.0	0.00
white clover	31.3	2.95

See Section 4.2.7 for details on how these values were obtained.

4.4. DISCUSSION

4.4.1. General

The efficiency of the seed recovery technique was relatively high, but the supplementary procedure for estimating the seeds that were missed did help increase the overall power of detection of excreted seeds (Table 4.4). Recovery was least efficient for perennial ryegrass and Californian thistle probably due to their seeds resembling pieces of undigested lucerne fibre, particularly of stems.

From the weed dispersal point of view, the seeds of interest are the viable ones, dormant or not, as they are the only seeds capable of generating new plants. However, the total figures give a better idea of the overall capability of the digestive system of goats to process seeds in general.

The average recovery of viable seeds was 8.0%, but this parameter is of limited value given that recovery varied significantly between species (Figure 4.1), even more so if the findings mentioned in Section 4.1 for other species are taken into account. Holst and Allan (1996) found that recovery varied between individual goats, but such variation was not significant (P>0.05) in the present experiment. There seems to be no clear relationship between recovery and physical characteristics of seeds. Amongst the species that were recovered in small percentages, for instance, are hard and soft seeds; large and small; round and oblong, and so on. Likewise, gorse and broad-leaved dock, which were recovered in greater proportion than other species, have few physical characteristics in common. Similarly, the results obtained by Simao Neto *et al.* (1987) from six tropical pasture species did not show any clear relationship between seed characteristics and recovery either. Definition of the seed characteristics influencing survival on passage was beyond the scope of the present experiment, and would have required a larger number of species. Thus, caution must be exercised in extrapolating from the species values shown in Figure 4.1.

While a reduction in percentage viability during passage through the gut (Section 4.3.3) was expected, the large increase in the percentage of hard seeds of white clover (from 2.0 to 53.3%) had not been anticipated. At first, this may seem incorrect, since it is generally believed that the proportion of hard seeds is determined during seed maturation (Rolston, 1978). If that is so, it is unlikely that any physiological transformation was involved during digestion, particularly considering that seed viability was tested only a few days before the trial. However, this change can be explained if one accepts that nonviable white clover seeds may have disappeared in a greater proportion than viable ones. Throughout the experiment, goats ingested *c.*12000 white clover seeds (*c.*1000 per animal x 4 goats x 3 weeks), 2.0% of which (Table 4.6) had hard coats (240 seeds). After digestion, 468 seeds were recovered (3.9%), 249 of which (53.3%) were hard seeds. This is illustrated in Figure 4.3.

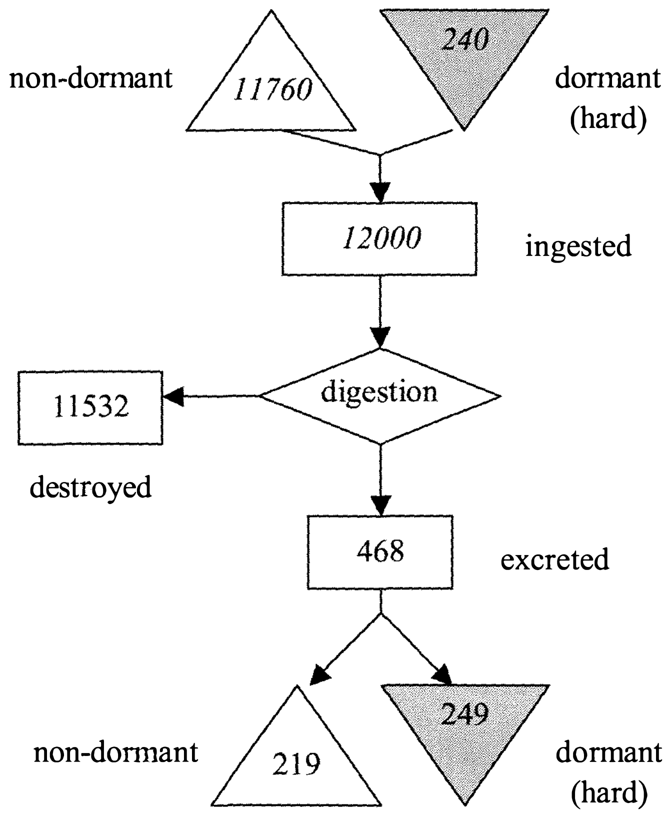


Figure 4.3 Flow of white clover seeds fed to goats. (Values in italics are estimates obtained from the 1000-seed weight, subject to the variability shown in Table 4.4.)

If the possibility of physiological changes in hardseededness after the initial seed test is ruled out, as suggested earlier, one is led to conclude that none of the 240 hard seeds was destroyed, especially knowing that there was no contamination with extraneous source of white clover seeds (Section 4.2.2). The white clover seeds used in this experiment were from a commercial seed lot (Table 4.1) and, like all commercial white clover seeds, they must have been scarified (i.e. treated for hardseededness) (Baker and Williams, 1987). Therefore, the fraction that was found hard (2%) in the pre-ingestion seed test (Table 4.6) was probably composed of seeds that were not affected by such a scarification. This suggests that their coats were very hard (i.e. they were probably the most resistant seeds of the whole lot), which may have helped them survive digestion.

The extra nine hard seeds (see the values within the shaded triangles in Figure 4.3) probably resulted from the actual number of seeds ingested being higher than 12000. Note that this figure was an estimate derived from the 1000-seed weight, subject to the variability shown in Section 4.3.1.

In contrast, hard-seed percentage was reduced in gorse during passage through the gut (Table 4.6), maybe because its hard seeds were not as resistant to mastication and digestion as those of white clover, which had apparently resisted scarification. Additionally, gorse seeds are much larger than white clover ones, thus more prone to being damaged by the teeth. They are also larger than the critical rumen particle size, which is the minimum size that food has to be reduced to in order to leave the rumen (McDonald, 1995). Thus, during rumination, they probably had to be processed in the mouth more intensely than white clover seeds. Even a small fracture on the seed coat is enough to break dormancy caused by hardseededness, which is the principal of the piercing method (ISTA, 1996) used in this experiment.

4.4.2. Some practical implications

Considering that sheep and cattle tend to avoid seed-heads (Hodgson, 1990; Thompson and Poppi, 1990), any proportion of weed seeds that can be destroyed by goats is advantageous. On average, goats destroyed 92% of the viable seeds they ingested in this experiment (Figure 4.1), which indicates that they are helping minimise the ingress of weed seeds into the soil seed bank when they eat seed-heads containing mature, viable seeds. However, because seed destruction was not complete, goats can also act as weed dispersal vectors (variegated thistle can be considered an exception to this because recovery of its viable seeds was negligible).

As seen in Section 4.3.4, though most seeds passed through the gut in the first 24 h (Figure 4.2), it took up to 72 h (3 days) for all the seeds to be excreted. Thus, from the weed management point of view, goats ideally should be held for at least 72 h in a place such as a pen (with hay and water available), so that all seeds can be excreted before animals are moved to an area where the seeds they ingested are not wanted (e.g. another property).

To support the decision of whether or not to implement such a scheme, it would be necessary to consider the following alternatives:

(a) not using goats to eat the weed seed-heads, thus accepting the full seed rain and the subsequent addition of seeds to the soil seed bank, though not contributing to the spread of the weed with goats;

(b) use goats to eat the seed-heads and shift them to new paddocks normally, thus saving the labour necessary for penning and feeding the animals as well as avoiding possible animal stress and health issues associated with concentration;

(c) use goats to eat the seed-heads, but penning them for seed passage, taking advantage of the reduction in viable seeds resulting from consumption of seed-heads and being reasonably confident that weed seeds will not be carried to new areas.

However, it should be noted that, under proper grazing management (Section 7.2.2), most seed-heads are consumed prior to seed maturity, which will result in a much greater reduction in seed rain than implied in this discussion. Additionally, seed-heads are often eaten when goats first enter a paddock (Section 3.3.4, p.38) thus, depending on grazing period (i.e. paddock occupation period), most seeds may have been excreted before goats are shifted.

The results also showed that the seeds of all the species included in this experiment can germinate and produce a normal and vigorous seedling in goat faeces. Harper (1977) claimed that most seeds will remain dormant in dung (livestock in general) until it is thoroughly decomposed and that very few will germinate before then. However, the current results contradict that, indicating that very high percentage germination can occur from dung (Table 4.7). Within 5 months, it reached more than 70% in five of the eight species studied. Moreover, figures were effective seedling emergence from faecal pellets as opposed to seed germination, which may have been higher (not all germinated seeds, in the laboratory sense, produce visible seedlings). Furthermore, it is possible that more seeds would still have germinated had seedling counting continued for longer than 5 months. Nevertheless, it is unlikely that the faecal pellets would remain intact in the field for so long.

4.5. SUMMARY

(i) *Are all the seeds ingested by goats destroyed in the digestion process?*

No. On average, 92% of the viable seeds were destroyed. Thus, by consuming mature seed-heads, goats help minimise the ingress of weed seeds into the soil seed bank.

(ii) *If not, are the recovered seeds viable?*

The mean percentage viability of the seeds recovered varied from 27.6% in Scotch thistle to 82.3% in white clover. In general, percentage viability was reduced during passage through the gut.

(iii) If viable, are they dormant or non-dormant?

This depended on the species. There were both cases (see below).

(iv) Will passage through the gut change the dormancy status?

Dormancy was either of undetermined cause ("fresh ungerminated" seeds in Table 4.6) or due to hardseededness. The main change in this was seen in the white clover hard-seed percentage, which increased significantly apparently due to a disproportionately higher destruction of non-hard seeds.

(v) How long will it take for seeds to pass through the gut?

All seeds were excreted by 72 h (3 days) after ingestion, but most of them were excreted in the first 24 h after ingestion.

(vi) If seeds do pass in a viable state, will they germinate from intact faecal pellets?

Yes, all seeds were capable of germinating in intact faeces and they emerged in much higher proportion than expected. By the fifth month, five of the eight species had reached 70% emergence.

(vii) Dispersal by goats should be minimal if it is considered that, under proper grazing management, most seed-heads are eaten while seeds are still immature. Additionally, most seeds are likely to be excreted in the same paddock because goats tend to look for seed-heads when they first enter a paddock, though this will depend on

grazing period (the longer the paddock occupation period, the lower the chances of dispersal).

CHAPTER 5

THE IMPACT OF GOATS ON THE COMPETITIVENESS OF PASTURE AGAINST WEED INVASIONS

5.1. INTRODUCTION

As discussed in Chapter 2, studies involving goats and pasture weeds have concentrated on the impact of these animals on established weed populations. No study seems to have explored the possibility that the presence of goats in the system might result in indirect benefits to the combat against pasture weeds in the long term. The experiment reported in this chapter was designed to test the hypothesis that *a sward grazed by goats becomes more competitive against weed invasions than a sward grazed by cattle.* This originated from general observations made during Experiment 1 (Chapter 3), especially with regards to the way goats harvest their feed and tread on the pasture canopy.

Additionally, this experiment attempts to confirm an increase in herbage production detected by Thompson and Power (1993) resulting from the addition of goats to a cattle system. These researchers added goats to a bull beef system at its maximum carrying capacity and obtained increased returns from the system as a whole (i.e. same bull performance, but with an added goat production), while adding more bulls had a negative effect on total animal output. This probably resulted from improved utilisation of herbage and weed biomass brought about by the goats, which will be discussed in Section 7.2.1.2. However, there was a trend for greater herbage production associated with increasing goat participation in the treatments, which was not followed up by the authors and may have been an additional factor influencing the observed increase in the productivity of the system. If confirmed, this could be another advantage of the integration of goats with cattle.

Thus, the main questions to be answered by this experiment were:

(i) *Is a pasture grazed by goats structurally different from a pasture grazed by cattle under the same grazing management?*

(ii) *If so, can the goat pasture be more competitive against weed invasions than a cattle one?*

(iii) *Can a goat pasture be more productive than a cattle one under the same grazing management? Why?*

5.2. MATERIALS AND METHODS

To investigate these issues, an experiment was conducted at the Massey University Pasture and Crop Research Unit, adjacent to the Palmerston North campus, from July 1999 to June 2000. The area is rolling downland country, historically grazed by sheep only. The soil mapping unit is the Tokomaru silt loam (Cowie, 1972) which is an Argillic-Fragic, Perch-gley, Pallic soil (Hewitt, 1992) with Olsen P values in the range of 20-30 mg/kg. The pasture was dominated by perennial ryegrass and white clover with a history of minor to moderate incidence of Scotch and Californian thistles, as the main weeds on the experimental site.

5.2.1. Treatments

The experimental units (grazed plots) were arranged in a randomised complete factorial design replicated in three blocks. Treatments consisted of four combinations of cattle and goats, ranging from cattle only to goats only, managed at two grazing severities, as shown in Table 5.1.

Table 5.1 Treatment combinations of Experiment 3 and plot areas adopted.

Treatment			Number of animals		Stock units (su)[1]	Plot area (m^2)
Grazing severity	Goat participation	Code	Cattle	Goats		
lax	nil	LN	3	0	15.0	125.0
lax	low	LL	3	3	17.4	145.0
lax	high	LH	3	18	30.2	251.7
lax	maximum	LM	0	18	15.2	126.7
hard	nil	HN	3	0	15.0	125.0
hard	low	HL	3	3	17.4	145.0
hard	high	HH	3	18	30.2	251.7
hard	maximum	HM	0	18	15.2	126.7

[1] Where 1 cattle beast = 5 stock units (SU); 1 goat = 0.8 SU (after Thompson and Power, 1993).

Plot areas were made proportional to the treatment stock units so that the stocking density (Forage and Terminology Committee, 1991) was the same in all treatments (i.e. 1200 SU/ha being grazed). This stocking density was chosen to allow the whole experiment to be grazed in no more than seven days.

5.2.1.1. Animals

The animals were obtained from commercial hill country farms in the Manawatu region. Cattle were nine Hereford-Aberdeen Angus cross cows, averaging 345 kg live weight (±SE 12 kg). Goats were 39 wethers of varied genetic background (37 of the cashmere type; one Boer, and two Angoras), averaging 32 kg live weight (±SE 8 kg). Average live weights are the arithmetic mean of initial (July 1999) and final (June 2000) live weights.

5.2.1.2. Grazing management

Plots were grazed once a month during the last week of each month by four groups of animals (Table 5.1) drafted at random before each monthly grazing. The same group was used to achieve both the lax and the hard grazing severities (e.g. the cows that grazed LN were the same to graze HN). Plots were always grazed in the same order, from Block 1 to Block 3.

Lax and hard grazing severities were achieved by removing animals when sward height reached 10 and 5 cm, respectively. To aid this decision process and to avoid disturbing the animals during grazing, three wooden pegs were placed vertically on each plot indicating the appropriate residual heights to be observed. Target residual heights were achieved within 8 to 37 hours, depending on the treatment (details are provided in Section 5.3.1).

Water was provided in troughs on a central race running across the blocks to minimise the number of troughs needed and to avoid pugging within the plots. Animals were allowed to drink every time they were shifted to a new plot.

During the intervals between experimental grazings, animals were kept in adjacent paddocks outside the experimental area. They were rotationally grazed, but most of the time goats were managed separately from cattle (unlike the experimental grazings described above). Usually, paddocks were grazed by cattle followed by goats, but the inverse order was also used. General observations of animal behaviour, diet selection, and their impact on plants were made. A fourth and independent experiment was carried out in this adjacent area and is described in Chapter 6.

5.2.2. Measurements

5.2.2.1. Routine measurements made at each grazing

Five herbage samples were taken at random from each plot immediately before and after every grazing. Herbage was cut at ground level within 0.1 m^2 quadrats (0.13 x 0.77 m^2) with electric clippers. The pre-grazing samples were used to obtain herbage mass (Grant, 1993; Frame, 1993); botanical composition (Grant, 1993); leaf area index (LAI), which included grasses, clover, and weeds, measured with a bench-based electronic leaf area integrator (Gay, 1993); green and dead matter (Grant, 1993); and tiller population density (herbage was cut carefully to preserve tiller and lamina integrity) (Jewiss, 1993). From the post-grazing samples, only herbage mass was obtained, except that in January 2000 the mass (kg DM/ha) of grass seed-heads was computed separately. Total herbage accumulation (i.e. for the 12 months of experiment) was calculated as the sum of the monthly herbage accumulation (i.e. pre-grazing herbage mass at time *t* minus post-grazing herbage mass at time *t*-1).

Prior to each grazing, weed and white clover seedlings were counted within each of the five quadrats before cutting the herbage. No attempts were made to identify weed seedlings to specific level.

Sward surface height was measured with a sward stick (Rhodes and Collins, 1993) at 20 random locations within each plot, both prior to and after grazing. Additionally, a vertical point quadrat (50 point hits per plot) was used to estimate the percentage of bare soil prior to grazing only (Grant, 1993). Grazing duration (i.e. the length of time it took animals to reach the target residual sward heights on individual plots) was recorded to help explain treatment effects.

5.2.2.2. *Non-routine measurements*

Five soil cores (5-cm diameter by 2-cm depth) were taken from each plot in January 2000 to provide an estimate of the soil seed bank. The soil cores were sectioned in thin layers (5-mm thick) and placed on top of sterile potting mix within plastic pots and kept in a glasshouse for 3 months. The average air temperature in the glasshouse was 22°C (range 18-31°C). Pots were kept moist through an automated mist irrigation system. Seedlings were identified, counted and removed as soon as they could be identified.

To help explain the effects of animals on the sward, the static pressure exerted on the soil by the hooves of goats, cattle, and sheep was calculated as follows:

$$\textit{body force}\,(\mathrm{N}) = \textit{body mass}\,(\mathrm{kg}) \times \textit{acceleration of gravity}\,(9.8\,\mathrm{m\,s^{-2}}) \quad (5.1)$$

$$\textit{hoof pressure}\,(\mathrm{hPa}) = \frac{\textit{body force}\,(\mathrm{N})}{\textit{total hoof area}\,(\mathrm{m^2})} \quad (5.2)$$

where:

N = newton
body mass = mean live weight (Section 5.2.1.1)
hPa = hectopascal

Total hoof area (Equation 5.2) was obtained from hoof prints left by a sample of animals (detailed below) that were made to walk on a wet lane denuded of vegetation, one at a time. The contour of each claw left on the ground was drawn with a pen on sheets of acetate laid on a sheet of transparent glass and this was placed on top of the prints. The acetates were scanned digitally and imported into AutoCAD R14 (a computer programme used in architecture and engineering) for calculating the hoof polygon areas.

Both body mass and total hoof area were obtained for individual animals. The animals were a random sample of 10 of the 39 goats and all 10 of the cows used in the experiment (Section 5.2.1.1), plus a random sample of 10 pregnant Perendale ewes from adjacent paddocks of the same Pasture and Crop Research Unit (sheep were not used in the experiment, but were included in this exercise for comparison).

Soil compaction was assessed on each plot in June 2000 with an impact penetrometer consisting of 1 cm^2 metal rod which was introduced vertically into the soil by the shock of a 1 kg weight piece hitting the end of the rod after falling from a height of 1 m (Field *et al.*, 1993). Compaction measurements were made at 20 randomly selected positions in each plot. A soil compaction index was calculated by taking the inverse of the penetration length, so the greater the index, the greater the soil strength or resistance to penetration (McLaren and Cameron, 1996).

Monthly rainfall and soil temperature data (10-cm depth, recorded daily at 9.00 a.m.) were obtained from the Palmerston North AgResearch Meteorological Station, which is approximately 700 m from the experimental site.

5.2.3. Derived variables and statistical analyses

A "pasture competitiveness index" (PCI) was devised as a measure of the overall resistance of the sward against weed invasions after 12 months of treatment imposition (i.e. in June 2000). PCI was calculated as the sum of five other indices, as shown below:

$$PCI = TDI + TWI + RLAI + DDI + GCI \qquad (5.3)$$

where:

TDI = tiller density index

TWI = tiller weight index
RLAI = relative LAI
DDI = dead matter index
GCI = ground cover index

Equation 5.4 shows how each of the five indices above were obtained (factors follow the same order as in Equation 5.3):

$$PCI_i = \frac{TD_i}{TD_{\max}} + \left(\frac{TW_i}{TW_{\max}}\right) \times 0.5 + \frac{LAI_i}{LAI_{\max}} + \frac{DD_i}{DD_{\max}} + \left(1 - \frac{BS_i}{BS_{\max}}\right) \times 1.5 \quad (5.4)$$

where:

i = value per quadrat (i.e. sub-sample), within treatment in June 2000
max = maximum value for that factor across treatments in June 2000
TD = tiller density
TW = tiller weight
LAI = leaf area index
DD = dead matter
BS = *bare soil*

The weights (0.5 and 1.5) are explained in Section 5.4.3.

Comparisons of hoof pressure means were made through the Student's t test, using the SAS STAT Procedure with t approximation due to unequal variances (SAS, 1996).

All other variables were analysed through an univariate ANOVA using the SAS GLM Procedure (SAS, 1996) in a randomised complete 2 x 4 factorial design with three replicates (treatment factors are detailed in Table 5.1). The soil seed bank estimates (viable seeds/ha) were used as covariates in the ANOVA of weed and white clover seedling densities.

With the exception of total herbage accumulation, which was the sum of the monthly accumulations (see Section 5.2.2.1), the ANOVA were run by month to determine when treatment effects first became statistically significant (*F* test). Multiple comparisons between treatments were made using the final treatment effects (i.e. June 2000 data) through the Fisher's least significant difference (LSD). Contrasts of "lax" versus "hard" and "with" versus "without goat participation" were obtained using the command CONTRAST of the same SAS GLM Procedure. The ANOVA were performed on logarithmically transformed data (ln Y or ln Y+1 when data contained zeros) because of the lack of homogeneity of treatment variances.

An ANOVA was performed on the mean within-plot variances for the variables related to sward structural characteristics (i.e. tiller density, tiller weight, LAI, percentage bare soil, and dead matter) to determine the uniformity of the sward within plots. Multiple comparisons were performed through the LSD following the procedure outlined above.

A non-linear (negative power) regression of PCI against weed seedling density was performed using the SAS NLIN Procedure (SAS, 1996) to determine whether PCI was indeed a measure of competitiveness.

5.3. RESULTS

5.3.1. General

Monthly rainfall and soil temperature data from the 12 months of the experiment are presented in Figures 5.1 and 5.2, respectively.

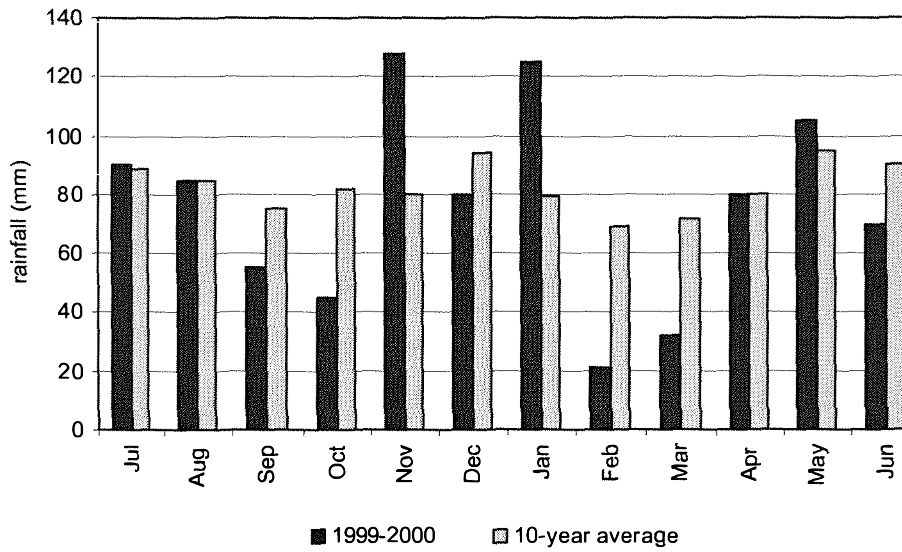


Figure 5.1 Monthly rainfall recorded at the Palmerston North AgResearch Meteorological Station, approximately 700 m from the experimental site.

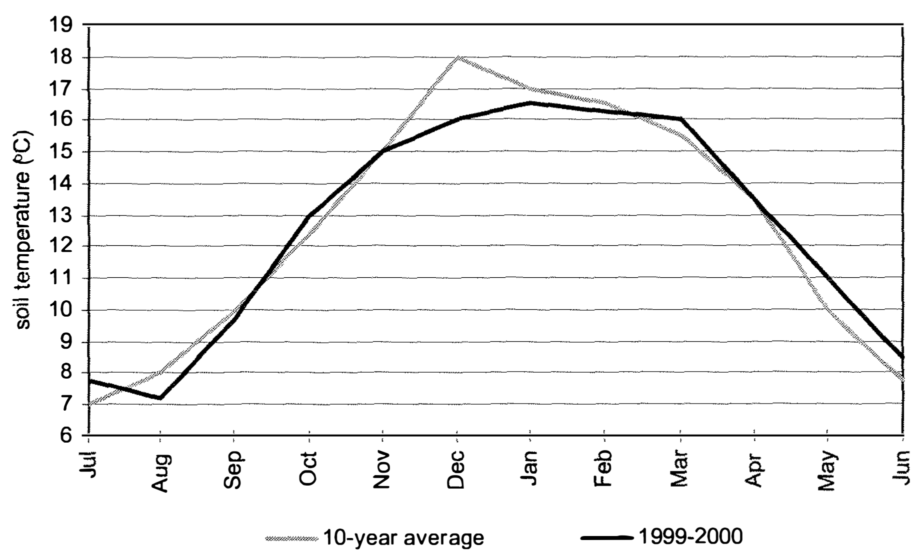


Figure 5.2 Monthly soil temperature (10-cm depth) recorded daily (9.00 a.m.) at the Palmerston North AgResearch Meteorological Station, approximately 700 m from the experimental site.

Sheep and cattle exerted 1.5 and 2.5 times more pressure on the soil than goats ($P<0.01$), respectively (see Table 5.2).

Table 5.2 Mean static load and pressure exerted on the soil by the hooves of the goats and cattle used in Experiment 3 and by sheep from an adjacent area as a function of their body mass and hoof area.

Animal species	Body mass[1] (kg)	Hoof area (cm^2)	Load (kg/cm^2)	Force (N)	Pressure[2] (hPa)	Relative pressure
goat	32c	40.32b	0.79c	313.6c	78c	1.0x
cattle	345a	176.32a	1.96a	3381.0a	192a	2.5x
sheep	51b	42.00b	1.21b	499.8b	119b	1.5x
SEM	2	5.04	0.09	82.5	10	—

[1] Live weight. [2] Means followed by the same letter within columns do not differ statistically ($P>0.05$). See Section 5.2.2.2 for details on the measurements and calculations.

The mean post-grazing sward surface heights were very close to the desired (Section 5.2.1.2) lax (10 cm) and hard (5 cm) grazing severities, as shown in Table 5.3. Note that the data summarised in this table are the means from the 12 months of the experiment, intended for general information only (details on patterns of herbage growth and total herbage accumulation are provided in the next section).

Table 5.3 Mean pre- and post-grazing sward surface height and herbage mass, herbage disappearance (HbDs), grazing period (GrPd), and apparent daily herbage intake (ADHI) following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Values are treatment means from the 12 months of experiment.

Treatments	Pre-grazing		Post-grazing		HbDs[1] (kg DM/ha)	GrzPd[2] (h)	ADHI[3] (kg DM/ SU/day)
	height (cm)	mass (kg DM/ha)	height (cm)	mass (kg DM/ha)			
lax nil (LN)	12.5	2166	10.5	1423	743	8.0c	1.858
lax low (LL)	14.4	2373	10.7	1686	688	8.2 c	1.678
lax high (LH)	17.7	2853	10.3	2139	713	8.4 c	1.699
lax max. (LM)	20.0	3241	10.6	2450	791	18.7 b	0.848
hard nil (HN)	7.8	1365	5.2	605	760	17.0bc	0.894
hard low (HL)	9.9	1678	5.5	878	800	17.2bc	0.930
hard high (HH)	13.8	2416	5.6	1386	1030	19.1b	1.078
hard max. (HM)	14.5	2420	5.1	1500	920	37.3a	0.493
SEM	2.0	305	2.2	319	288	1.9	0.265

[1] Herbage consumed + herbage destroyed by trampling.

[2] Duration of grazing per plot. Means followed by the same letter within this column do not differ statistically (P>0.05).

[3] ADHI = (HbDs / GrzPd) x 24 h.

Treatment effects were significant on all response variables, except on white clover seedling density and the grass and white clover components of the botanical composition. A summary of the results of the statistical analyses of the main variables is shown in Table 5.4. However, the effects over time and the magnitude of the differences between treatments are better illustrated in a series of charts that follow (Sections 5.3.2 and 5.3.3).

Table 5.4 Effects of goats and cattle on sward structure, overall competitiveness, and botanical composition. The analyses were carried out on the natural logarithms of the values recorded at the end of the experiment (June 2000), except for grass seed-heads (GSH), which was recorded in mid-summer (January 2000). (For means, see figures Figure 5.3 to Figure 5.17.)

Treatments	TD	TW	LAI	DD	GSH	BS	MHA	THA	SCI	PCI	WSD	CSD	GR	WC	WD
lax nil (LN)	c[1]	bc	c	b	a	a	cd	cd	b	c	ab	a	a	a	a
lax low (LL)	bc	c	c	ab	a	ab	d	d	bc	bc	b	a	a	a	ab
lax high (LH)	b	c	bc	a	b	b	c	cd	c	b	b	a	a	a	b
lax max. (LM)	ab	c	b	a	b	bc	bc	bc	d	a	b	a	a	a	b
hard nil (HN)	c	a	d	c	a	a	b	b	a	d	a	a	a	a	a
hard low (HL)	b	ab	c	b	b	a	a	ab	ab	cd	a	a	a	a	a
hard high (HH)	a	b	a	bc	b	b	a	a	bc	ab	b	a	a	a	ab
hard max. (HM)	a	c	a	a	b	c	a	a	c	a	b	a	a	a	b
F	****	****	***	**	****	****	**	**	*	****	***	NS	NS	NS	**
GS*GP[2]	***	***	***	*	*	**	**	**	**	***	***	NS	NS	NS	***
lax vs. hard[3]	NS	NS	NS	*	*	NS	****	**	*	****	NS	NS	*	***	NS
goat vs. no goat[4]	***	NS	**	*	***	NS	NS	NS	*	**	*	NS	NS	NS	**

Column headings: TD = tiller population density; TW = tiller weight; LAI = leaf area index; DD = dead matter; GSH = grass seed-heads; BS = percentage bare soil; MHA = monthly herbage accumulation; THA = total herbage accumulation (i.e. for the 12-month period); SCI = soil compaction index; PCI = pasture competitiveness index; WSD = weed seedling density; CSD = (white) clover seedling density. Botanical composition: GR = grasses, WC = white clover, WD = weeds.

[1] Treatments displaying the same letters within columns do not differ statistically ($P>0.05$).
[2] Interactions between grazing severity (GS) and goat participation (GP).
[3] Contrasts between lax and hard grazing severities.
[4] Contrasts between treatments containing goats and treatments with no goats.

NS = not significant ($P>0.05$); * = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$; **** = $P<0.0001$.

5.3.2. Sward structure, herbage accumulation, and soil compaction

For most variables, it took a few months (minimum three, maximum nine) for significant differences between treatments to appear. The month when the differences first became statistically significant is indicated by an arrow in all line graphs that follow. Additionally, to aid the identification of treatments, all lax grazing treatments are represented by dotted lines and all hard grazing ones, by continuous ones.

After 12 months, tiller density was lowest in HN and highest in HM and HH (Figure 5.3).

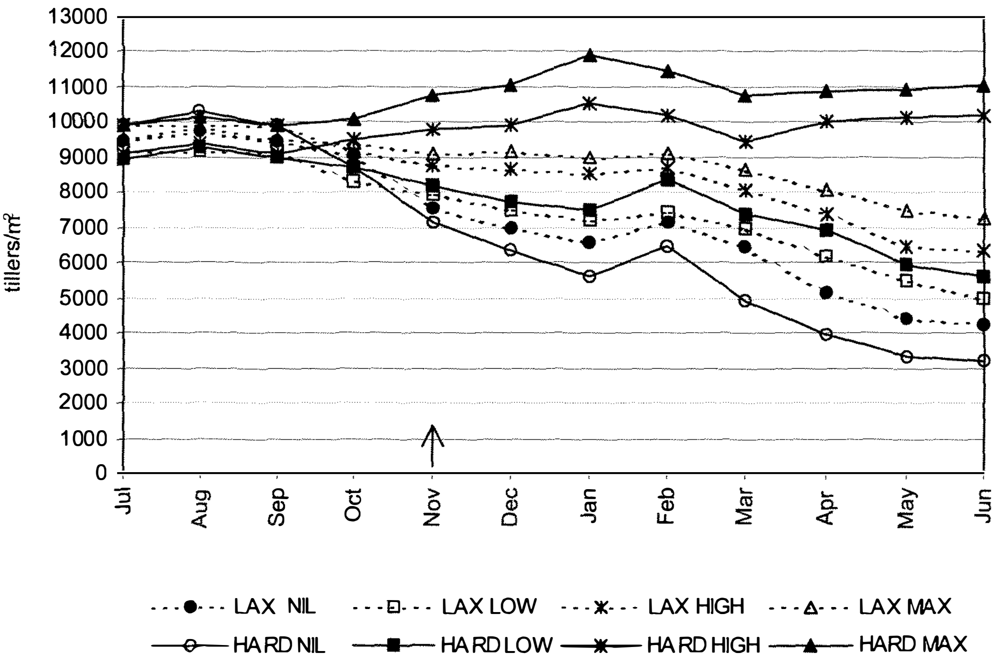


Figure 5.3 Monthly tiller population density following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Grass tillers became heaviest in HN and HL treatments, but tiller weight remained similar in the other treatments (Figure 5.4).

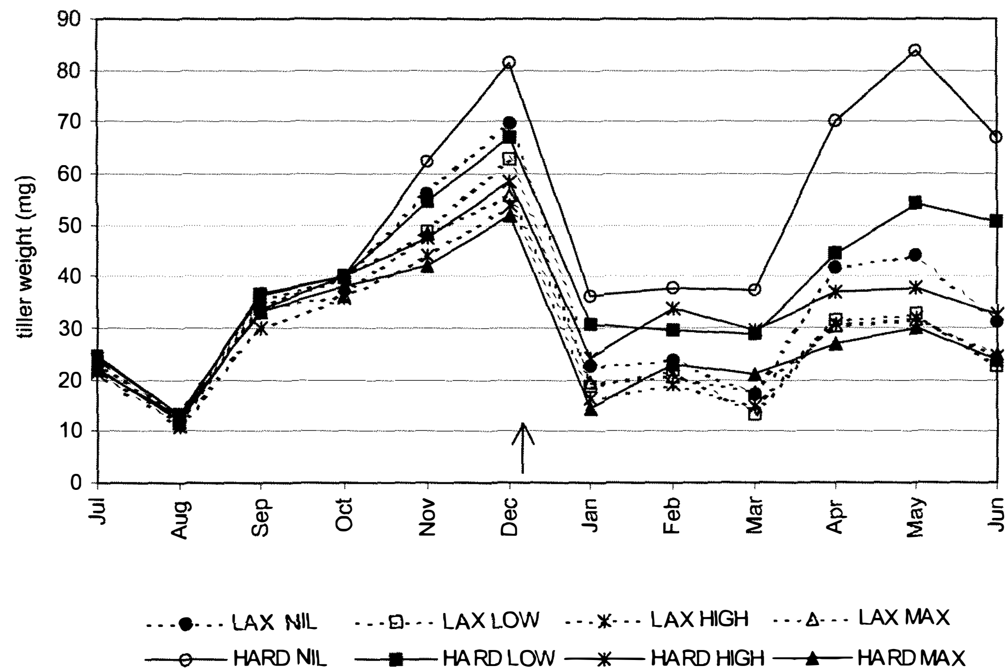


Figure 5.4 Monthly tiller weight following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

HM and HH were significantly leafier than the other treatments, especially when compared to HN, which produced the lowest LAI of all treatments (Figure 5.5). So HM and HH produced light, leafy tillers at high population density, while HN produced heavy tillers at low density, bearing few or small leaves.

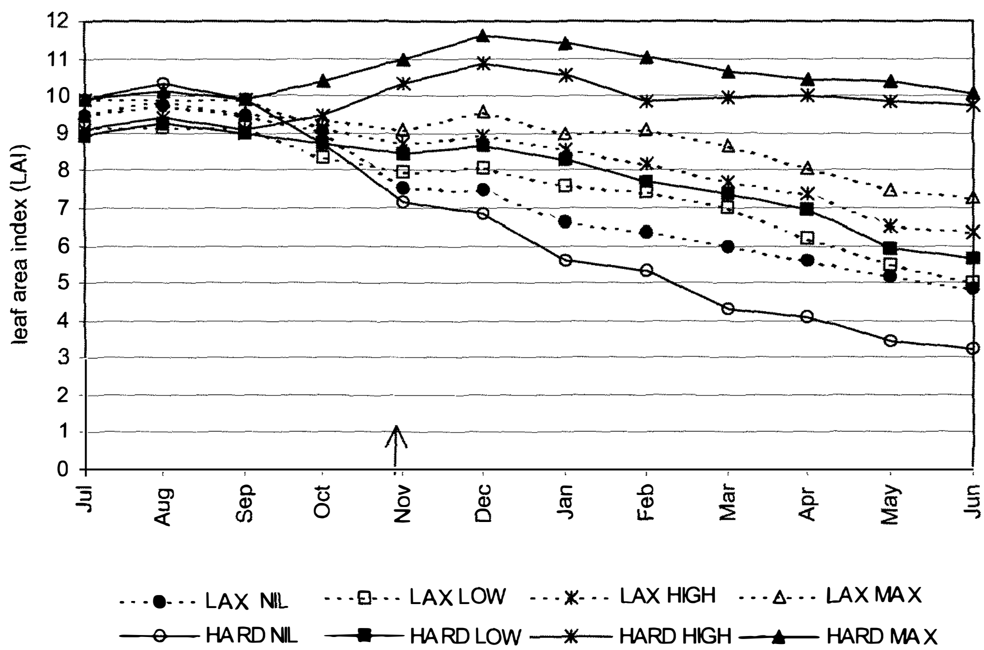


Figure 5.5 Monthly leaf area index (LAI) following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

HN produced the lowest percentage of dead matter and LM, the most (Figure 5.6). These effects became apparent very early (significant after the third month).

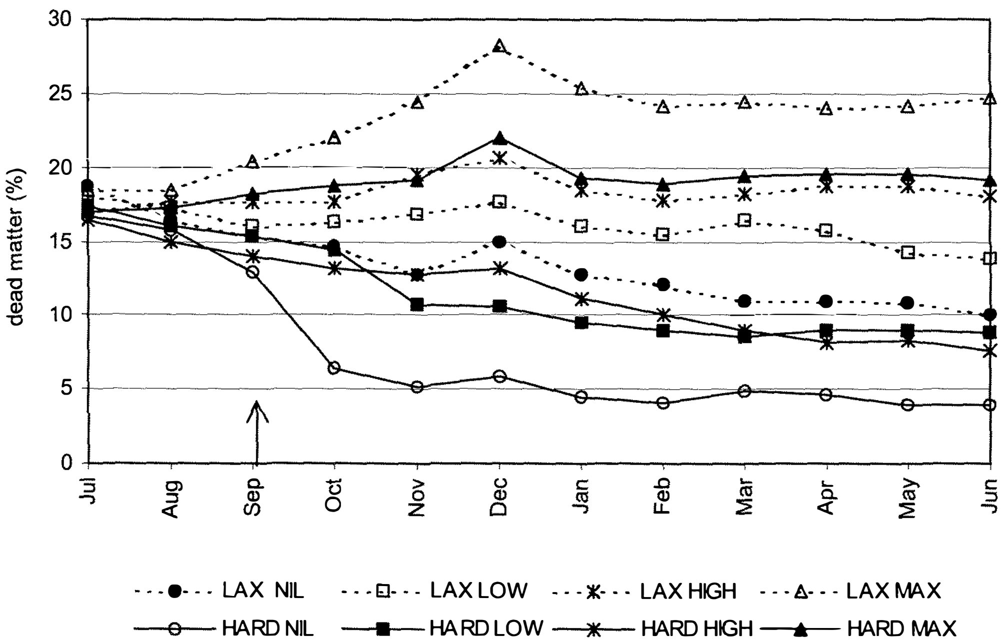


Figure 5.6 Monthly dead matter following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically (P<0.05). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Large amounts of grass seed-heads were left untouched in LN, LL, and HN during summer (Figure 5.7), while few were left in the other treatments (virtually none in HM).

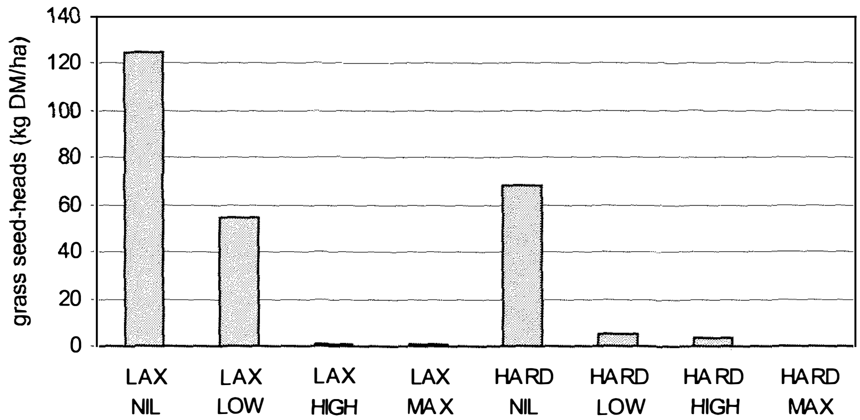


Figure 5.7 Weight of grass seed-heads left after lax and hard grazing by cattle and/or goats in mid-summer (January 2000) (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

The percentage ground area found denuded of herbage cover immediately before grazing is shown in Figure 5.8. At the end of the experiment, it was largest in HN and HL and lowest in HM and LM.

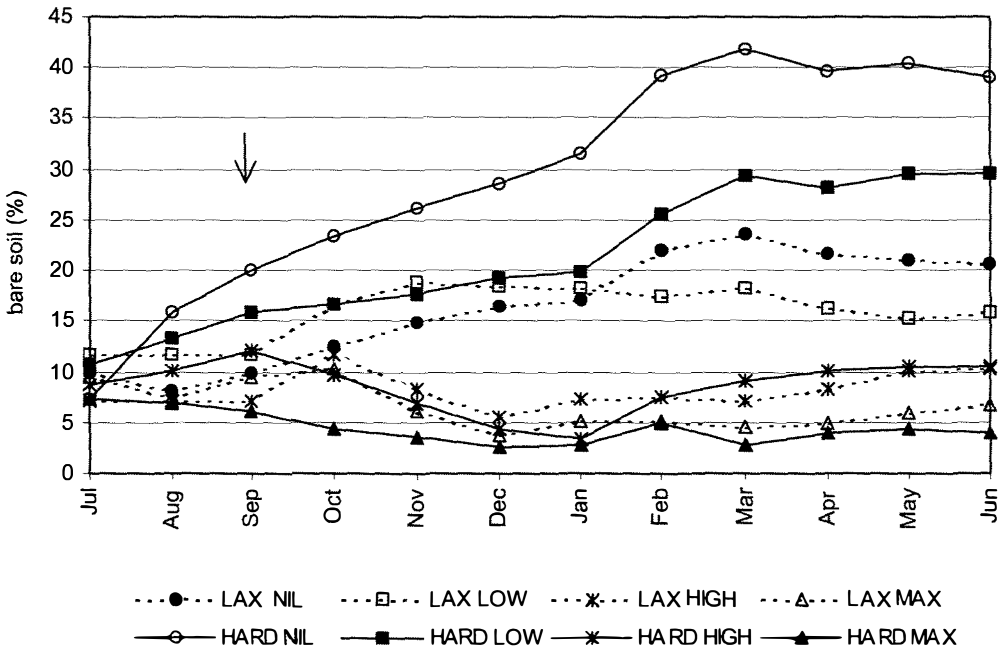


Figure 5.8 Monthly pre-grazing bare soil following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Differences in herbage accumulation between treatments only became significant after 8 months of treatment imposition (Figure 5.9), but the cumulative differences were considerable at the end of 12 months (Figure 5.10). HH produced the largest amount of herbage.

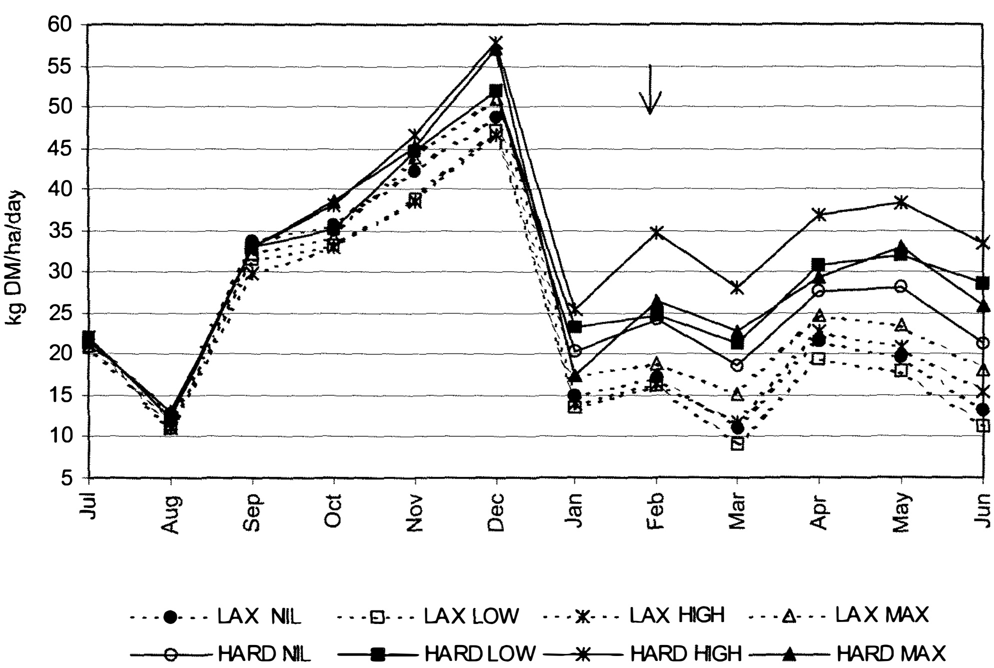


Figure 5.9 Monthly herbage accumulation following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Figure 5.11 shows that the greater the participation of goats within lax or hard grazing treatments, the lower the soil compaction index at the end of the experiment.

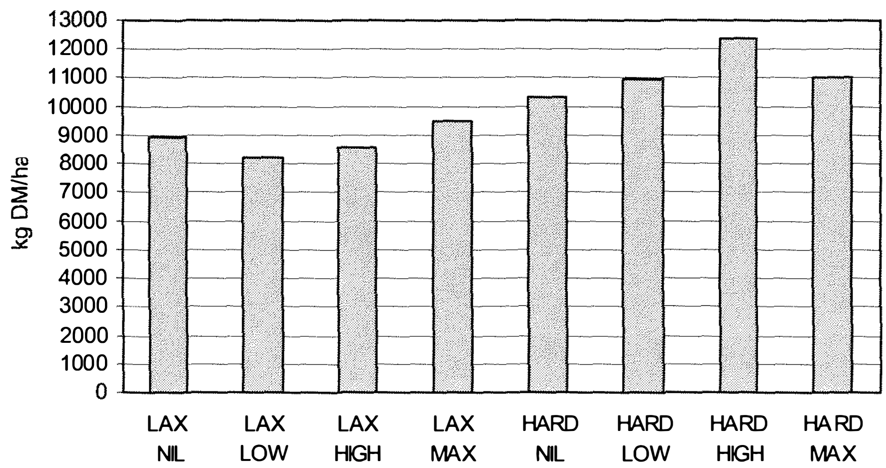


Figure 5.10 Total herbage accumulation during the 12 months of experiment (July 1999 to June 2000), following lax and hard grazing by cattle and/or goats (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

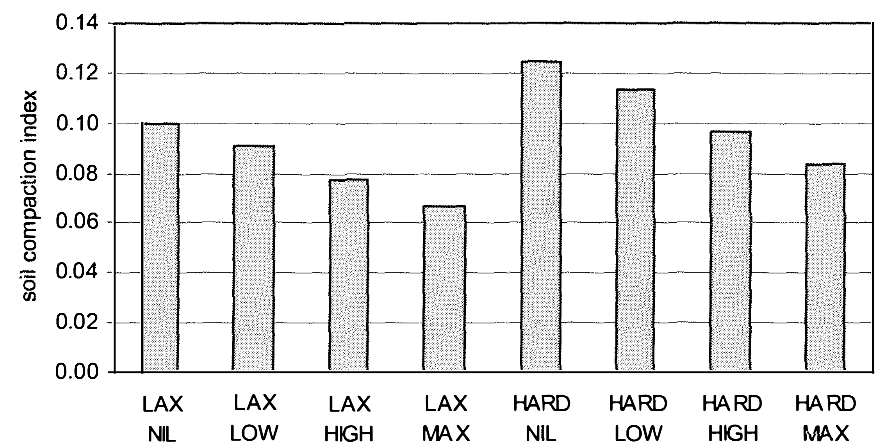


Figure 5.11 Soil compaction index (the greater the index, the greater the soil resistance to penetration) assessed at the end of the experiment (June 2000), following lax and hard grazing by cattle and/or goats (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

5.3.3. Soil seed bank, seedling density and botanical composition

Weed seedling density increased significantly in HN and, to a lesser extent, in HL as well, particularly in May 2000 (Figure 5.12). Table 5.5 shows the plant species that were present in the soil (excluding grasses) and the magnitude of their soil seed bank.

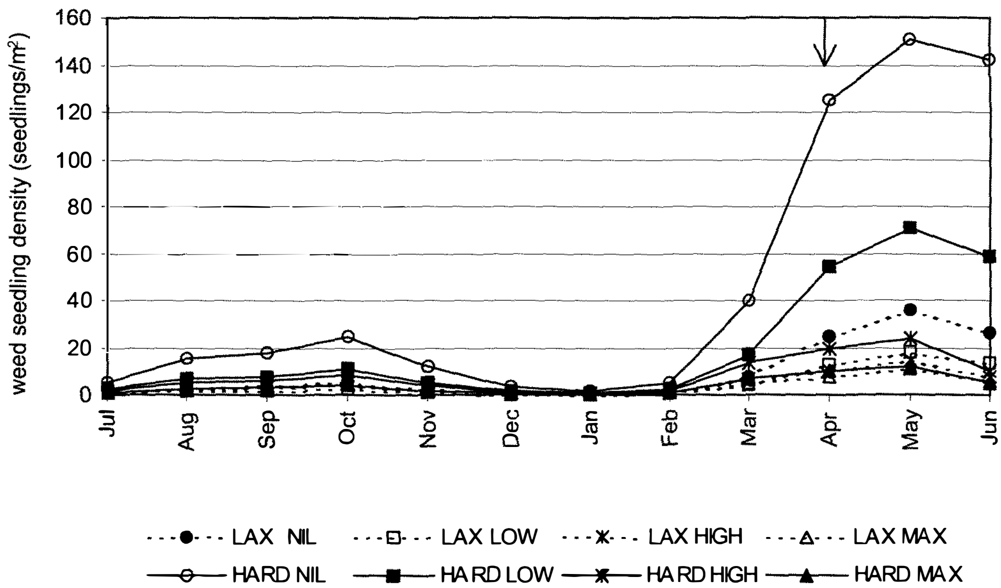


Figure 5.12 Weed seedling density following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically ($P<0.05$). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Table 5.5 Number of viable seeds in the soil seed bank (to 2-cm depth) estimated from seedling emergence in glasshouse. (Species are in decreasing order of seed bank magnitude.)

Common name	Botanical name	seeds/m^2 (±SEM)	Present in vegetation[1]
pennyroyal	*Mentha pulegium*	12,128 (825)	yes
dandelion	*Taraxacum officinale*	1,442 (214)	yes
catsear	*Hypochaeris radicata*	937 (132)	yes
rushes	*Juncus* sp.	729 (59)	no
narrow-leaved plantain	*Plantago lanceolata*	646 (114)	yes
twin cress	*Coronopus didymus*	542 (95)	yes
broad-leaved dock	*Rumex obtusifolius*	437 (67)	yes
field speedwell	*Veronica arvensis*	271 (59)	no
annual mouse-ear chickweed	*Cerastium glomeratum*	208 (159)	no
mouse-ear chickweed	*Cerastium fontanum*	195 (75)	no
broad-leaved fleabane	*Conyza albida*	188 (91)	no
turf speedwell	*Veronica serpyllifolia*	187 (56)	no
creeping yellow cress	*Rorippa sylvestris*	125 (29)	no
black nightshade	*Solanum nigrum*	105 (88)	no
yarrow	*Achillea millefolium*	104 (12)	yes
hawksbeard	*Crepis capillaris*	85 (15)	yes
white clover	*Trifolium repens*	83 (55)	yes
chickweed	*Stellaria media*	60 (39)	no
Scotch thistle	*Cirsium vulgare*	42 (13)	yes
procumbent pearlwort	*Sagina procumbens*	41 (16)	no
daisy	*Bellis perennis*	20 (8)	yes
milkweed	*Euphorbia peplus*	12 (5)	no
silky cudweed	*Gnaphalium calviceps*	11 (5)	no
Californian thistle	*Cirsium arvense*	5 (4)	yes
creeping buttercup	*Ranunculus repens*	3 (2)	yes
Total seeds		18,606	

[1] This denotes whether the species was present in the samples of the above ground vegetation. Species showing "no" were not seen growing on the plots during the experimental period.

The white clover seedling density was relatively low in all treatments (Figure 5.13), especially if compared to weed seedlings (Figure 5.12). Differences between treatments for white clover seedling density were small and not statistically significant (Table 5.4).

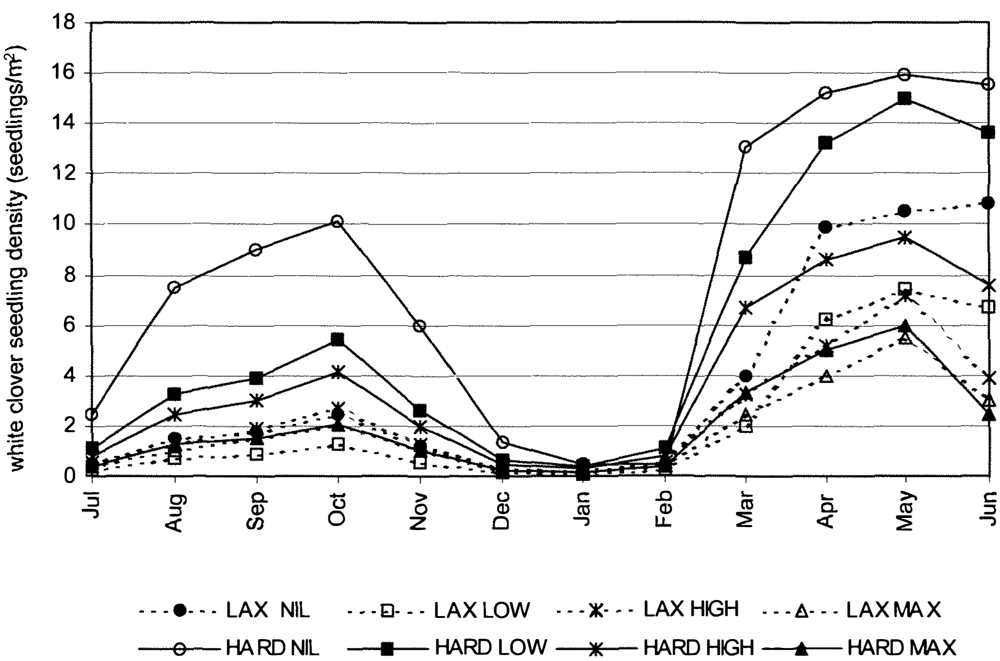


Figure 5.13 White clover seedling density following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. Differences were not significant statistically.)

LN resulted in the greatest proportion of weeds in the botanical composition, followed by HN. Weed cover was minimal in LM (Figure 5.14). Most of the weed cover in LN and HN were Scotch thistle, Californian thistle, and docks. In the other treatments, the main weeds were pennyroyal and docks (no thistles survived in any goat treatment).

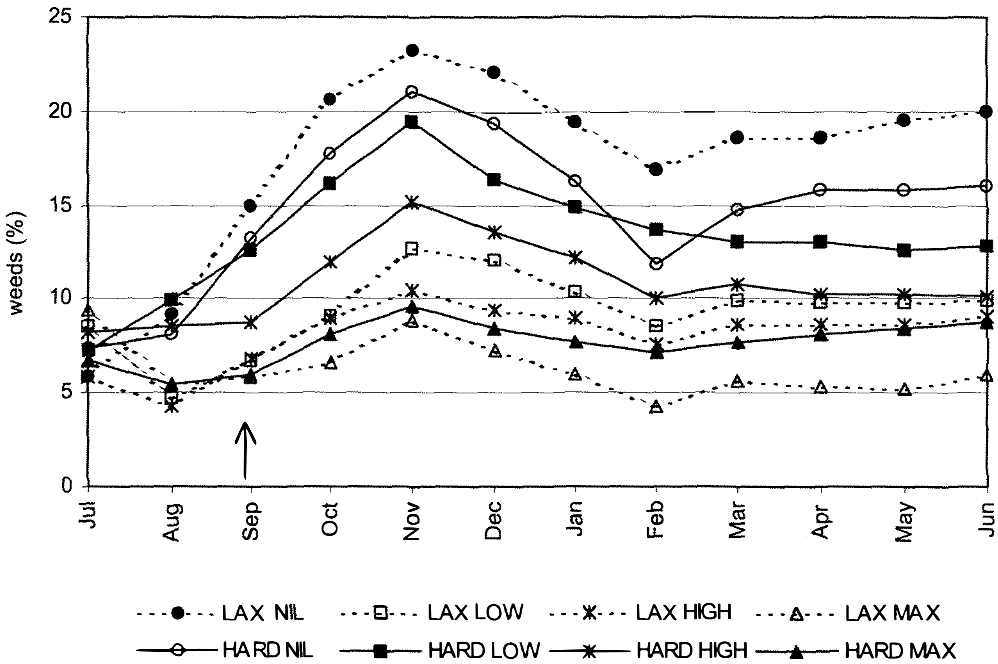


Figure 5.14 Monthly contribution of weeds to the botanical composition (kg weed DM/kg herbage DM) following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). Arrow indicates when treatments first differed statistically (P<0.05). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

The site was very poor in white clover prior to the experiment (less than 5% of the herbage mass in July 1999) but this increased substantially in all of the treatments (Figure 5.15). While treatments did not differ statistically in white clover cover at the end of the experiment (Table 5.4), differences were consistent over time (Figure 5.15). Clover was minimal in LM and maximal in HL.

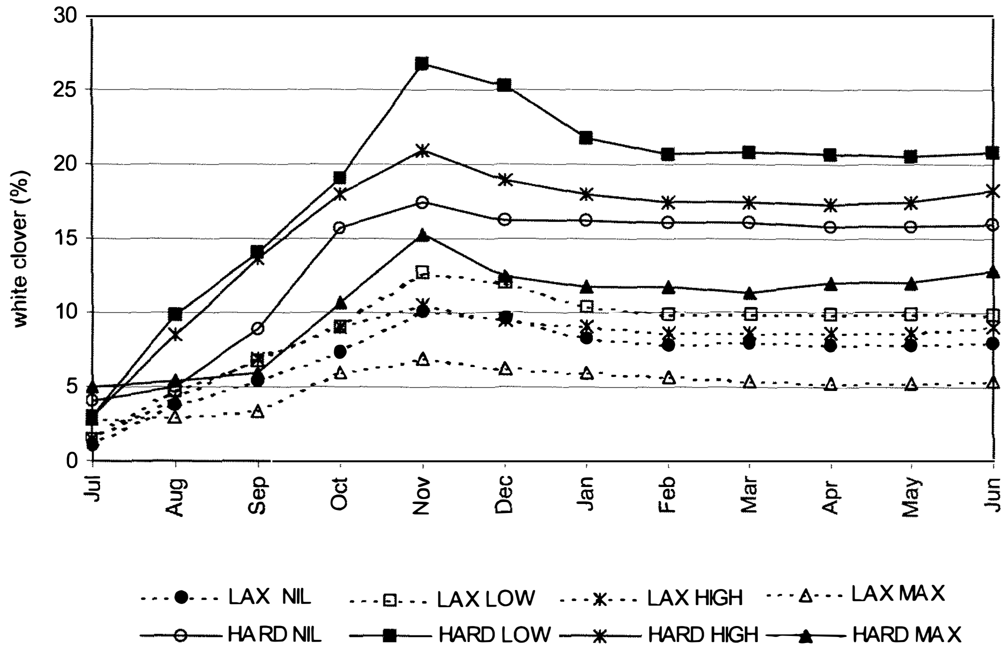


Figure 5.15 Monthly contribution of white clover to the botanical composition (kg white clover DM/kg herbage DM) following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

Figure 5.16 shows the effects of treatments on the grass component. Note that the proportions of weed (Figure 5.14), clover (Figure 5.15), and grasses (Figure 5.16) sum to100%.

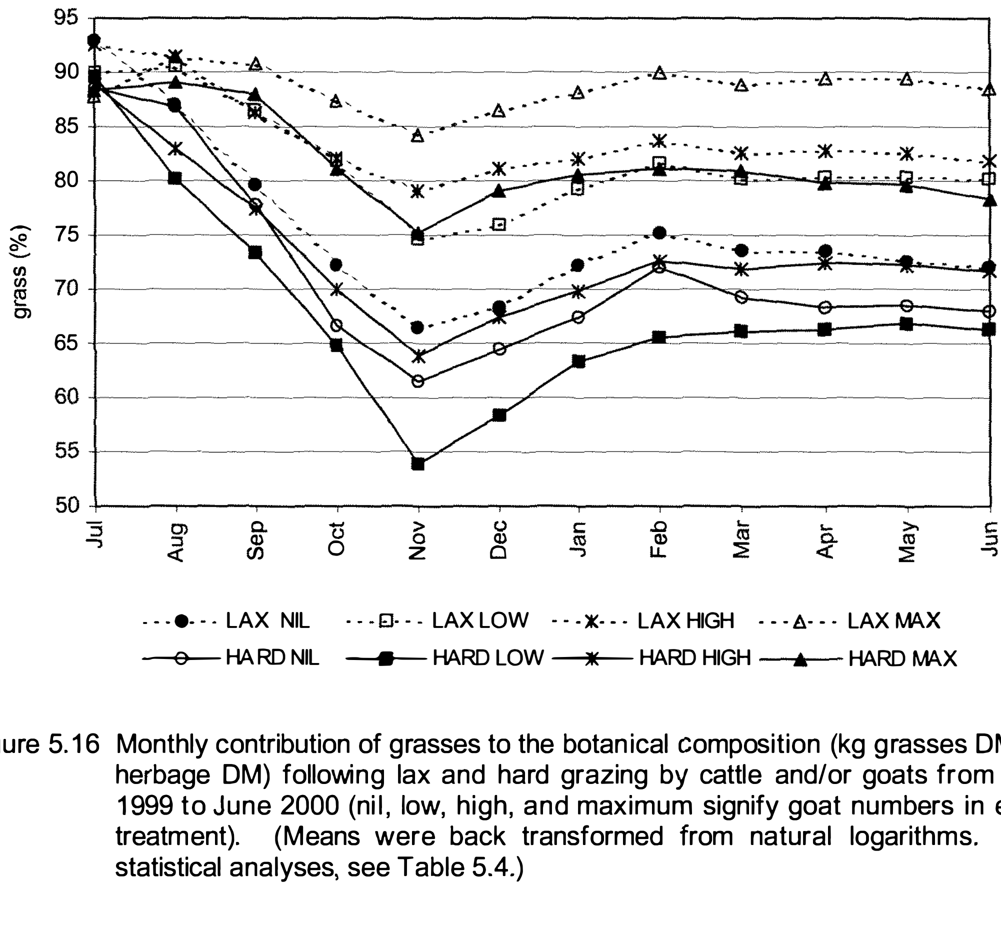


Figure 5.16 Monthly contribution of grasses to the botanical composition (kg grasses DM/kg herbage DM) following lax and hard grazing by cattle and/or goats from July 1999 to June 2000 (nil, low, high, and maximum signify goat numbers in each treatment). (Means were back transformed from natural logarithms. For statistical analyses, see Table 5.4.)

5.3.4. Pasture competitiveness

PCI differed significantly between treatments at the end of the experiment (Table 5.4, p.90). The greater the goat participation in either lax or hard grazing treatments, the greater the PCI, as shown in Figure 5.17. The same figure also shows the relative contribution of each index to the PCI (note that PCI is the sum of those indices).

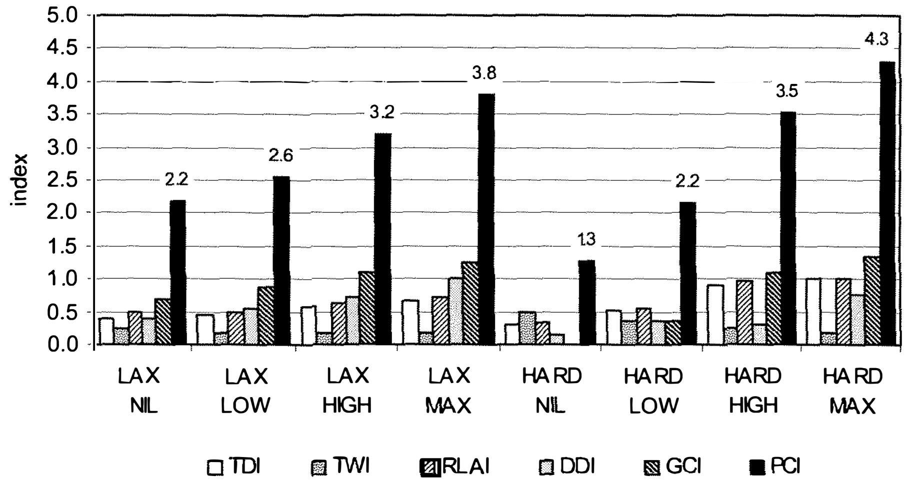


Figure 5.17 Tiller density (TDI), tiller weight (TWI), relative LAI (RLAI), dead matter (DDI), ground cover (GCI), and pasture competitiveness (PCI) indices, following lax and hard grazing by cattle and/or goats (nil, low, high, and maximum signify goat numbers in each treatment). (For statistical analysis of PCI, see Table 5.4.)

Weed seedling density was strongly related to PCI ($P<0.001$), i.e. the greater the index, the fewer the seedlings (Figure 5.18). Ninety three percent of the variation in seedling density was explained by PCI, as denoted by the coefficient of determination (r^2) in Figure 5.18 (each dot on the graph is the mean of 15 replicates, i.e. 5 quadrats per plot times 3 blocks). Note that the treatments with high and maximum goat participation are on the right hand side of the curve (i.e. high PCI, low seedling density) and the ones with nil or low participation are on the left one (i.e. low PCI, high seedling density).

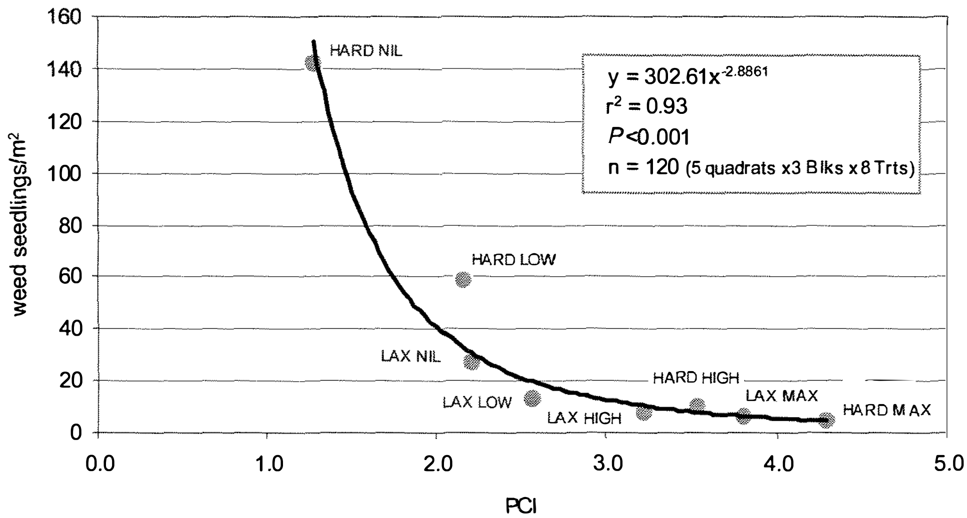


Figure 5.18 Relationship between pasture competitiveness index (PCI) and weed seedling density in June 2000, following lax and hard grazing by cattle and/or goats (nil, low, high, and maximum signify goat numbers in each treatment). (For definition of PCI, see Section 5.2.3.)

5.3.5. Within-plot variability

The differences between the mean variances of tiller density, LAI, percentage bare soil, and dead matter within plots were very large in treatments with nil or low goat participation and very small in the ones with high or maximum number of goats (Table 5.6). HN presented the largest within-plot variance in all structural variables, but the lowest variance of each variable was not so consistent, though it only occurred in treatments with high and maximum goat participation only. Differences in within-plot variation between treatments were not so marked in tiller weight as they were in the above variables, though they were statistically significant (Table 5.6).

Table 5.6 Mean within-plot variances of variables related to sward structural characteristics as a measure of sward uniformity at the end of the experiment (June 2000).

Treatments	Tiller density	Tiller weight	LAI	Bare soil	Dead matter
lax nil (LN)	7763 c	230 a	39 b	83 b	51 c
lax low (LL)	7440 c	227 ab	31 c	67 c	46 cd
lax high (LH)	6122 d	220 b	25 d	53 d	34 d
lax max. (LM)	5669 d	221 b	19 e	40 e	27 e
hard nil (HN)	9261 a	258 a	58 a	123 a	81 a
hard low (HL)	8375 b	245 a	45 b	95 b	62 b
hard high (HH)	5054 e	233 a	38 bc	80 bc	57 b
hard max. (HM)	4115 f	229 a	30 cd	64 cd	54 bc

Means followed by the same letter within columns do not differ statistically (P>0.05).

5.3.6. Other observations

In general, goats presented the same foraging behaviour patterns reported in Chapter 3 despite being different animals in a different environment. When available, they grazed thistles and grass seed-heads first. Pennyroyal was strongly rejected by goats (only two of the 39 goats were ever seen to eat it).

Goat foraging activities were strongly reduced once the sward had been grazed down to a height of approximately 10 cm and, for this reason, animals in HM had to be left on the plots for much longer than the other treatments (Table 5.3, p.89) in order for them to graze pasture down to the required 5 cm. Despite that, some goats stood almost still and refused to graze any further.

Cows tended to chase the goats in the hard grazing treatments when pasture became scarce (usually close to 7-8 cm high), especially in HL. However, this happened much less often in HH. Goats usually fought amongst themselves for a short period of time (normally less than 1 minute) when the treatment groups were first formed every month, but tended to remain very quiet (i.e. either grazing or standing still) and in sub-groups, most of the time.

Animals respected the electric fences at all times, thus confining goats at high stocking densities was not a problem.

5.4. DISCUSSION

To assist with interpretation, the discussion will be focused on Treatments HM and HN (i.e. hard grazing by goats and cattle only, respectively), which produced the most extreme effects, overall (i.e. responses of other treatments were generally intermediate between HM and HN).

5.4.1. Effects on sward structure

Treading was a very important factor in this experiment. Differences between treatments in terms of disturbances to the sward canopy and soil surface caused by the hooves became noticeable right after the first grazing in July 1999, as illustrated in Plate 5.1-A. The top images show swards grazed hard by goats (HM-A) and cattle (HN-A) only. Note the absence of gaps in the sward canopy in HM-A contrasting with the various gaps and hoofprints left in HN-A by the cattle.

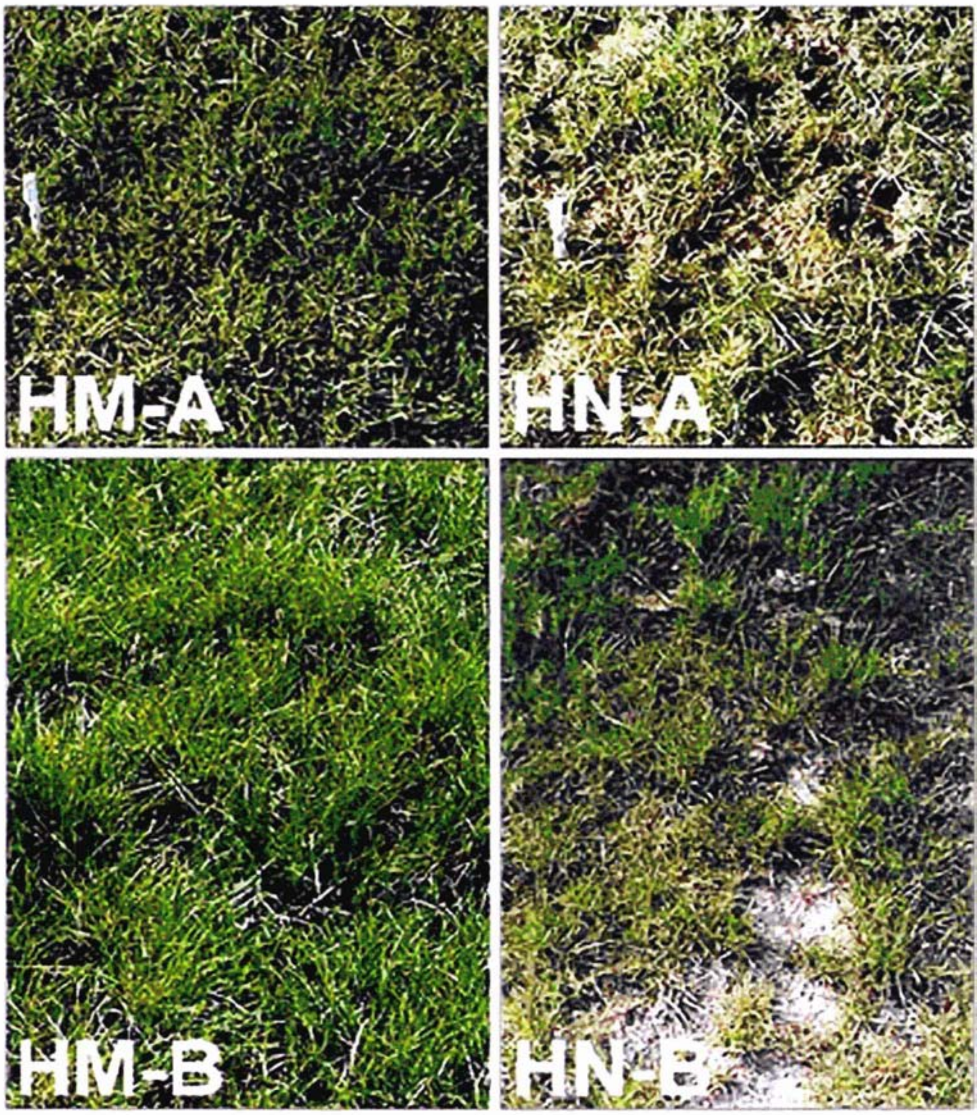


Plate 5.1 Swards grazed hard (5 cm post-grazing height) once a month by (HM) goats and (HN) cattle only, (A) immediately after the first grazing (July 1999), and (B) immediately before grazing (i.e. after 4 weeks of regrowth) in April 2000.

Defoliation *per se* did not result in any difference between the cattle and goat swards (i.e. both animal species grazed the swards down to the target heights of 5 and 10 cm). The contrast above was largely attributed to cattle exerting a much higher pressure (192 hPa) on the soil surface than goats (78 hPa) (Table 5.2).

However, these two animal species also presented some important behavioural differences which contributed to treatment effects (see Table 5.7). In summary, the table shows that goats were more settled than cattle when the soil was more vulnerable to treading damage, i.e. wet (Edmond, 1962) and with reduced herbage cover (Brown, 1968). Note that the pressure calculated in this experiment was static, i.e. it used acceleration of gravity (Equation 5.1, Section 5.2.2.2) and not of the limbs in downward movement, which would not be easy to measure and would depend on the type of movement as well (e.g. walking, fighting, etc.). However, in general, the dynamic pressure exerted by ruminants is believed to be twice as high as the static one (Watkin and Clements, 1978), which magnifies the importance of the behavioural differences shown in Table 5.7.

Note that the grazing period necessary to achieve the target post-grazing sward height was much longer in HM than HN (Table 5.3), so goats had more scope for causing treading damage than cattle.

Treading is known to have both direct and indirect adverse effects on pasture (Brown and Evans, 1973; Greenwood and McNamara, 1992; Betteridge *et al.*, 1999; Pande *et al.*, 2000). The most important direct effects are tiller death (through damage to, and burial of, growing points) and reduction of LAI (Edmond, 1958; Pande *et al.*, 2000), particularly if soil moisture is high. The main indirect effects are increased soil bulk density (Brown and Evans, 1973; Kondo and Dias Junior, 1999) and reduced macroporosity (Greenwood and McNamara, 1992) when soil is wet, and destruction of soil aggregates (Edmond, 1962), when soil is dry.

Table 5.7 Contrasting behaviour patterns of goats and cattle grazed separately in a rotational method at hard grazing severity (5 cm post-grazing sward height).

	Goats	Cattle
A. Agonistic behaviour[1]		
A.1. during the first few hours of the grazing period (coinciding with abundant herbage cover)	very common: this was usually related to reinforcement of social dominance (e.g. by head clashing) and/or competition for a specific plant	almost nonexistent: they lowered they head and grazed intensively; if challenged, they tended to avoid conflict and to continue grazing
A.2. during intermediate period	from common to very rare: the less feed they had, the more quiet they became (markedly so once sward height reached about 10 cm)	from very rare to common: the less feed they had, the more unsettled they became
A.3. during the last few hours of the grazing period (coinciding with reduced herbage cover)	almost nonexistent: animals stood still and waited to be shifted	very common: cattle continued to search for feed and constantly pushed each other out of the way, though this was intercalated by periods where they behaved in a similar manner to goats (see left)
B. Reaction to rainfall	stopped all activities and stood absolutely still while it was raining (even during light rain)[2]	no noticeable change in activities, thus they continued walking and feeding normally
C. Reaction to puddles and mud	avoided stepping in these whenever possible (i.e. they went around them)	did not seem to be affected by these

[1] Aggression expressed by approach and fights (Kilgour and Dalton, 1984).
[2] Also noticed by Schaller (1977) in the Himalaya region and Greaves *et al*. (1991) in New Zealand hill country.

Thus, the main sward effects observed in this experiment are linked in the following way:

- treading caused reduction in tiller density (Figure 5.3) (through tiller death), some direct reduction in LAI and dead matter (i.e. leaves crushed by the hooves), and soil compaction (Figure 5.11);
- reduction in tiller density resulted in further reduction in LAI, i.e. fewer tillers for leaves to grow on (Figure 5.5);
- reductions in tiller density, LAI, and dead matter content (especially litter trodden into the ground) resulted in canopy gaps, represented by percentage bare soil (Figure 5.8);
- bare soil is more susceptible to treading damage than soil protected by the sward canopy (Brown, 1968), thus the development of bare soil probably facilitated further soil compaction (Figure 5.11);
- as a compensatory effect, tillers grew heavier (Figure 5.4) as their population density decreased—a phenomenon known as "size-density compensation" (Matthew *et al.*, 1995).

Cattle treatments developed very heterogeneous swards, especially with regard to tiller density, LAI, bare soil, and dead matter. Within hard or lax grazing severities, the more cattle in the treatments, the greater the within-plot variance (Table 5.6). This is illustrated in Plate 5.1-B. In contrast, swards in the goat only treatments (HM and LM) were very uniform.

Apparently, treading was the main determinant of such variations because of its direct and indirect effects on sward structure, as discussed above. However, cattle dung seems to have contributed to the variation too. Goat dung was distributed evenly throughout the plots, while cattle dung was more concentrated, particularly in summer and autumn when the digestibility of feed on offer was low. At this time of the year, cattle dung that was not disintegrated by treading remained concentrated in round patches of 18-25 cm in diameter and when they broke down they left patches of bare soil (some cattle dung can be seen in Plate 5.1 at the top in HN-B).

Uniformity is an important characteristic against weed invasions. Two swards may have the same mean tiller density, for instance, but one may have no gaps in the canopy while the other may have many gaps, even large ones. Thus, their tiller density is only the same on average. This phenomenon is often overlooked (Harper, 1977).

In summary, sward was denser, leafier, more uniform, and covering the soil more thoroughly with increasing participation of goats in the treatments. Lax versus hard grazing *per se* had little influence on these characteristics (Table 5.4). Instead, the effects resulted primarily from interactions (Table 5.4) of grazing severity and goat participation. This suggests that simply incorporating goats to a cattle grazing system will not necessarily result in changes in sward structure (i.e. it will also depend on grazing management and on the extent of goat participation).

5.4.2. Effects on weed seedling density

As shown in Table 5.4 and Figure 5.12, treatments did have a significant effect on weed seedling densities. While the highest densities were produced by the hard grazing treatments (HN and HL), seedling density was not a simple effect of lax versus hard grazing severities, because their contrast was not statistically significant (Table 5.4). However the contrast of "goat" versus "no goat" treatments was significant and, in fact, the highest densities were produced by treatments containing no goats.

As discussed in Chapter 2, there is enough information available to allow the generalisation that any factor that increases the number and/or the size of gaps in the sward canopy will result in an increase in seedling emergence, provided that (a) viable seeds are present in the soil and that (b) other conditions (e.g. moisture and temperature) are favourable for germination. Tiller density, LAI, dead matter (especially litter in the base of the sward), and percentage bare soil are factors which are closely related to such gaps in the canopy and in this experiment weed seedling density was higher in treatments with low tiller density, low LAI, low dead matter content, and larger percentage of bare soil.

5.4.3. Pasture competitiveness index

The purpose of the PCI was to compare treatments with respect to an overall measure of competitiveness. A multivariate analysis of variance (MANOVA) could have been used, but it would not yield the same information. The MANOVA would have revealed whether there was any difference between treatments for the overall effects in sward structure, but it would not have produced a measure of competitiveness.

PCI was based on the hypothesis that the greater its value, the greater its competitiveness. This hypothesis was then tested through a regression analysis (Section 5.2.3), in which PCI (Figure 5.17) explained most of the variation (93%) in weed seedling density at the end of the experiment (Figure 5.18). Thus, PCI was a reliable measure of competitiveness in this experiment.

It should be reinforced that the indices which formed PCI were relative to the maximum values obtained in June 2000, as explained in Section 5.2.3. Thus, PCI was also relative, which means that its values are meaningful within this experiment only. Nevertheless, the concept is of general application and could be used to compare other swards.

The weights 0.5 and 1.5 were included in Equation 5.4 (Section 5.2.3) to reduce the relative importance of tiller weight and increase the importance of bare soil, respectively. Tiller weight *per se* is not expected to have any direct effect on weed seedling emergence. However, it was included in PCI because it is related to carbohydrate reserves and sward regrowth capacity (Lemaire and Chapman, 1996), i.e. everything else being equal, a sward formed by heavy tillers is more vigorous than a sward formed by light ones. As for bare soil, of all the factors that formed PCI, it is the one that gives the most direct information on the light conditions on the soil surface, i.e. sunlight reaching the soil surface with a high red:far-red ratio because it was not filtered by the sward canopy. Red light is very important for weed seed germination and seedling establishment, as discussed in Section 2.2.

5.4.4. Other effects

5.4.4.1. Botanical composition

Overall, treatments under hard grazing severity developed greater weed cover than under lax grazing. A marked exception to this was LN, which presented the highest weed cover of all treatments (Figure 5.14). In contrast, the lowest weed cover at the end of the experiment was recorded in LM. Within grazing severity, the greater the participation of goats in the treatments, the lower the weed cover.

In cattle-only treatments (LN and HN), the main weeds were broad-leaved dock, Scotch and Californian thistles. In goat-only treatments (LM and HM) the main weed was pennyroyal, followed to a lesser extent by creeping buttercup. In the other four treatments, which contained both goats and cattle, the main weeds were broad-leaved dock and dandelion.

The results of this experiment do not support earlier reports (e.g. Radcliffe, 1984) that adding goats *per se* will cause an increase in the proportion of white clover in the sward. An increase in clover from the original status (Figure 5.15) occurred in all treatments, irrespectively of goat participation and there was no interaction between grazing severity and goat participation (Table 5.4). Additionally, the contrast of "goat" versus "no goat" treatments was not significant (Table 5.4). Similarly, the density of white clover seedlings was not affected by the goat factor (Table 5.4; Figure 5.13).

Most of the reports of clover increase have followed a partial or complete replacement of sheep by goats. In this study all the treatments could be seen as replacements of sheep by cattle and/or goats, as the site was historically grazed by sheep before the experiment (Section 5.2). So the clover increase reported elsewhere may have been largely due to the total or partial replacement of sheep, rather than the introduction of goats *per se*, as the same happened with cattle in this study. Sheep are known to differentiate between legume and grass species very efficiently and to positively select white clover (Ridout and Robson, 1991; Parsons *et al.*, 1994; Penning *et al.*, 1997), which may reach more than 70% of their diet (Parsons *et al.*, 1994). In contrast, goats tend to avoid white clover (Clark *et al.*, 1982; Penning *et al.*, 1997), though this does vary seasonally (Chapter 3).

5.4.4.2. Herbage accumulation

Adding goats *per se* did not result in an increase in herbage accumulation as the "goat" versus "no goat" contrast was not significant (Table 5.4). Total herbage accumulation was an interaction between grazing severity and goat participation, though hard grazing, in general, produced more herbage than lax grazing (Table 5.4; Figure 5.10).

The highest total herbage accumulations (Figure 5.10) were recorded in the three treatments containing goats, managed at hard grazing severity (HL, HH, and HM) and these did not differ statistically between themselves (Table 5.4). Additionally, HL was not different from the HN (i.e. cattle only), statistically. Except for the hard versus lax grazing contrast, there was no clear pattern following the treatments.

Thus, it can be concluded that the addition of goats to a cattle system *per se* is unlikely to result in a significant increase in herbage production.

5.4.5. Sheep

Arosteguy (1982) studied the effects of cattle and sheep grazing on herbage production and found that cattle grazing resulted in lower tiller density than sheep grazing and that the lower tiller density was responsible for lower herbage production in cattle treatments.

Sheep static hoof pressure (119 hPa) was intermediate between cattle (192 hPa) and goats (78 hPa), which would suggest that treading damage caused by sheep would be intermediate between the other two species, at least for the average size and weight of animals measured in this study.

5.5. SUMMARY

(i) *Is a pasture grazed by goats structurally different from a pasture grazed by cattle under the same grazing management?*

Yes. Pasture was denser, leafier, more uniform, and covering the soil more thoroughly with increasing participation of goats in the treatments. The effects were attributed primarily to cattle causing more treading damage than goats. The effects were cumulative over time.

(ii) *If so, can the goat pasture be more competitive against weed invasions than a cattle one?*

invasions than a cattle one?

The pasture competitiveness index (PCI), which involved all the structural factors measured in this experiment, explained 93% of the variation in seedling density. The greater the participation of goats in the treatments, the higher the PCI. Thus, goat pasture was much more competitive against weed invasions than cattle pasture.

(iii) Can a goat pasture be more productive than a cattle one under the same grazing management? Why?

Adding goats *per se* did not result in greater herbage production. Grazing management was more important than animal species.

CHAPTER 6

EFFECTS OF GOAT FORAGING ON ROSETTES OF CALIFORNIAN AND SCOTCH THISTLES

6.1. INTRODUCTION

It has been claimed in numerous reports that goats only eat thistles when plants are in reproductive stages, from bolting to mature seed-head formation, but especially at flowering (e.g. Clark *et al.*, 1982; Crouchley, 1983; Batten, 1984). The study by Campbell and Holst (1990) on the use of goats for the control of Illyrian thistle (*Onopordum illyricum*) in Australia seems to be the only study to present evidence that goats also consume thistle rosettes.

In the study reported in Chapter 3, it was observed that goats did eat some Scotch thistle rosettes (Section 3.3.4). However, this phenomenon seemed erratic. While some rosettes were eaten to ground level, others had just the tip of their leaves removed or were not even touched. Often, the rosettes that were eaten were identical in physiological stage, size, and shape to the rosettes that were left untouched. The only apparent explanation related to the state of surrounding pasture (Section 3.4.3), as the rosettes that were eaten were often surrounded by short pasture, while the untouched ones were surrounded by a dense sward, at least as high as the rosettes. The same phenomenon was again observed during the third experiment (Chapter 5), especially in the area adjacent to the experiment where goats were kept when off the experimental plots (see Section 5.2.1.2).

The experiment reported in this chapter was designed to verify whether the sward surrounding thistle rosettes affects their selection by goats. The specific hypothesis to be tested was that *rosettes that are eaten are those not closely surrounded by pasture plants*.

6.2. MATERIALS AND METHODS

The experiment was carried out in January 2000 in the field adjacent to the site used for the third experiment (Chapter 5). For a description of the area see Sections 5.2 and 5.2.1.2.

6.2.1. Treatments

Two treatments (henceforth referred to as "Intact" and "Clipped") were applied to single, randomly distributed rosettes of two thistle species: Scotch and Californian thistles.

Twenty naturally occurring rosettes of each thistle species were selected at random within two 0.1 ha paddocks (the requirement for two paddocks was dictated by the number of replicates needed). Herbage within a 20 cm radius from each rosette was cut at ground level with an electric clipper and removed, leaving the rosettes exposed in the centre of a circle (Clipped). The pasture surrounding another 40 randomly selected rosettes (20 of each species) was left intact as a control treatment (Intact).

The position of each rosette was marked in the field using two wooden pegs per rosette placed 4 m apart with the thistle in the middle (i.e. 2 m from either peg).

6.2.2. Grazing management

Three weeks prior to the commencement of this trial the area had been rotationally grazed by cattle and goats, as described in Section 5.2.1.2. These animals were the same ones used in Experiment 3 (more details on the animals can be found in Section 5.2.1.1).

In the present experiment, the two 0.1 ha paddocks were grazed once by 41 wether goats only (i.e. cattle did not take part in this experiment), which was equivalent to 328 SU/ha/day. The average pre-grazing herbage mass and sward surface height were 2550 kg DM/ha and 21 cm, respectively. Goats were removed from paddocks when the average sward surface height reached 10 cm. This was a "lax grazing" by the definition used in the previous experiment (Section 5.2.1.2). It took 3 days to graze each paddock to the specified residual height resulting in a post-grazing herbage mass of 1700 kg DM/ha.

6.2.3. Measurements

Post-grazing herbage mass (10 quadrats per paddock) and sward surface height (50 samples per paddock) were measured using the methods described in Section 5.2.2.1. Additionally, the following characteristics were assessed: neighbouring sward surface height, i.e. the grass leaf surface height at 10 cm (horizontally) from the outer limit of the rosette leaves; rosette leaf surface height (cm), measured from ground level to the top of the leaves; number of rosette leaves before grazing; number of intact rosette leaves after grazing (i.e. leaves that were not damaged by goats); and standing rosette volume (cm^3) before and after grazing. For Scotch thistle rosettes, which are short with little or no internode elongation (leaves touch the ground), standing rosette volume was computed as the volume of a cylinder, measuring the radius of the horizontal leaf surface and the leaf surface height. For Californian thistle rosettes, which have an elongated stem with its lowest leaves above ground, this was calculated as the volume of two cylinders: one formed by the leaf portion and the other by the stem (from ground surface to the height of the first leaf).

6.2.4. Derived variables and statistical analyses

The following variables were derived from the measurements described above:

- percentage reduction of the neighbouring sward surface height, i.e. the percentage difference between its pre-grazing and post-grazing values;
- percentage reduction of the rosette leaf surface height, obtained in the same way as above;
- percentage of damaged leaves, obtained from the percentage difference between number of rosette leaves before grazing and number of intact rosette leaves after grazing;
- percentage rosette volume eaten, also obtained from the differences between pre- and post-grazing values.

Statistical models involving percentage reduction are multiplicative rather than additive (Steel *et al.*, 1997). As the additivity of the model is an important assumption for the ANOVA, values were transformed into natural logarithms and the analyses were carried out on transformed data.

The derived variables were analysed using the SAS GLM Procedure (SAS, 1996) in a 2 x 2 factorial design (i.e. two thistle species and two pre-grazing treatments). The linear contrast between intact and clipped pre-grazing treatments were obtained using the command CONTRAST in the same SAS GLM Procedure.

6.3. RESULTS

Reduction in rosette height, percentage of damaged leaves, and rosette volume eaten by goats were all significantly higher (P<0.01) in Clipped than in Intact, both for Californian and Scotch thistles (Table 6.1). Results are presented per species because the main objective is to compare the effects of the two pre-grazing treatments within species.

Table 6.1 Effects of goats on rosettes of Scotch and Californian thistles after two pre-grazing treatments: Intact (rosettes surrounded by pasture plants) and Clipped (surrounding sward clipped to ground level within 20 cm radius).

Variables	Scotch thistle		Californian thistle	
	Intact[1]	Clipped	Intact	Clipped
sward surface height[2] (cm)				
before grazing	13	0	13	0
after grazing	10	0	12	0
reduction (%)	23	0	8	0
rosette height (cm)				
before grazing	11	11	14	15
after grazing	10	1	12	5
reduction (%)[3]	9	91	14	67
number of intact leaves (No.)				
before grazing	17	20	9	11
after grazing	10	3	6	1
damaged (%)[3]	41	85	33	91
volume eaten (%)[3]	3	75	5	97

[1] Control treatment. [2] Neighboring sward surface height (within 10 cm horizontally from the outer limit of the rosette leaves). [3] Means of rosette height reduction, number of damaged leaves, and volume eaten are statistically different (*P*<0.01) within thistle species (the analyses were performed on natural logarithms).

Figure 6.1 illustrates the differences in percentage of rosette volume eaten by goats for each thistle species. While the values were similar between species ($P>0.05$) in the intact treatment, Californian thistle was eaten to a significantly larger extent than Scotch thistle in the clipped treatment ($P<0.01$).

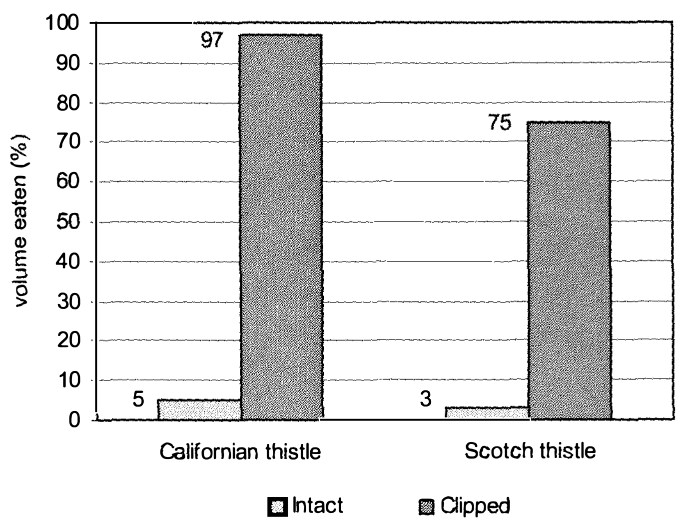


Figure 6.1 Percentage volume of rosettes of two thistle species eaten by goats after two pre-grazing treatments: "intact" (rosettes surrounded by pasture plants) and "clipped" (surrounding sward clipped to ground level within 20 cm radius).

The interaction between thistle species and pre-grazing treatments was statistically significant ($P<0.05$ for all derived variables).

6.4. DISCUSSION

As shown in Table 6.1, 67% of the leaves of Californian thistle and 85% of Scotch thistle had some degree of herbivory damage after grazing in the Clipped treatment, while in the intact treatment these were 14 and 9%, respectively. In the case of Californian thistle, defoliation effected a reduction of 97% in the rosette standing volume in the Clipped treatment (Figure 6.1); the reduction was smaller in Scotch thistle (75%), but was again significant (Table 6.1).

The damage inflicted by goats on rosettes of the intact treatment was superficial, with only the tips of some leaves being eaten. This is reflected in the small average reduction in rosette height, by 2 and 1 cm for Californian and Scotch thistles, respectively (see Table 6.1). Note also that the rosette height after grazing was exactly the height of the surrounding sward in the intact treatment for both species, i.e. only the portion of the rosettes that were taller than the surrounding sward were eaten.

The significant interaction between thistle species and pre-grazing treatments confirms that the extent of the damage (for any variable analysed) does depend on the species. The different results between species observed in the clipped treatment (e.g. 97 versus 75% volume reduction) is probably explained by differences in plant architecture and the way goats harvest these plants. Californian thistle has an elongated stem, with leaves well above the ground, while Scotch thistle leaves often touch the ground due to the lack of internode elongation during the vegetative stages. Goats often approached the rosettes sidewise with their heads parallel to the ground (probably to minimise contact with the tips of the spines) and prehended them with their molar teeth. For Californian thistle this gave them clear access to the whole leaf portion of the plant from below, while in the case of Scotch thistle they were still faced with the prickly leaves. To counteract this problem they had to use their horns (this was seen many times) in order to make an "entrance point" through the spines on the side of the Scotch thistle rosettes, which took more time and effort than for Californian thistle.

Claims that "goats will not eat thistles until flowering" (e.g. Batten, 1984) are usually derived from anecdotal observations and not from controlled studies designed to determine whether rosettes are consumed or not. The study by Campbell and Holst (1990) mentioned in Section 6.1 does not provide details on the conditions of the surrounding pasture, but it does show that goats ate rosettes of Illyrian thistle.

In conclusion, in the present experiment the selection of rosettes was clearly related to the presence or absence of a surrounding sward. Exposed rosettes were heavily defoliated (or entirely destroyed), while rosettes surrounded by pasture plants were only lightly damaged or not damaged at all. The exact reason for this cannot be deduced from this study, but is probably related to goats having access to the side of the rosettes, as discussed earlier. Some rosettes may have gone unseen by goats, though it is clear that they could be noticed within a dense pasture because many of them were browsed by these animals.

This experiment suggests that it might be possible to improve the consumption of rosettes by using other livestock (e.g. cattle) to remove as much pasture from around the rosettes as possible and then use goats to eat the rosettes. Grazing management issues, including this kind of option, are discussed in Chapter 7.

6.5. SUMMARY

(i) This experiment confirmed the hypothesis that rosettes that are exposed in the sward are more likely to be eaten by goats than

rosettes that are closely surrounded by pasture plants.

(ii) The reason why goats preferred exposed rosettes seems to be related to the horizontal access to the plants. Most rosettes were eaten from their sides and not from above.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

7.1. INTRODUCTION

The central theme of this study is the integration of goats into grazing systems as a tool for herbaceous weed control. As discussed in the review of the literature (Chapter 2), the alternative of using goats for weed control is not new (Section 2.4), but little attention has been given to integrating them permanently with other livestock. Having goats and cattle, for instance, on the same farm does not necessarily mean that these two species are integrated. Some New Zealand hill country farmers have goats for weed control on a permanent basis, but they are often set stocked on their own (or sometimes in long rotations), typically in back paddocks dominated by scrub weeds (Yerex, 1986). Cattle and sheep are seldom taken to those paddocks and goats are rarely taken to other parts of the farm. Therefore, in cases such as this, goats are clearly not integrated with other stock. Integration, as signified in the present study, requires interaction between the different animal species and for that to occur they need to frequent the same area, either together or in sequence. On the other hand, having goats and other stock frequenting the same paddock does not necessarily mean that goats are being used effectively as a weed control tool. For them to be effective, farmers must understand their function and limitations. These are discussed in the next section.

7.2. GENERAL CONSIDERATIONS AND APPLICATION

7.2.1. Why integrate goats

7.2.1.1. Botanical composition and population dynamics

As discussed in Chapter 1, the primary reason to integrate goats with other livestock is to promote and maintain a desirable pasture botanical composition. The botanical composition will be desirable if the resultant pasture is:

- productive (Langer, 1990);
- of high feeding value (Thompson and Poppi, 1990); and
- persistent (Laidlaw and Reed, 1993).

Additionally, in commercial situations its establishment and maintenance must also be economically viable (Keeney, 1993), e.g. pasture productivity and persistence can be improved through fertilisers (Clark and Lambert, 1982), but the costs of the operation often impose an economic limit to its application (McLaren and Cameron, 1996). Thus, in this context, a plant species is undesirable in the pasture if it is not productive, or has low or no feeding value (e.g. spiny and poisonous plants that are not eaten), or is not persistent.

Traditionally, pastures are dominated by a mixture of grasses and legumes (Kemp *et al.*, 1999), though other species can also be considered as desirable. One such example is chicory (*Cichorium intybus*), which belongs to the Asteraceae family, where many pasture weeds are represented (e.g. thistles and ragwort). Improved chicory has the potential to produce more than 10 t DM/ha/year of leaf mass with up to 85% digestibility (Kemp *et al.*, 1999). Conversely, not all grasses and legumes are desired in pastures, e.g. barley grass and gorse are important pasture weeds in New Zealand (Field and Daly, 1990), though they are a grass and a legume, respectively.

A number of other variables are involved in determining which species should be favoured and which ones should be eliminated or discouraged in the pasture. It is beyond the scope of this discussion to pinpoint them all, especially because each case is unique. Moreover, the choice or preference for a plant species is relative. As an example, browntop (*Agrostis capillaris*) is generally undesirable in New Zealand pastures (Thompson and Poppi, 1990). However, this is only a realistic view where more productive species such as perennial ryegrass can persist and produce more herbage than browntop, which is the case on lowland, high-fertility farms (e.g. dairy farms). On these farms, browntop is considered a weed, but on hill country farms, soil fertility is much lower and perennial ryegrass does not persist (Chapman and Macfarlane, 1985). Thus, under these conditions, browntop is an important forage species, albeit of low quality compared to ryegrass (White, 1990).

Previous research has shown that goats will cause significant damage to a number of plant species and this is summarised in Table 7.1. The present study has identified a number of other species that are eaten by goats and has also confirmed some of the species shown in the table (i.e. rushes; Californian, Scotch, and winged thistles). This study has also provided information as to when these are more likely to be consumed and how much effort goats will make to find them in the pasture (Chapter 3). Contrary to popular belief (Section 6.1), it has also shown that thistle rosettes are not only eaten, but that they can be damaged quite heavily, depending on the conditions of the vegetation immediately around them. This happened despite the availability of abundant alternative feed, i.e. goats were not forced to eat the rosettes (Chapter 6).

Table 7.1 List of some weeds for which there is evidence of control by goats. Details on most of these studies can be found in Section 2.4.

Common Name	Scientific Name	Sources†
artichoke thistle	*Cynara cardunculus*	13
barberry	*Berberis glaucocarpa*	3, 12, 16, 17
blackberry	*Rubus fruticosus*	3, 5, 6, 7, 9, 12, 16, 17, 20
blackbrush	*Coleogyne ramosissima*	13
bracken	*Pteridium esculentum*	20
Californian thistle	*Cirsium arvense*	3, 12, 16, 17
cotton thistle	*Onopordium acanthium*	13
gorse	*Ulex europaeus*	3, 12, 15, 16, 17, 20
Illyrian thistle	*Onopordum illyricum*	2, 11, 19
juniper	*Juniperus occidentalis*	8
manuka	*Leptospermum scoparium*	3, 12, 16, 17
marsh thistle	*Cirsium palustre*	3, 12, 16, 17
matagouri	*Discaria toumatou*	4
rushes	*Juncus pallidus, J. australis, J. gregiflorus, and J. sarophorus*	3, 12, 16, 17
sagebrush	*Artemisia tridentata*	8
Scotch thistle	*Cirsium vulgare*	3, 12, 16, 17
sweet brier	*Rosa rubiginosa*	1, 10
variegated thistle	*Silybum marianum*	11, 18
winged thistle	*Carduus tenuiflorus*	3, 12, 16, 17

† Key: **1**. Batten (1979); **2**. Campbell and Holst (1990); **3**. Clark and Lambert (1989); **4**. Cossens *et al.* (1989); **5**. Crouchley (1983); **6**. Delow (1988); **7**. Fawcett (1925); **8**. Fajesmin *et al.* (1996); **9**. Guthrie-Smith (1929); **10**. Holgate and Weir (1987); **11**. Holst and Allan (1996); **12**. Lambert *et al.* (1981); **13**. McGregor *et al.* (1990); **14**. Provenza *et al.* (1983); **15**. Radcliffe (1983; 1984; 1985; 1987; 1990); **16**. Rolston *et al.* (1981); **17**. Rolston *et al.* (1983); **18**. Stanley *et al.* (2000); **19**. Torrano *et al.* (1999); **20**. Wright (1927).

The findings of the present study that are expected to affect weed population dynamics are summarised in Figure 7.1, which illustrates the potential impact of goats on the lifecycle of an annual or biennial pasture weed.

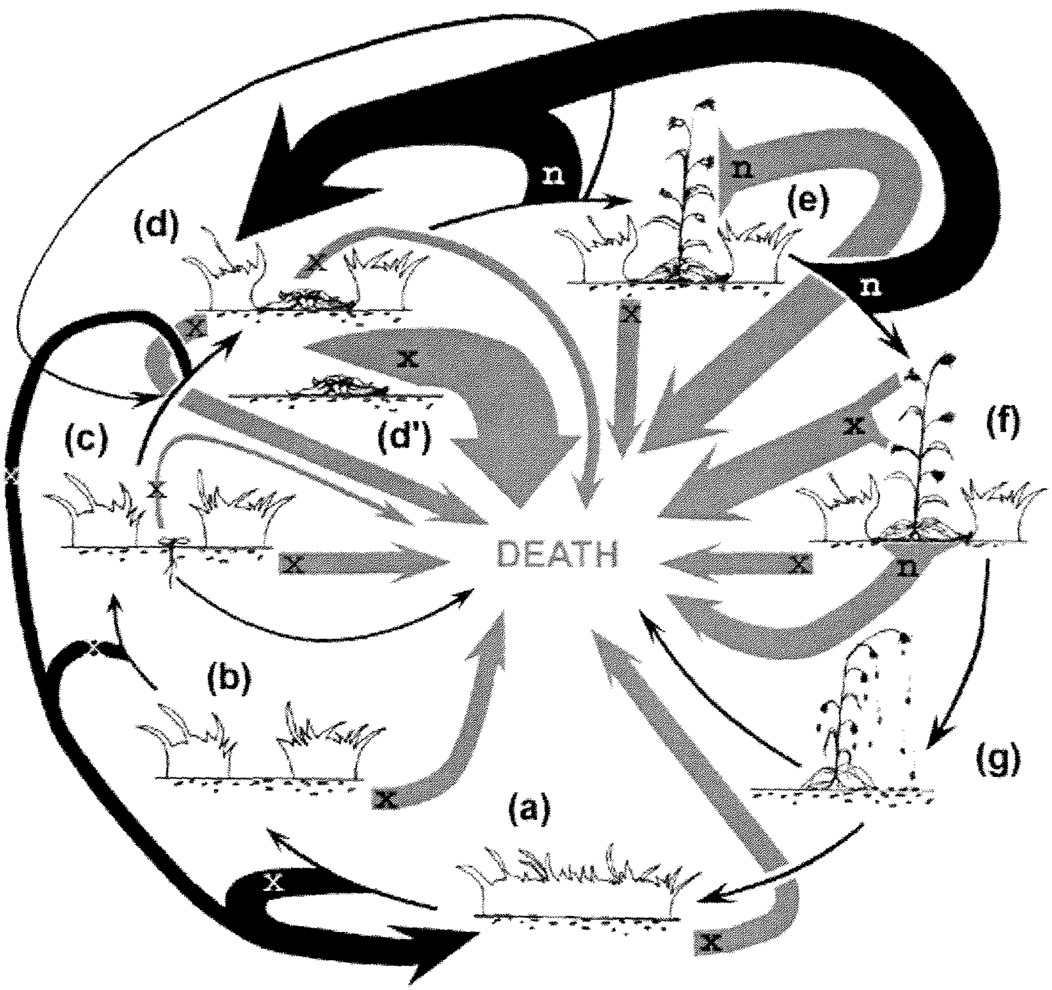


Figure 7.1 Potential impact of goats on the lifecycle of an annual or biennial pasture weed. Thin, black arrows signify natural changes in physiological state, regardless of goat activities. All other arrows signify the direction and relative effectiveness of the effects caused by goats (the thicker the arrow, the greater their potential to cause that effect). The thickened, black arrows signify that the weed remains in that state or returns to a previous one, while the grey ones indicate death. States are: (a) seed in the soil seed bank under an undisturbed sward canopy; (b) disturbance; (c) seed germination and seedling emergence; (d) rosette surrounded by pasture plants; (d') exposed rosette; (e) bolting and flowering; (f) seed maturation; and (g) seed rain. Arrows with an "x" denote new pathways revealed by the present study (directly or indirectly); "n" signifies that pathway was already known.

The cycle above can be explained as follows:

(a) Viable seeds are in the soil seed bank, covered by a competitive sward (i.e. dense, leafy, uniform, and vigorous), which is partly an effect of the presence of goats in the system (Experiment 3, Chapter 5). Under these conditions seeds do not germinate (Sections 2.2, 5.3.4, and 5.4.3), but they die due to aging, predation, infections, etc. If no disturbance occurs, viable seeds remain dormant and recalcitrant seeds die (Harper, 1977).

(b) A disturbance to the sward canopy has occurred, e.g. from cattle treading (Plate 5.1, p.109); the seeds can perceive the change in the light conditions through their phytochrome (Salisbury and Ross, 1992) and/or from alternating soil temperatures (Thompson *et al.*, 1977) and germinate when soil moisture and temperature are favourable (c). While such favourable conditions do not occur, seeds remain in the same state (Harper, 1977). If the sward canopy closes up, favoured by its competitiveness prior to disturbance, the site is returned to (a). Seeds continue to die in areas where disturbance did not occur, exactly as in (a).

(c) Seed germination and seedling emergence have taken place. Goats seem to have little direct effect on seedling survival, but do affect it indirectly through the sward structure (c $\rightarrow$ a). This is the most vulnerable phase of the weed lifecycle and a large proportion of seedlings will die before reaching (d) (Harper, 1977; Beskow, 1995). (Note that the thickness of the arrows that signify natural changes is fixed, so no relative importance is implied.)

(d) A seedling has developed into a rosette. If it becomes exposed (means to achieve that are discussed later) it is very likely to be severely defoliated by goats (Chapter 6) and die (d'), but if it remains surrounded by herbage plants, goats will have almost no direct impact on its survival. Regardless of the sward conditions surrounding the rosette, under proper grazing management (Section 7.2.2), goats will stop it from bolting and flowering. If the rosette survives this and goat grazing pressure is maintained, it will have its life cycle extended (denoted by thick, black arrow pointing back to d). The thin, black arrow which also points back is the natural pathway of the biennials (i.e. they take longer to flower than undisturbed annuals).

(e) The rosette has bolted and flowered. This seems to be the physiological state preferred by goats (Chapter 3). Defoliation by goats can kill the plant, or return it to (d), or not be severe and frequent enough to avoid its next natural phase (f). The outcome will depend mostly on the weed species and on grazing management (Section 7.2.2).

(f) The reproductive plant has now produced seeds and these are mature. Most of the viable seeds ingested by goats are expected to be destroyed (Chapter 4).

(g) The weed returns to its original state—the seed in the soil. The mother plant, as an annual or biennial, dies after producing seeds.

Figure 7.2 is mostly the same as Figure 7.1. The main differences are that: it represents a perennial weed, one that can reproduce itself both vegetatively (Figure 7.2-e) and reproductively; flowering and seed maturation are represented in one step (f) to minimise clutter; the plant does not die after producing seeds (g); and, overall, the impact of goats on its death is expected to be lower than on annual/biennial due to its greater regrowth capacity.

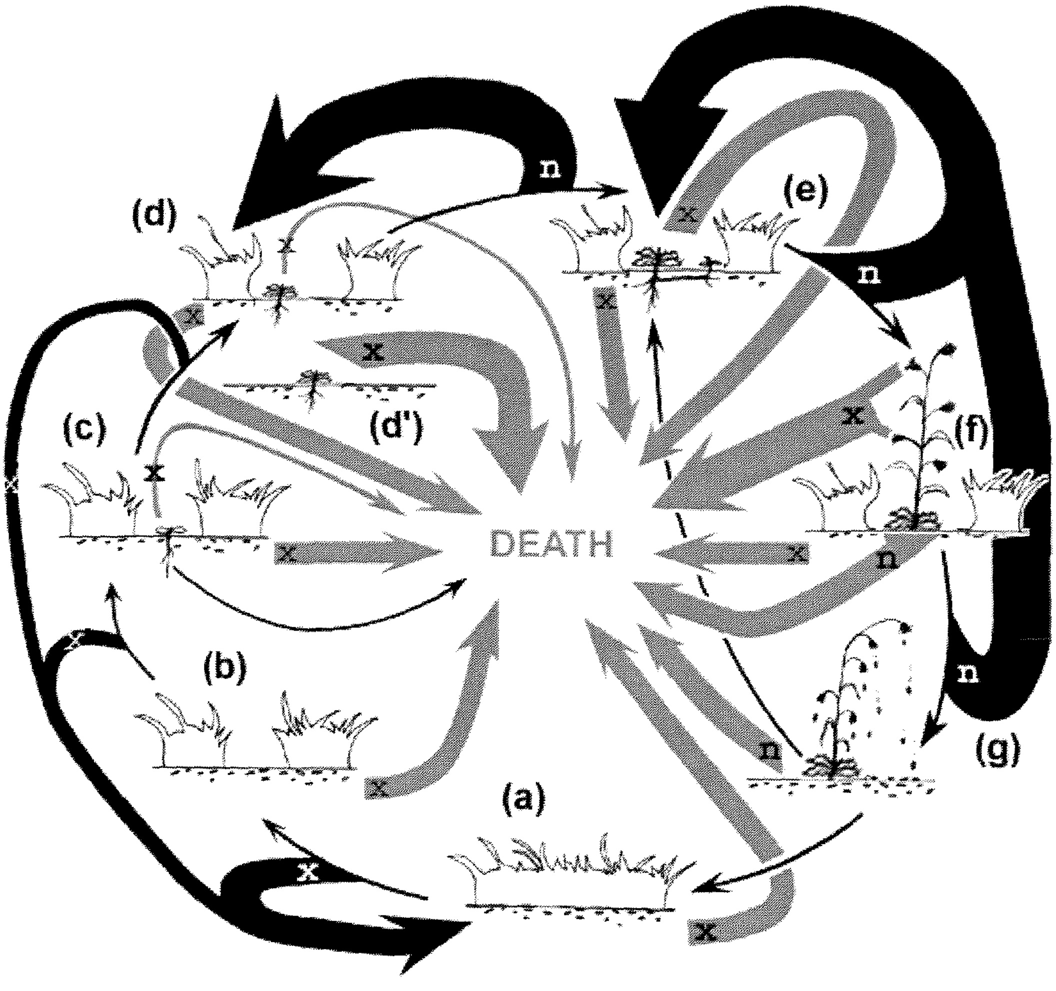


Figure 7.2 Potential impact of goats on the life cycle of a perennial pasture weed. Thin, black arrows signify natural changes in physiological state, regardless of goat activities. All other arrows signify the direction and relative effectiveness of the effects caused by goats (the thicker the arrow, the greater their potential to cause that effect). The black, goat arrows signify that the weed remains in that state or returns to a previous one, while the grey ones indicate death. States are: (a) seed in the soil seed bank under an undisturbed sward canopy; (b) disturbance; (c) seed germination and seedling emergence; (d) rosette surrounded by pasture plants; (d') exposed rosette; (e) vegetative reproduction; (f) bolting, flowering, and seed maturation (incorporates the equivalent of e and f of Figure 7.1 because of space limitations); and (g) seed rain. Arrows with an "x" denote pathways revealed by the present study (directly or indirectly); "n" signifies that pathway was already known.

Some of the species included in the present study, particularly those that are important weeds in New Zealand, will now be discussed in more detail. Where applicable, information is gathered from all four experiments and also from the period when animals remained in the paddocks adjacent to Experiment 3 (Section 5.2.1.2). The latter were not described in any of the previous chapters because they were not part of any of the four experiments, but some of these observations will help clarify a few points in this discussion.

Broad-leaved dock

In Experiment 1 (Chapter 3), goats rejected dock in summer, but this may have been partly because no seed-heads were available at the time the observations were carried out. However, goats selected its leaves during all other seasons, especially in winter, when they clearly demonstrated positive selection pressure for it (Section 3.3.3) and grazed many dock plants down to ground level (Section 0).

Dock seed-heads were available in summer on the plots of Experiment 3 (Chapter 5) and adjacent paddocks, and were eaten readily by goats whenever they had access to them. Plate 7.1 shows goats being attracted by dock seed-heads in a paddock with abundant grass.

In Experiment 2 (Chapter 4), 76% of the viable dock seeds ingested by goats were destroyed during the digestion process (Section 4.3.2), which is an important reduction in the number of viable seeds that would enter the soil seed bank. However, the overall reduction of viable dock seed production by goats is even greater if it is considered that most seed-heads will be eaten before seed maturity, as discussed in Section 4.4.2.

Broad-leaved dock is a problem weed in cattle systems, especially on dairy farms (Panetta and Wardle, 1995) where sheep and goats are typically not present. This indicates that cattle are not effective in controlling the species. Humphreys *et al.* (1997) found that spreading cattle slurry on the pasture will promote the dispersal of broad-leaved dock, so presumably some dock seeds are ingested by cattle and do pass through their digestive tract in a viable state, but some destruction would be expected, as occurred with the goats (Chapter 4). The critical particle size, which is the minimum particle size to which food has to be reduced in order to leave the rumen (McDonald, 1995), is larger in cattle than in goats, so a greater proportion of dock seeds could remain viable on passage through cattle than through goats.

Plate 7.1 Goats selecting broad-leaved dock seed-heads growing in a gateway. Photograph was taken in early summer 1999-2000 in the area adjacent to Experiment 3. Note that pasture is abundant in the paddock.

Reducing the number of viable seeds entering the soil seed bank through goat grazing will help reduce the chances of new seedlings becoming established in the long term (Sakanoue *et al.*, 1995). However, depleting the soil seed bank would not be enough to control this species. Broad-leaved dock is a tap-rooted perennial, so established plants will regrow from root sugar reserves after defoliation. However, frequent and severe defoliation (cutting) associated with the promotion of a competitive pasture has been shown to suppress broad-leaved dock (Hopkins *et al.*, 1997). In fact, docks are not a problem weed in sheep systems, which indicates that it can be placed in a competitive disadvantage through grazing management. Goats can defoliate docks severely, as mentioned earlier, and they will also help suppress it through their beneficial effect on pasture competitiveness (Chapter 5).

Creeping buttercup

This is another important weed on New Zealand dairy farms, though probably not as important as the giant buttercup (*R. acris*) (James and Rahman, 1999). It is a stoloniferous perennial herb (Webb *et al.*, 1988) that reproduces itself both through seeds and vegetatively. The vegetative (or clonal) reproduction is achieved by the formation of new rosettes at the tip of the stolons, which eventually become detached from the mother plant (Sarukhán and Harper, 1973), in a similar way to white clover.

Unfortunately, not enough creeping buttercup seeds could be collected to allow its inclusion in the seed passage experiment (Chapter 4), so the effect of goats on their viability after ingestion remains unknown.

In Experiment 1, goats looked for buttercup in summer, were indifferent to it in autumn (i.e. did not look for, nor rejected it), avoided it in winter, and strongly rejected it in spring (Section 3.3.3). In Experiment 3, the species was also present throughout the area and the seasonal pattern of selection was similar. Unlike Experiment 1, in

Experiment 3 and on adjacent area goats did eat buttercup flowers in spring. However, most of the time some flowers were left untouched, whereas with other species all flower-heads were always consumed, irrespective of grazing management. The only exception to this was pennyroyal, which was not eaten at all (Section 5.3.6), and creeping buttercup, whose flowers were only entirely removed under hard grazing.

No goat was ever seen going from one buttercup plant to another as they did with so many other species (Section 3.3.6), nor were they ever seen eating a buttercup plant to ground level. Defoliation was always light and only progressed as the rest of the plot/paddock was eaten down. As discussed in Section 3.4.3, this might be related to claims that creeping buttercup may be poisonous (Connor, 1977). Though no symptoms of poisoning were detected in this study, it could explain why goats do not seem so interested in it.

A number of goat farms were visited throughout the country during this study, though not as part of any planned survey. Some farmers reported that creeping buttercup was initially abundant on their properties but that these were substantially reduced with the introduction of goats (e.g. H. Arnopp, Milson Line, Palmerston North). This was corroborated by other farmers during open discussions at the 1999 Mohair New Zealand and the Goat Meat Producers annual conferences in Palmerston North. None of the farmers (approximately 90 in total) had any problems that could be suspected as poisoning.

Considering that creeping buttercup (a) is a perennial species, (b) that in this study it tended to be defoliated lightly by goats (except at high grazing pressure), and that (c) some flower-heads usually escaped grazing, it is very likely that the species would survive in the presence of goats, even with them permanently in the system. However, their damage should be enough to keep buttercup from becoming dominant. This would depend on other variables, especially grazing management, which is discussed in Sections 7.2.2. Note that buttercups are not a problem weed in sheep systems.

Californian thistle

Californian thistle is a perennial species, whereas most other thistles that are weeds in New Zealand pastures are annuals or biennials (Webb *et al.*, 1988). It is a troublesome pasture weed, especially because of its creeping root system, vegetative reproduction, and regrowth capacity (Sagar and Rawson, 1964), which make it one of the most important weeds on New Zealand dairy farms (Bourdôt *et al.*, 1994).

Webb *et al.*, (1988) reported that the species produces few seeds. However, when collecting seeds for Experiment 2, it became obvious that many capitula contained dozens of seeds, though some were empty. The species is dioecious and the flowers are pollinated by insects (Dersheid and Schultz, 1960), which may explain such variation. After cleaning (Section 4.2.1), 86% of the seeds were viable (Section 4.3.3), which is a very high percentage for a weed. However, according to Amor and Harris (1975), seedlings develop slowly and are quite sensitive to competition from other plants.

In Experiment 2 (Chapter 4), 95% of the viable seeds ingested by goats were destroyed. Considering that few seedlings manage to become established (Amor and Harris, 1975), such a reduction in the number of seeds entering the soil seed bank should make seedling establishment even less probable, at least in the long term with progressive death of seeds in the soil. This is with regard to the consumption of mature seed-heads, but considering that goats can be managed to prevent flowering entirely (Section 7.2.2), establishment from new seeds could become negligible.

However, Californian thistle multiplies itself chiefly by vegetative means. Under favourable growing conditions the tap root produces lateral running roots which grow horizontally and form a creeping root system. Sections of these running roots become thicker and grow vertical rhizomes which reach the soil surface and form new stems (Sagar and Rawson, 1964).

Manual defoliation (Henskens *et al.*, 1996) and defoliation by goats (Rolston *et al.*, 1981) are known to kill Californian thistle. However, as found in Experiment 4 (Chapter 6), rosettes that are tightly protected by surrounding pasture are unlikely to be eaten. If unchecked, rosettes will grow further creeping roots and new shoots, so where goats are used for weed control, it is important to facilitate their access to the rosettes. This is particularly important at early flower bud formation when root assimilates are at their lowest. Repeated defoliation at this stage will kill Californian thistle faster (Harrington, 1983). A grazing management strategy to address this is discussed in Section 7.2.2, but an example with Scotch thistle is given below.

Scotch thistle

This is a taprooted biennial species (Webb *et al.*, 1988) that can be a problem in a wide range of grazing systems in New Zealand. Cattle and sheep will not eat it, unless forced to. Plate 7.2-A, B, and C shows Scotch thistle rosettes (both true and bolting ones) rejected by sheep and cattle on different farms (Plate 7.2-D is dealt with below).

During the 12 months that Experiment 3 was run, Scotch thistle needed controlling twice by chipping (i.e. cutting rosettes below ground level with a hoe) on the adjacent paddocks grazed by sheep only (note that before the experiment, this whole area was managed as a single sheep block, as explained in Section 5.2). Similarly, the species was rejected by cattle in the lax and hard grazing treatments (HN and LN) of Experiment 3 (Chapter 5). However, in this case no control was attempted (as part of the trial) and plants managed to flower and produce seeds freely. On the other hand, where goats were present with or without cattle, both on plots of Experiment 3 (treatments LL, LH, LM, HL, HH, HM) and the adjacent area, not a single Scotch thistle survived their grazing. Plate 7.2-D shows an example of damage caused by goats to a Scotch thistle rosette which had been exposed by cattle grazing the surrounding pasture (Plate 7.2-C).

Some vegetative multiplication does occur in Scotch thistle, but it is very limited, thus the survival of the species is almost entirely dependent on the production of seeds (Randall, 1994). These do not remain viable for more than a year if close to the soil surface, so the species needs a new supply of seeds every year to continue the cycle or some sort of soil disturbance in order to bring up viable seeds from greater depths where they survive longer (van Breeman and van Leewen, 1983).

Nearly 97% of the viable seeds ingested by goats in Experiment 2 were destroyed (Section 4.3.2). Thus if goats are only given access to Scotch thistles when seeds have already been formed (not an ideal situation), it is not too late to break its cycle, as most seeds will be destroyed (Figure 7.1, p.132).

7.2.1.2. Pasture utilisation

The integration of goats with other livestock should also improve the utilisation of the available plant resources. This is because goats consume components of the vegetation (Chapter 3) that are not considered desirable in the system. This not only includes weeds rejected by other livestock, but also portions of the pasture that are known to have lower nutritional value, such as grass seed-heads and stems (Thompson and Poppi, 1990; Hodgson and Brookes, 1999). Thus, when cattle and sheep are managed for optimum performance these elements are generally not consumed. Nevertheless, they occupy space and immobilise resources (Tilman, 1982) that could otherwise be free to constitute plant components that are better utilised by cattle and sheep.

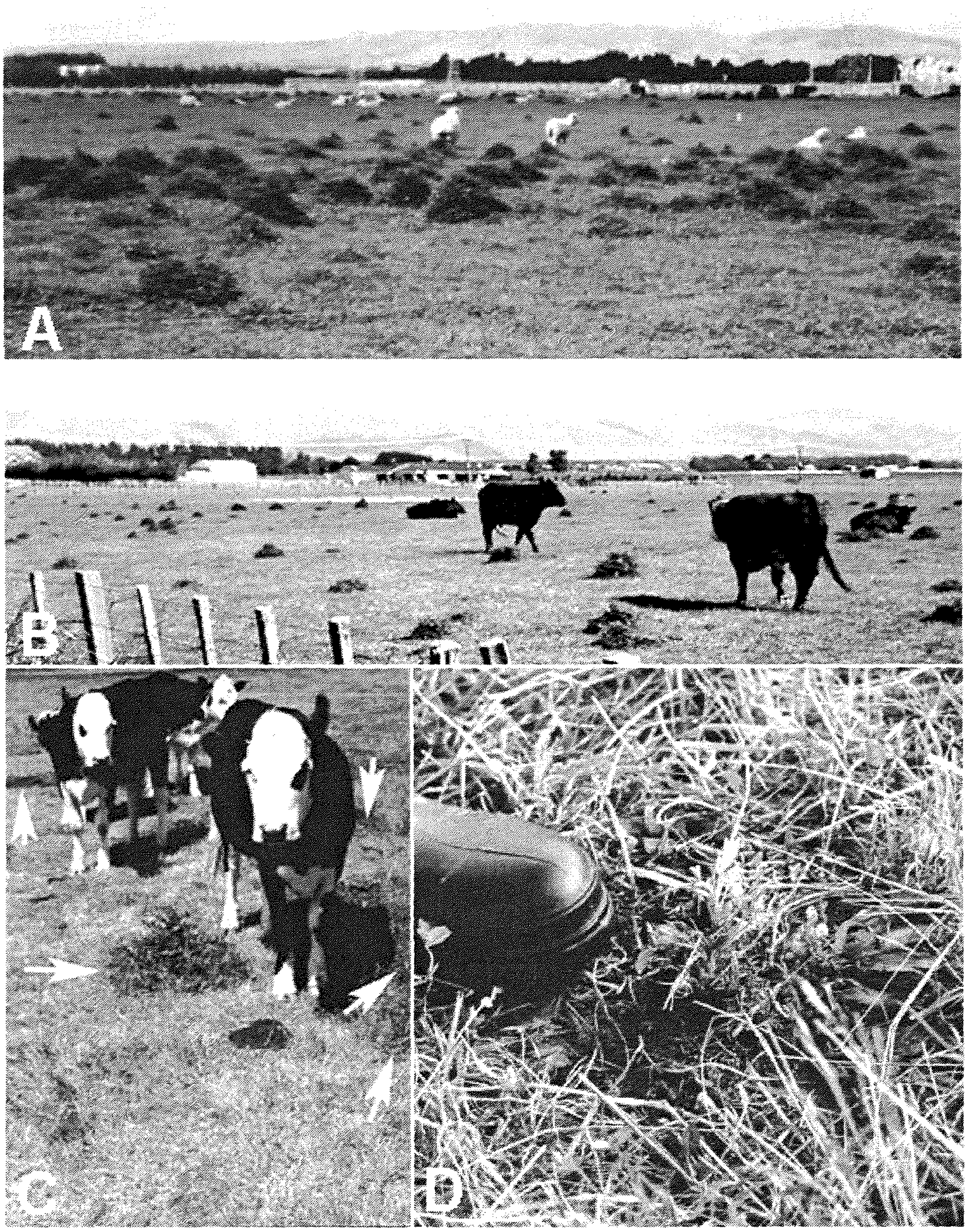


Plate 7.2 Scotch thistle rosettes rejected by sheep (A) and cattle (B and C) but eaten to ground level by goats (D). Commercial (A) sheep and (B) beef cattle breeding farms under continuous grazing, located 10 and 1 km northwest of Palmerston North, respectively; (C) area adjacent to Experiment 3 of the Massey University Pasture and Crop Unit, rotationally grazed by cattle followed by goats (Section 5.2.1.2); (D) rosette eaten by goats in (C). Photographs taken in the spring of 1999.

Many studies have concentrated on devising or refining management techniques to control the reproductive growth of pasture in spring and summer, as reproductive growth is associated with losses of herbage quality (Valentine and Matthew, 1999), reduced tiller population density and pasture productivity (Hernández Garay *et al.*, 1997), and waste of feed (Smetham, 1990).

In Experiment 1 (Chapter 3), of all the feeding time invested by goats on grasses in spring and summer, more than half (58%) was spent grazing seed-heads (Section 0). Additionally, seed-heads were always the first component to be selected when goats entered a new paddock (Section 3.3.6), despite the abundance of green leaves, which is the preferred dietary component of cattle and sheep (Hodgson, 1990). The same pattern was again observed in Experiment 3 and adjacent paddocks, despite these being different goats on a different farm. Experiment 3 produced evidence of goat grazing (alone or with cattle) resulting in significantly less seed-head component in the sward compared to cattle-only treatments. Hard grazing in the goat-only treatment (HM) resulted in complete removal of grass seed-heads (Section 5.3.3; Figure 5.7). This grazing behaviour fits well with the need to control reproductive growth of grasses at this time of the year and, if well managed, could minimise the need for traditional methods such as "topping" (i.e. mowing pasture to keep tillers from becoming reproductive).

One of the problems caused by pasture weeds is that herbage growing close to spiny or poisonous weeds are largely avoided by cattle and sheep (Popay and Thompson, 1981). For example, Allen and Meeklah (1972) found that one 30-cm diameter nodding thistle (*Carduus nutans*) plant/m^2 prevents grazing in 10% of the area. Note that the area of a 30-cm diameter circle is 0.07 m^2. Thus the plant alone would prevent grazing on 7% of the area. The other 3% is accounted for by pasture immediately around the thistles that is not eaten. Thus, by eliminating (Section 2.4) or preventing the establishment of weeds (Chapter 5) such as this, or even by keeping them small, goats would be helping improve the utilisation of pasture.

So, in summary, the improved utilisation of available plant resources would occur through the consumption of (a) a broader range of species, (b) grass seed-heads, and (c) pasture that would otherwise be close to weeds (especially spiny and poisonous species) and not be consumed.

7.2.1.3. Herbicides

One important advantage of using grazing animals for weed control is the reduction or possibly elimination of the use of herbicides, both for economic and environmental reasons (Popay and Field, 1996). Herbicides can be used to control all the species that have been mentioned in this study. However, with increasing costs of herbicide application and decreasing prices paid for animal products, the decision of whether to use herbicides becomes critical, and in some grazing systems the use of herbicides is economically prohibitive.

Additionally, there are confirmed cases of herbicide resistant weeds in pastures, such as nodding thistle (Harrington *et al.*, 1988) and giant buttercup (Bourdôt *et al.*, 1994) in New Zealand. Herbicide resistance results from persistent applications of the same herbicide, or of herbicides with the same mode of action, to the same area. Susceptible individuals are killed but the resistant ones, which are initially few, eventually become dominant due to the herbicide selection pressure (Preston, 2000).

Another problem related to herbicide application is that most herbicides used to control weeds in pastures (especially mature plants) also damage white clover. New Zealand pastoral systems have historically relied on white clover to promote nitrogen fixation (Langer, 1990), so damage to these plants leads to reduction in nitrogen, which results in reduced grass growth. White clover also has higher feeding value than grasses (Hodgson and Brookes, 1999).

The alternative of integrating goats with other livestock for weed control can potentially eliminate the use of herbicides and reduce weed control costs. However, the net economic advantages of integrating goats into a grazing system compared with the continued use of herbicides, though worthwhile in most circumstances, will not necessarily always be so in all cases (this is discussed in the next section).

No weed control measure is perfect (i.e. capable of killing all individuals, all the time). This is the case with herbicides and is also the case with goats—ultimately, they make the decision of whether to eat any given weed plant or not.

7.2.1.4. Economics

From the economic point of view, weeds should only be controlled when their populations have reached a certain critical size where the economic benefits are greater than the control costs (except in cases when control is enforced by law). This critical size (e.g. weed cover or density) is known as the "economic threshold" (ET) or as the "economic optimum threshold" (EOT) if it takes into account future benefits of control instead of current season benefits only, which is the case of ET (Jones, 2000).

However, in pastoral systems it is very difficult to determine such a threshold, especially because the benefits come ultimately from the animals and not from the plants (unlike crops). So, for benefits to occur, the weed control measure (e.g. herbicide application) must kill the weeds, or at least reduce their cover and vigour significantly, and this must result in increased herbage utilisation (if weed cover is significant, it must also result in increased herbage production). The extra herbage must then be transformed by the animal into a marketable product, which has then to be sold for the real benefits to be known. This is obviously a long sequence of events and on top of that, when herbicides are used, there is the need to separate any growth inhibiting effects of the herbicide from the effects of weeds on herbage growth and utilisation. For these reasons there is very little scientific work done to determine economic thresholds for weed control in pastures, and even if these were widely available, it would still be necessary to correct the figures to current application costs and product prices. Because of all the above difficulties, weed control decisions in pastoral systems are often based on visual thresholds and intuition (Popay and Field, 1996).

However, if goats are integrated permanently into grazing systems, economic thresholds becomes immaterial (though this does not mean that the economics of using goats is irrelevant). This is because goats would be permanently on site, literally so if under continuous stocking management and spread throughout the farm, but not really so if they are on a rotational system. Nevertheless, provided goats have access to the weeds, the decision to graze them is ultimately made by the goats and not by the farmers. The farmers will have the power to intervene in order to improve control effectiveness, thus minimising costs (which is where grazing management comes in), but no further economic decision is required regarding the control of weeds once goats are integrated in the system. The exception would be for weeds that are not controlled by goats, pennyroyal being a clear example from this study (Section 5.3.6).

Determining the profitability of integrating goats with other stock is not a straightforward issue as it depends on combinations of a number of biological and economic variables that will generally be unique for each case. Daniels (1996) carried out a detailed case study of the profitability of goats used for scrub weed control on a North Island hill country sheep and beef farm. The method used to calculate the net benefits (partial budget) is outlined in Table 7.2.

Table 7.2 The profitability of goats used for weed control on a Southern North Island hill country farm[‡] (Daniels, 1996). Values are per annum for the whole farm as at 1996.

A. Advantages from goats	**NZ$**
Financial income:	
fibre	2,450
meat	1,420
Weed control:	
scrub cutting savings	270
additional grazing	420
Total advantages from goats	**4,560**
B. Disadvantages from goats	**NZ$**
Direct expenditure	610
Cost of capital invested in:	
livestock (goats)	365
handling facilities	120
Reduction in land available for most profitable alternative:	
90 sheep SU @ $26.71/SU[†]	2,400
Total disadvantages from goats	**3,495**
C. Net benefits	**NZ$**
Total advantage from goats	4,560
Total disadvantage from goats	3,495
Net advantage to running goats	**1,065**
Net advantage to running goats per SU	**8.19**

[†] Stocking unit.

[‡] Effective area: 500 ha. Average stocking rate: 8.3 SU/ha.
Livestock: 2905 sheep (2725 SU; 66%); 270 cattle (1265 SU; 31%); 203 (130 SU; 3%).

Note that the item "additional grazing" (Table 7.2-A) only included the extra herbage grown in the area that would otherwise be occupied by the weeds. It is probably underestimated because it did not consider any gains in herbage utilization (see Section 7.2.1.2).

The item "reduction in land available for most profitable alternative" (Table 7.2-B) can be seen as an opportunity cost. It considers that goats occupy a pasture area that would be occupied by other livestock if goats were not present. At the time and for that particular property, the gross margins (i.e. income less expenditure and cost of capital) were \$26.71, \$19.21, and \$22.27 per SU for sheep, cattle, and goats, respectively. As the sheep gross margin was the largest, it was used as the opportunity cost. However, this does not take into account the probability that the presence of goats would be affecting positively the production from sheep and cattle, particularly in light of the results obtained in this study, e.g. increased herbage quality (more clover, more leaves, less seed-heads). This was likely to be significant in the case evaluated by Daniels (1996), because goats had been on the property for more than 10 years, i.e. had the goats not been in the system, it is possible that the sheep and cattle gross margins would be lower. The studies conducted by Radcliffe (1991) and Thompson and Power (1993) have demonstrated that the performance of sheep and cattle can improve significantly when goats are added to the system, though weeds were not considered in these studies.

A similar consideration should be made about the weed control savings (Table 7.2-A). The above method calculates the annual cost of the control method that would be used if goats were not present and attributes that same value to the advantage of using goats instead. This is a logical solution, but it assumes that the two methods (i.e. goats versus any other alternative) have the same effect. The validity of this assumption is questionable, but the discrepancy will depend on the alternative control method that is considered. For example, most herbicides used to control pasture weeds will cause damage to legume plants, reducing their presence in the pasture (see Section 7.2.1.3), while goats grazing is conducive to clover growth. Clearly these two methods are not perfect substitutes. Thus, if the pasture in question contains legumes and the herbicide is not selective, an allowance for legume damage should be made, i.e. using a herbicide method should include an extra cost resulting from clover damage (certainly not a straightforward issue).

In the case study above, the alternative method used for the calculations was "scrub cutting", which is certainly more comparable to the goat alternative than herbicides. Nevertheless, the gains in herbage quality and increase in sward competitiveness resulting from the presence of goats would still be issues to consider.

Despite its limitations, the procedure outlined above appears to be an effective tool for assessing the economic impact of introducing goats to a grazing system (alternative methods are discussed by Jones, 2000). At this stage, the incorporation of any extra gain from goats into the above model would require very rough estimates. An overestimation of these gains would be more detrimental than leaving them out altogether. However, once reliable estimates do become available (see Section 7.3) they should be used.

Apparently, no comparable case study is available for herbaceous weeds nor for more intensive farming systems (e.g. dairy farming). However, the method above should be appropriate to any farming type. Note that cattle-only systems, such as dairy farms, are free from intestinal worms that infect goats, which is an economic advantage compared to the integration of goats with sheep (this is discussed in more detail in Section 7.2.3.2).

7.2.1.5. Early experience in life

Another advantage of having goats integrated in the system comes from the knowledge that experience early in the life has profound and persistent effects on the voluntary intake of goats throughout their lives (Distel and Provenza, 1991). Goats that have access to a certain plant species during their first year of life tend to accept or even look for that species throughout their lives, while those that did not have contact with the plant in the first year are unlikely to show any interest in it. Additionally, the tolerance to diets containing high concentrations of chemical defences and low in nutritional quality is also established during the first year. This would indicate that if goats were permanently on the farm, as opposed to being brought from different places for transient control only, they would be better adapted to the local flora and would possibly select a wider range of species.

As mentioned in Section 5.3.6, only two of the 39 animals used in Experiments 3 and 4 were ever seen eating pennyroyal. One of them clearly looked for it and would actually select pennyroyal plants under the electric wire. Perhaps these two animals had contact with pennyroyal when kids while the others did not. This could not be determined due to lack of records of individual animal histories (Section 5.2.1.1).

7.2.2. Aspects of grazing management

Some fundamental aspects of grazing management will now be discussed, especially those that are likely to have a direct effect on the efficiency of goats as a weed control tool.

7.2.2.1. Stocking rate

Imagine two contrasting hypothetical cattle farms, one (Farm A) having a small proportion (e.g. 5%), and the other (Farm B) with a large proportion (e.g. 50%) of the grazing area covered by the same weed species. Suppose that both farms have the same goat stocking rate (i.e. goats or SU/hectare) and, for the sake of simplicity, that the objective for the goats on both farms is simply to keep the weed cover from increasing (all other variables being the same in both cases).

In general, if the stocking rate is high enough to allow Farm B to achieve its weed control objective, it will probably be excessive on Farm A, in which case goats would be consuming more herbage than necessary and consequently competing more strongly with cattle. If, on the other hand, the stocking rate was just enough to achieve control on Farm A, it would probably be too low for Farm B, where competition between goats and cattle would be minimal, but control would not be achieved. Thus, for goats to work effectively as a weed control tool some measure of the weed infestation will have to be considered when deciding how many goats to incorporate in a grazing system.

Despite the potential importance of this issue, most of the research done to date on the impact of goats on weeds (Section 2.4) has adopted goat stocking rate or a combination of this and the livestock ratio (e.g. sheep:goat) to decide how many goats to use in total. However, Batten (1979) identified the problem as early as 1977, thus he based his recommendations on a parameter defined as "g.e./ha of weed cover" (Batten 1979; 1984), where "g.e." was a standard "goat equivalent", i.e. a 40 kg liveweight goat. This is also a measure of stocking rate, but it is not relative to the total farm area allocated to grazing, which can have any conceivable proportion of its surface occupied by weeds, as implied in the example above. Instead, his parameter is relative to the weed cover, i.e. the area that is effectively occupied by weeds.

While this is certainly an improvement over the conventional use of stocking rate, it should be noted that it too presents limitations. The first one is that it is not easy to determine weed cover, not so much in research conditions, but particularly in commercial farming situations. In research, it can be determined in a number of ways, ranging from the accurate but laborious point quadrat technique (Grant, 1993), to a less time consuming (though less accurate) option such as visual appraisal (Kent and Coker, 1992), as adopted in Experiment 1 of this study (Section 3.2.2.2). However, for commercial farming it would be necessary to use a simple scoring system if it were to be adopted in practice. Nevertheless, considering that accuracy in this case would not be critical, this is probably the least important of the limitations (i.e. an approximate estimate of weed cover would suffice).

A second and more important difficulty, however, is related to weed biomass, both with regard to standing biomass and dry matter accumulation (i.e. net growth). Two farms with the same weed biomass (e.g. 500 kg DM/ha) would probably represent two very different situations if, on one of them, the weed species was broad-leaved dock and gorse on the other one, for instance. However, Batten (1979; 1984) was specifically concerned with scrub weeds in New Zealand and did not generalise his method to include herbaceous weeds.

Nevertheless, the biomass accumulation of three of the most common scrub weeds in New Zealand, namely gorse, broom (*Cytisus scoparius*), and manuka (*Leptospermum scoparium*), can be very different. In a detailed study aimed at determining the potential of various shrubs as a feed source for goats, Lambert (1988) found that gorse and broom produced 5.8 and 4.2 times more forage than manuka, respectively (see also Lambert *et al.*, 1989a). These are large differences, yet they are all shrub species.

A similar study would be necessary for herbaceous weeds that are eaten by goats. For example, how much above ground dry matter would one hectare of Californian thistle produce in one year? How would that compare to one hectare of, say, broad-leaved dock? What would be the effect of different defoliation severities on their above ground dry matter accumulation? Ideally, this type of information would have to be linked with knowledge of diet selection as affected by seasons and correlated to growth stage of plants, such as that produced by Experiments 1 (Chapter 3) and 4 (Chapter 6) of this study.

The third limitation of the parameter g.e./ha weed cover to be pointed out is related to diet selection. Contrary to the popular belief that "goats eat anything", the scientific evidence shows that they are in fact very selective animals (see Section 2.3 and Chapter 3). While goats will eat weed species that are rejected by other livestock, they do discriminate amongst them, i.e. they make efforts to find some species and organs and actively reject others. Furthermore, this phenomenon varies between seasons, as discussed in detail in Section 3.4. Thus, weeds cannot be seen as a single, uniform type of feed for goats.

Yet, the concept of a weed cover does not allow for the variations above. This is a problem even if the two limitations discussed earlier are addressed (i.e. proper determination of percentage cover and dry matter accumulation). Two farms of the same size might have weeds producing the same amount of dry matter per hectare, yet they might need different numbers of goats to keep weeds under control. This is theoretically possible even if only one group of weeds is involved (i.e. either herbaceous or woody species).

As an example, consider Scotch thistle and creeping buttercup (two herbaceous weeds). Scotch thistle is readily accepted by goats both in the flowering (Clark *et al.*, 1982; Chapter 3) and in the vegetative stages (Chapter 6), provided rosettes are not closely surrounded by the sward. Additionally, goats often eat Scotch thistles to ground level (Lambert *et al.*, 1981), though normally after several visits to the same plant (see Section 3.3.4, p.38). In contrast, creeping buttercup tends to be defoliated only lightly by goats and, even under hard grazing management, no complete defoliation was observed in the present study. Also, goats tended to leave some flowers untouched, though this is of secondary importance for the control of this perennial species, as discussed in Section 7.2.1.1 (p.138). Thus, even if these two species produced the same amount of dry matter per hectare of weed cover, creeping buttercup would probably require a greater goat stocking rate (g.e./ha weed cover) than Scotch thistle, if similar level of defoliation was to be achieved (i.e. damage to the aerial parts, in general).

However, the defoliation intensity required to control annuals and biennials is not the same for perennials. This is the fourth and last aspect of the g.e./ha weed cover to be discussed. As pointed out in Section 7.2.1.1, the key strategy to control annual and biennial weeds is (a) to avoid flowering so that seeds are not formed and the soil seed bank is not replenished, and (b) to promote a dense and vigorous pasture that will minimise the emergence and establishment of new plants. Depending on the species, the simple removal of the flowers is enough to achieve (a) (i.e. severe defoliation is not essential). In contrast, perennial weeds require frequent and, ideally, extensive defoliation in order to minimise their leaf area and consequently exhaust their food reserves, which will prevent them from growing and multiplying vegetatively and eventually kill them. A competitive pasture will also help avoid new establishment from seeds.

Thus, if two farms had the same weed cover, but on one of them the species was Scotch thistle and on the other, creeping buttercup, the former would probably need a lower g.e./ha weed cover than the latter in order to achieve the objectives outlined in the previous paragraph. This is particularly evident if it is considered that the first component selected by goats when they entered a new paddock was Scotch thistle flower-heads. In general, they only started to select other components when this was no longer available (Section 3.3.4, p.38). As a result, all thistle flower-heads had disappeared completely before grass leaves were first selected (between these two components there were other weeds as well as grass seed-heads). This is a very different pattern of defoliation compared to creeping buttercup, which was usually eaten down along with the grass and clover components of the sward (Section 7.2.1.1).

In practice, goats will be used to control more than one weed species on the same paddock as farms rarely have only one weed species (unlike the examples used above). This is potentially a further complication, but it is probably not an important one, because usually one species is of greater concern to the farmer than others for reasons such as adverse effects on stock, density, control costs, control difficulties, purely cosmetic issues, or combinations of these. This being the case, it will be logical to adjust goat stocking rate to the weed that is judged to be most important. However, if goats are required to control an array of weed species, it would be necessary to adjust their stocking rate based on the species that is most difficult to control with goats, which would naturally result in others being controlled at least as well, but probably even more effectively.

Currently there is not enough information to allow safe decisions to be made regarding goat stocking rate. The concept of a goat stocking rate based on weed cover is undoubtedly an advancement over the usual concept. However, as discussed above, it needs significant refinements. These will only be possible when factors such as the biomass accumulation of herbaceous weeds in pastures are quantified, particularly for perennial species and under different defoliation regimes.

Depending on the reasons for running goats (Section 7.2.3.1) as well as on other aspects of grazing management (Section 7.2.2.3), it would also be important to know the feeding value of the various herbaceous weeds (i.e. their nutrient composition and digestibility), as specified by Radcliffe (1986) for gorse and by Lambert *et al.* (1989b; 1989c) for gorse and other woody species.

7.2.2.2. Combination of animal species

As mentioned in the beginning of the previous section, livestock ratio is another parameter that has been adopted in research for decisions of how many goats to use in weed control experiments. The advantages of this parameter are that no weed measurements are required (unlike the stocking rate based on weed cover) and that it can be easily adopted in commercial farming situations. However, if a weed infestation differs significantly from that reported by research (e.g. a different weed biomass) then it is very likely that the ratio of goats to other stock would have to be adjusted for similar results to be achieved. Note that the ratio *per se* would not be dictating the need for adjustments, instead it is the weed infestation that will require more or less goats and, as a consequence, the ratio will be altered. Therefore, this parameter has basically the same limitations discussed in the previous section for the goat stocking rate on a weed cover basis.

Some New Zealand farm advisors claim that an addition of 10% of goats can be made to any cattle and/or sheep farm (based on its total SU), without any loss of income from other stock (Minchin, 2000). For example, if a farm has 500 cattle SU and 500 sheep SU (i.e. a total of 1000 SU), then their recommendation would be to add 100 goat SU (i.e. 125 mature goats if the equivalence of 0.8 SU is used). This recommendation is also supported by the Meat New Zealand Goat Council (Meat New Zealand, 2000).

Considering all the variables that are involved in such a generalisation (e.g. sheep versus cattle diet selection patterns, weed species, weed biomass, grazing management, topography, etc.), it is scientifically intriguing how this can hold true across so many different farms, as it is claimed (Minchin, 2000). On the other hand, "without any loss of income from other stock" does not mean that the results are the same on every farm, and most probably they are not.

The fact that goats can be added to a farm that is often close to its maximum carrying capacity, with no loss of income from other stock, is not surprising in itself, especially in light of the study carried out by Thompson and Power (1993) with bulls, discussed in Section 5.1. The intriguing factor is the 10% figure. Consider the following:

(a) the available pasture quantity and quality can be improved by goats through weed control, consumption of seed-heads, increased clover content, and more herbage accumulation, as discussed in Section 7.2.1;

(b) goats will consume pasture (Clark *et al.*, 1982; Chapter 3), thus competing with other stock for feed;

(c) the gross margin of goats can be smaller or greater than the gross margins of cattle and sheep.

The main variables underlying (c) are simple market fluctuations of input and product prices. However, (a) and (b) are biological functions that have not been sufficiently studied to allow quantification and predictions, as discussed in Section 7.2.1.4.

If the 10% rule can be applied as successfully as is claimed, despite the infinite number of combinations that the above factors can have, then it would appear that this value is actually at the lower (i.e. safer) end of the scale. Otherwise, cases of it not being successful should be just as common and even more common if it was excessive. On one hand, it could be argued that the Goat Council is interested in promoting the goat industry, thus could be partial in such recommendations. While this is theoretically possible, it would be a short-sighted policy with no lasting effects. Thus, it is improbable. Similarly, consultants have a business interest in making recommendations that are economically sound.

Thus, if the 10% value is indeed at the more conservative end of the scale, it might be possible, at least in some specific cases, to add goats by more than 10% of the total SU to systems that are at their maximum carrying capacity for the present stock composition, with no detrimental effects.

As far as weeds are concerned, the addition of goats *per se* says nothing about weed control. In some cases 10% goats may be insufficient for the effective control of weeds. However, ultimately the decision should not be based simply on whether the addition of goats will cause any loss in cattle/sheep income or on weed control *per se*. Instead, it is the net economic benefit that should be considered, as discussed in Section 7.2.1.4. Perhaps the benefit that will be most difficult to quantify financially is the prevention of weed establishment that is expected to follow the introduction of goats in light of the results obtained in Experiment 3 (Chapter 5).

The discussion above reinforces the points that each case requires special considerations and that our knowledge of the biological interrelationships involved in such a problem is not yet sufficient to allow safe predictions of how many goats can be added profitably to existing cattle and/or sheep systems.

7.2.2.3. Grazing method

In general, the greater the stocking density (i.e. animals or SU per ha of area being grazed), the greater the competition between animals for feed and the less options they have for selection (Hodgson, 1990; Smetham, 1990). High stocking density is normally achieved through intermittent grazing methods, where animals are concentrated in a smaller area of the farm for a short period of time, instead of being spread throughout the property, as in continuous grazing methods. Rotational grazing is the most common of the intermittent grazing methods and mob-stocking is the most extreme in terms of stocking densities used (Smetham, 1990).

Significant impacts on established weed populations have been achieved both through intermittent and continuous grazing methods (Section 2.4). For the control of scrub weeds, Batten (1984) concluded that, in the long term, set stocking (a continuous grazing method) is as effective as mob-stocking, because of the "grindstone effect of continuous browsing that weakens the plants." However, it should be pointed out that, in continuous grazing, plants are not defoliated continuously, as implied in his statement. Instead, plants are revisited by animals at a frequency strongly related to stocking rate, i.e. the greater the stocking rate, the smaller the interval between defoliations (Hodgson, 1966). For example, for sheep feeding on a grass dominated pasture, this interval may vary from one week for a stocking rate of 75 young sheep/ha (Hodgson, 1966), to five weeks for 24 young sheep/ha (Morris, 1969). No such information seems to be available for goats feeding on weeds.

Few studies have compared the effects of different grazing methods on weed control by goats (e.g. Radcliffe, 1985), but presumably the importance of grazing method will depend on the target weed species and how well goats accept it. As discussed earlier, this is affected by factors such as early experience in life (Section 7.2.1.5), time of the year and weed development stages (Chapter 3), location of the weed in the sward profile (Chapter 6), and availability of alternative species (Section 3.4.2).

If the species is attractive to goats, they will make strong efforts to find it, as discussed in depth in Chapter 3. Additionally, the chances of preferred weeds being severely defoliated are maximised by the fact that goats often detect when a peer has found something attractive and run towards that animal to compete for the same plant (Section 3.3.4, p.38). This was a typical behaviour with regard to thistles in this study.

Conversely, the less attractive the weed is to goats, the more important the grazing method will become in order for them to defoliate it. If there were no adverse effects, goats could perhaps be forced to graze almost any plant species found in New Zealand pastures, at any stage of development. Forcing animals to eat something that they would normally reject requires that their taste threshold is lowered through hunger (Launchbaugh, 1996). This can be achieved through any intermittent grazing method, though more powerfully with mob-stocking, by leaving animals in the paddock for a longer period of time, which forces them to eat what they would normally leave behind when shifted to the next paddock. This is a common practice in New Zealand, for instance, for grazing ewes between weaning and tupping to clean up rank pasture left behind as a result of poor utilisation (Smetham, 1990) and has also been used in a number of experiments with goats (Section 2.4).

The main drawbacks of such a method are related to feed intake and treading damage to pasture. Feed intake is inevitably reduced, especially at the end of the grazing period (Ungar, 1996), which can lead to reduced performance (Thompson and Poppi, 1990). For this reason, it is not recommended to use animals that are immature, pregnant (particularly in late pregnancy), suckling or being finished for sale. These animals have high nutritional requirements, thus tend to suffer more than mature, dry ones, that can lose or stop gaining weight without further adverse effects (McCutcheon, 1986). If this method is to be used with goats, wethers are the most appropriate category (Batten, 1984).

Hard grazing by cattle or sheep can cause severe treading damage to pastures, particularly if soil is wet. The main adverse effects of this are reduced herbage growth (Brown and Evans, 1973; Pande *et al.*, 2000; Sections 5.3.2 and 5.4.4.2) and greater vulnerability to weed invasion (Beskow *et al.*, 1994; Beskow, 1995; Chapter 5, especially Sections 5.3.4 and 5.4.3).

However, no study has linked goats with such damage. In Experiment 3 (Chapter 5), goats caused no visible damage to the sward canopy and soil surface, even when grazed hard on wet soil. This was explained by their lower hoof pressure combined with their distinct behaviour pattern, i.e. minimal walking at most critical times (Section 5.4.1). Thus, if it becomes necessary to force goats to eat any weed species through an intermittent hard grazing method, their negative impact to the sward canopy and soil surface should be minimal. However, goats can be very reluctant to graze below 10 cm. In Experiment 1, goats chose to graze above 10 cm whenever this was possible (Section 3.3.5) and in Experiment 3, goats reduced their grazing activity when sward height reached about 10 cm and it took them many hours more than cattle to graze it down to 5 cm (Section 5.3.6). Collins and Nicol (1986) found that the apparent dry matter intake of goats decreases at a faster rate than that of cattle and sheep as herbage mass declines and observed that goats stopped grazing at a relatively high post-grazing mass of about 1000 kg DM/ha. In the present study this behaviour pattern was even more marked if pasture had become contaminated with soil, urine or dung. When only fouled pasture was available, goats stopped their feeding activities entirely, regardless of how much feed was left.

Grazing managers should realise that the general post-grazing appearance of a pasture grazed hard by goats will be different from one grazed by cattle (see Plate 5.1, p.109) or sheep. The pasture will look cleaner (i.e. less soil contamination resulting from less trampling), less disturbed (i.e. few or no gaps in the canopy and almost no soil disturbance, unless the paddock is extremely wet and occupation period is excessively long) and it will have a greater residual herbage mass. For people accustomed to grazing cattle or sheep but who have no experience with managing goats, it would be advisable to start by observing the feeding behaviour of the goats instead of monitoring the pasture. If goats are not grazing at times of the day when they should be, i.e. from late morning to late afternoon, but especially in the afternoon (Greaves *et al.*, 1991), it is because they have reached a limit and will not continue to graze. Leaving them longer on the paddock after that point is only justified if the objective is to limit their daily intake to save feed (i.e. ration existing pasture and transfer it *in situ* to another period). No further effect on the vegetation should be expected.

In grazing systems that are largely or entirely based on pasture, it is very difficult to maximise (a) animal performance, (b) pasture performance (quality, quantity, and persistence), and (c) pasture utilisation at the same time. This is particularly challenging in systems where conservation, topping, etc., cannot be used to help control the sward (e.g. due to topography limitations). Such systems have to rely entirely on grazing management. However, the performance of animals that are forced to consume seed-heads, stems, or any dead plant material, is reduced (Thompson and Poppi, 1990). Thus, this job must be carried out by a class of animals that has lower priority. This means that the same paddock must be grazed by two different classes, separately: one to be managed for optimum animal performance (a high priority class, e.g. finishing animals) and the other for the maintenance of herbage quality and utilisation (a low priority class, e.g. dry, mature, females) (Sheath and Clark, 1996).

Continuous grazing methods are not conducive to this. However, in intermittent grazing methods, classes can be grazed separately. This is done in sequence, so the class that grazes first is called the leader and the other is the follower (Sheath and Clark, 1996).

Leader animals generally perform better than the followers (Morton, 1992; Liu *et al.*, 1998) because (a) they have more feeding options; (b) leaf:stem ratio of available herbage is higher (note that leaves are selected in preference to stems and have higher feeding value; Hodgson and Brookes, 1999); (c) sward is taller and herbage mass and bulk density are higher, thus potential intake rate is greater (Hodgson, 1990; Laca *et al.*, 1992); and (d) herbage is less trampled (Harris, 1990).

A typical example of such a method is the leader-follower rotational grazing used in summer in New Zealand, where lambs are run as leaders in order to be finished as quickly as possible, followed by ewes or cows to "clean" the pasture (Smith *et al.*, 1976). This is popularly known in New Zealand as the "summer clean-up grazing" (Smetham, 1990).

Leader-follower intermittent grazing methods offer great scope for maximising the efficiency of goats as a weed control tool in the system. Based on what was discussed above, it would be logical to think of them as followers. This was carried out in the present study in the area adjacent to Experiment 3 (see Section 5.2.1.2) where goats and cattle were kept when they were not grazing the plots of that experiment (i.e. three of every four weeks, for 12 months). When cattle were run as leaders they consistently left rosettes of Californian and Scotch thistles untouched, but sufficiently exposed by removing pasture from around them (see Plate 7.2-C, p.143). Goat followers defoliated these rosettes severely, most of them to ground level (Plate 7.2-D). However, goats were not forced to do this, as indicated by the results from Experiment 4 (Chapter 6), where thistle rosettes were severely defoliated despite the abundance of other feed options (Sections 6.3 and 6.4). Many broad-leaved dock plants and grass seed-heads were also left by cattle but were readily consumed by goats, provided the plants were not trampled down and fouled. The leader-follower rotational method is perhaps the most powerful grazing method to direct goats to eat what the farmer wants to them to eat and seems to be the best option for addressing the rejection of thistle rosettes when they are not exposed.

For goats to be run as followers, their grazing pressure (i.e. the animal-to-feed relationship) should be high enough to allow them to have their task accomplished when the leaders are shifted to the next paddock. Thus, the actual goat stocking density needed will depend on how much feed the leaders leave behind for the goats (including weeds). This will often vary from paddock to paddock, but it can be partly compensated for by increasing or decreasing the grazing period of the leaders. Should an imbalance arise between shifting needs of leaders and followers, it is better to have followers finishing earlier than later, as this will ensure that they are ready to be shifted when the leaders are shifted. Holding goats on the paddock after they stop grazing will cause minimal damage to pasture, as discussed in Chapter 5. This is only a good option from the pasture management point of view, as goats will be underfed, which stresses the importance of choosing an appropriate goat class for the task (see comment on p.161).

Contrary to the logical option of running goats as followers, goats can also be run as leaders, apparently with no detrimental effect to the followers. This may seem a paradox in light of what was discussed earlier about the aim for the leader class and its diet opportunities, but it is actually a logical expectation given the pattern of diet selection shown by goats throughout this study. The following are key elements that support this claim:

- when goats entered a new paddock, they selected seed-heads first (Section 3.3.4, p.38);
- goats made minor to strong efforts to find weeds (depending on species and season), no effort to find grasses, and neutral to moderate effort to avoid clover, except in summer (Section 3.3.3);
- goats competed strongly for large thistle plants (Section 3.3.4, p.38);
- when seed-heads were available, 58% of the time spent on grasses was spent on seed-heads (Section 0);
- goats grazed above 10 cm whenever possible (Section 3.3.5) and were reluctant to graze when pasture became shorter than this (Section 5.3.6);
- goats did not trample the herbage down at any time, even under hard grazing (Sections 5.3.2 and 5.4.1; Plate 5.1, p.109);

- goats were run as leaders from mid-spring to late-summer in the same area mentioned earlier; flowering thistles (the whole plant), grass and weed seed-heads were consistently the first options they selected.

When feed supply is greater than demand (e.g. from mid-spring to mid-summer) it is important to maximise feed intake on the farm as a whole for better utilisation and maintenance of feed quality (Nicol, 1987; Matthews *et al.*, 1999). During such times and given the points above, holding follower goats on the paddock once they finish grazing cannot be justified, because there is excess feed on the farm that is becoming rank and decaying, while goats are being underfed. Thus, whenever follower goats become ready for shifting earlier than the leaders, they could be moved ahead of the priority class and be made the leaders. Note that this does not change the aims for each class nor their priorities and this is only possible because of the points listed above. Once the priority class was ready to be shifted, goats could be moved to their paddock as followers once again and the priority class would be shifted to the paddock where the goats had been grazing. In other words, it is an interchange between the positions (not the functions) of leader and follower to maximise feed intake and utilisation, to maintain feed quality, and to best feed all classes.

Goats could also be run ahead all the time (i.e. as leaders without interchange of positions) if they are to control grass seed-heads and annual weeds that only need to have their flowers removed (Section 7.2.1.1). This alternative would be recommended particularly for goat classes that should never be underfed (e.g. does in late pregnancy or suckling). The followers (e.g. cattle or sheep) would find a leafy pasture with few or no grass seed-heads and less weeds, provided the occupation period of the goat leaders was well managed.

For perennial weeds that require a more severe defoliation, running goats as followers (preferably wethers) or in continuous grazing should be more effective. Also, in winter when less weed biomass and no flower or seed-heads are available, running goats as followers will minimise the competition for herbage. However, at this time of the year, paddocks are often wet and temperature is low. Goats are sensitive to cold and wet environments (Gall, 1981; Smith and Sherman, 1994) and should be kept well fed to minimise health problems (see Section 7.2.3.2).

Ultimately, the choice of a grazing method will depend on the objectives of the farm, the performance targets for each class, and the reason(s) for having goats in the system. This will be discussed next.

7.2.3. Other factors to be considered

7.2.3.1. Objectives of the farmer

Before integrating goats in the system, farmers should consider the purpose of running goats and what is expected from them. As argued throughout this chapter, there are many variables underlying the effectiveness of goats as a weed control tool, but the problem can be greatly simplified if the objectives are clearly established. The most important decision, which will help set a firm goat management policy on the farm, is whether goats will be run:

(a) for production only (i.e. fibre, meat, milk, semen, embryos, or live breeding animals), with no expected weed control;
(b) primarily for production, but also for weed control;
(c) primarily for weed control, but also for production;
(d) for weed control only, with no expected production.

In Case (a), the farm will have to rely on other weed control methods, because decisions should always favour production. This is a rather extreme case, but some goat stud managers do follow this policy in New Zealand. It is an understandable decision, since the animals have a relatively high value and these farms usually do not have classes such as wethers to use for harder weed control work (dairy goat farms are a similar example). Nevertheless, goats will still provide some weed control and pasture improvement in such cases.

In Case (b), goats are expected to provide weed control and, at times, they will be managed specifically for that purpose, provided it will not compromise production targets, in which case, other weed control methods will be used.

In Case (c), goats are an important weed control method and may even be the only method used on the farm. Though goats are in the system specifically for weed control, production is also expected (i.e. they must also generate revenue). In cases such as this, it is important to choose an appropriate type of goat. For example, the Angora breed is specialised in producing mohair. This fibre is easily contaminated with plant material, particularly from tall vegetation and when the fleece is long (Batten, 1984; Yerex, 1986). As lower prices are paid for contaminated fibre, this problem will limit their use for the control of some weeds at certain times of the year, if revenue is not to be compromised. Additionally, Angora goats can become tangled in dense blackberry bushes and even die if not helped (Yerex, 1986).

This situation changes in Case (d), where production will be regarded as an added bonus. Goats will be managed for the purpose of controlling weeds and goat production losses will be accepted, if they become necessary. This policy provides the greatest management flexibility for using goats as a weed control tool, but those adopting it should realise that there are limits as to how far goats can be pushed with the aim of controlling weeds. This will be briefly discussed in the next section.

Additionally, it is important to define what level of weed control will be sought, especially whether the aim is to:

(a) keep weed cover from increasing;
(b) reduce weed cover and maintain it below a defined level;
(c) avoid seeding;
(d) eliminate a species from the above ground vegetation;
(e) promote a more competitive pasture to prevent new recruitment and establishment;
(f) achieve a combination of two or more of the options above;
(g) eradicate a species from the property.

Most farmers would probably aim for Option (f) is likely to be the best option in most cases, though depending on local conditions, others may be justified in isolation. If annual/biennial weeds are the main concern, for instance, (f) should be a combination of (c) and (e), though it could also include (a) or (b). Option (b) will certainly be chosen in any situation where a significant proportion of the area is occupied by a weed, regardless of the species. Option (d) will often not be justified as such on biological or economic grounds, though in some cases, legal or cosmetic reasons may dictate its adoption. It appears that goats will lead to (e), whether they are managed for that purpose or not (Chapter 5). Alternative (g) may be very difficult or even impossible to achieve, particularly if the species has a persistent soil seed bank and/or new propagules are allowed to enter the property (eradication is unlikely to be justified economically in most cases). If goats were found to be the best option for the eradication of a given weed species, but also to cause detrimental effects to the system, then the option of eradication would seem justifiable (i.e. once goats had provided the eradication, they could be removed from the farm). However, it appears that goat grazing will seldom be the most effective way of eradicating a species and, as seen in this study so far, their permanent presence in the system is beneficial, not detrimental (further considerations are made in Sections 7.2.3.2). Nevertheless, for a system containing goats, eradication is a real possibility for some weed species in the long term, even if it is unintentional (see Section 7.2.1.1).

Batten (1984) postulated two alternative approaches to scrub weed control by goats:

(a) "fighting the weeds" and

(b) "farming the weeds".

In "fighting the weeds" he stated that the aim is to use goats to "get rid of most plants" (note that this author was concerned with scrub weeds, as pointed out in Section 7.2.2.1). For this to be achieved, the author recommended at least 6 g.e./ha weed cover and pointed out that the maximum stocking rate should be about 16 g.e./ha weed cover. The former stocking rate was said to be enough to keep scrub weed cover from increasing, but not to reduce it (see discussion on current limitations of weed cover in Section 7.2.2.1). This alternative reflects the usual view to weed control, where the aim is to reduce weed cover or even eliminate the weeds from above the ground, i.e. (b) or (d) of the earlier set of control options (p.169).

Conversely, for "farming the weeds" Batten (1984, p.2) argues that:

- "it requires a different philosophy of plant and farm management;
- the farmer has to accept that the weeds are a source of feed to farm goats;
- providing weeds are not getting worse in size or density, they are not a problem."

This proposition has received very little attention in research (Radcliffe, 1986), as most studies of weed control by goats have not considered the implications of having them permanently integrated in the system (Chapter 1).

From the nutritional point of view, a pasture should ideally be composed of highly productive species that yield herbage of high nutritional quality in a way that best matches the seasonal fluctuations of feed demand (Chapter 1; Section 7.2.1.1). If a weed species that is well accepted and consumed by goats were found to be superior to grasses and legumes with regard to the above qualities, then it would seem appropriate to manage goats so to maintain the species in the system (i.e. "farm the weeds"). However, grasses and legumes that are found in pastures have developed a tolerance strategy to grazing through mechanisms that increase plant growth following defoliation. In contrast, most pasture weeds rely on an avoidance strategy with mechanisms that reduce the palatability and intensity of grazing (Briske, 1996). In general, plants that invest energy to produce chemical or physical deterrents to herbivory (e.g. secondary compounds, spines, hairs, etc.) are less productive than those that do not (Begon *et al.*, 1996). This stresses the need to quantify above ground biomass production and regrowth capacity of herbaceous weeds, as argued in Section 7.2.2.1 (p.156).

Hypothetically, the presence of some herbaceous weed species in the system could improve soil nutrient cycling. For example, tap rooted plants, in general, are able to explore deeper layers of the soil (Tilman, 1988), which allows them to intercept and absorb nutrients that have been leached (McLaren and Cameron, 1996) and are not accessible to grasses, because of their shallower root systems (Tilman, 1988). By eating such plants, goats would be helping improve the fertility of pasture, if some of those previously leached nutrients were spread through their urine and faeces, thus becoming available to grasses and legumes. Eliminating such plants would interrupt this cycle.

For more details on the role of grazing animals in nutrient cycling, see McLaren and Cameron (1996) and Begon *et al.* (1996).

7.2.3.2. Limitations of goats and potential drawbacks

As pointed out by Batten (1984), "goats are not bulldozers." The reason for stressing such an obvious fact is that the biological needs and limitations of goats are often overlooked, i.e. as if they were machines. However, this view needs to change if goats are to be integrated permanently and profitably into grazing systems, even if they are run purely as a weed control tool, with no expected production.

Equipment needs adequate maintenance to perform work efficiently and to last longer. As a weed control tool, goats should be treated in a similar way. Farm motorbikes, tractors, mowers, sprayers etc. need cleaning, lubrication, replacement parts, adjustments, and so on. Similarly, goats need adequate feed (Morand-Fehr, 1981; McCall and Lambert, 1987), water (AFRC, 1998), control of parasites (Smith and Sherman, 1994), foot care (Thompson, 1987a; 1988b), etc. Failure to provide basic maintenance needs such as these increases their chances of having health problems (Smith and Sherman, 1994), which, in turn, increases the costs of running them (Yerex, 1986).

Goats thrive in areas of the world where other livestock have difficulties in surviving (Garcia and Gall, 1981). This is because of their powerful feeding capabilities (Gall, 1981) that allow them to select flowers from within leafless, spiny shrubs, to dig the soil, climb cliffs and even trees in search for food, where necessary (Section 2.3). This feeding behaviour has led people to assume that they can withstand unfavourable conditions (e.g. lack of good quality feed and water, extreme temperatures, wet soil, etc.) with little or no detrimental effects to them. However, this assumption is not correct. Underfed goats, for instance, are much more susceptible to internal parasites

(Thompson, 1989b) and low temperatures (Shelton, 1981). Wet soils are not only uncomfortable to them (Table 5.7, p.111), but are also conducive to feet problems (discussed at the end of this section). Farmers who use goats for weed control without expecting any revenue from them are potentially more likely to neglect the basic needs of goats because they are primarily interested in the work done by the animals without necessarily monitoring their physical performance or well being. Lack of experience with goats, assumptions that they can be managed just like sheep, poor management, and neglect seem to be the most common causes of their health, behavioural, and performance problems.

The issues that follow have been mentioned as reasons for not integrating goats with other livestock for weed control (K. Betteridge, 1997, personal communication). These were pointed out in Section 2.4.3, but are now discussed in more detail and in light of some observations made during this study.

"Goats share the same worms as sheep"

Goats are infected by the same gastrointestinal worm species as sheep (Smith and Sherman, 1994), thus they cannot be used to "clean up" pastures (i.e. eat and destroy infective worm larvae) for sheep or vice-versa, while cattle can (Thompson, 1987b). However, this is not an impediment to the integration of goats with sheep. It just means that, as far as grazing management for minimising worm burdens is concerned, adding goats to a system that contains sheep is the same as adding more sheep to it.

While the resistance developed by adult goats to gastrointestinal worms is generally not as strong as in adult sheep (Thompson, 1987b), the grazing behaviour of goats seems to help them minimise the ingestion of infective larvae. In the present study, goats grazed above 10 cm when given the opportunity (Experiment 1, Section 3.3.5) and were reluctant to graze below that when forced to (Experiment 3, Section 5.3.6). Since infective worm larvae seldom climb more than 4-5 cm above ground level (Thompson, 1988a), infection can be greatly reduced by not forcing goats to graze down to this height. This is a good reason for running goats as leaders whenever possible (Section 7.2.2.3, p.163), as this will allow maximum choice of bites at greater heights. However, though this decision will normally be dictated by the weed and sward control requirements (for a detailed discussion of grazing management, see Sections 7.2.2.1 to 7.2.2.3).

Resistance to anthelmintic drugs ("drench resistance") is a very serious problem affecting the sheep and goat industries (Pomroy *et al.*, 1992; Smith and Sherman, 1994). Other alternatives to worm control are pasture management (Thompson, 1987b) and breeding. Breeding resistant goats is possible because their resistance to parasites is partly inheritable (this is termed "genetic resistance to parasites" or simply "parasite resistance") (Lloyd, 1994; Ruvuna and Taylor, 1994). However, this method does not seem to have received the attention it merits. There are indications that parasite resistance in cattle is negatively correlated with production traits (i.e. it may not be possible to obtain an animal that is resistant to parasites and highly productive at the same time), though some studies show little or no correlation (Ruvuna and Taylor, 1994). If such a correlation holds true for goats, this line of breeding would be a drawback for commercial goat farming. However, it should not represent a barrier for goats that are to be run primarily or solely as a weed control tool (i.e. alternatives "c" and "d" in Section 7.2.3.1, p.167). This is discussed further in Section 7.3.3.

<u>"Goats are difficult to confine within paddocks"</u>

In their original habitat, goats are cliff dwellers, capable of jumping and climbing with great dexterity in search for food or escaping from predators (Schaller, 1977). For domestic goats, these capabilities are not vital for their survival on most farms, but when the need arises they know how to use them. However, there is a marked difference in this regard between feral goats and farmed goats with distant or no feral origin. Feral goats are domestic goats of various breeds that escaped from farms to areas such as national parks and cross-bred freely (DOC, 1998). They are not wild goats (Schaller, 1977), but because of the environment (normally vast hilly areas of forest and grasslands), risk of being hunted, and lack of contact with humans (except hunters), they had to adopt a wild behaviour in order to survive. Feral goats formed the basis of the New Zealand and Australian goat industries. They were caught and mated to "feral" bucks for cashmere production, crossed with Angora for "cashgora" production, or upgraded to Angora or milk breeds for mohair or milk production, respectively (Yerex, 1986). More recently they also served as a basis for the Boer breed expansion in New Zealand (Sutherland and Fordham, 2001).

In general, farmers have no problems confining pure-bred goats or cross-bred goats with distant feral origin (i.e. after three or more generations). The troublesome animals are mainly the feral goats themselves (though not all of them), which are not used to being confined by fences and need to be taught to respect them when brought to farms. However, some goats do not learn it and need to be culled so that others will not follow their habit. This seems to be an effective way of obtaining a flock that respects fences at all times (Yerex, 1986). Additionally, fences and yards can be upgraded to become "goat proof" or they can be built to specifications such as the ones designed by the New Zealand Ministry of Agriculture and Fisheries (information on this has been compiled by Yerex, 1986).

In Experiment 3 (Chapter 5), goats were confined on small plots at high stocking density (Section 5.2.1), and despite this being a rather extreme situation, they respected the fences at all times (Section 5.3.6). Similarly, farmers who were contacted during the present study (Section 7.2.1.1, p.139) did not have problems containing goats within paddocks.

However, due to the impact of feral goats on native vegetation and the costs of controlling them, it is imperative that farmers follow the fencing and culling recommendations mentioned above (DOC, 1998).

"Goats can damage trees"

There is a popular saying in New Zealand that "goats and trees don't mix" (Anonymous, 1996) and this is because they can cause serious damage to trees by debarking them (Rolston *et al.*, 1983). However, not all trees are debarked by goats. Young radiata pines (*Pinus radiata*), for instance, are particularly vulnerable (Rolston *et al.*, 1983), especially before their third year (Anonymous, 1996), but older pine trees are not debarked (Rolston *et al.*, 1983; Anonymous, 1996; K. Thompson, 1998, personal communication).

Anonymous (1996) reported the experience of a New Zealand farmer (K. Holt, Napier) who has been using goats for weed control in his forestry system for over 50 years and claims that goats can be run under trees, provided they are not forced to eat any weeds, are grazed under mature trees first, monitored daily, and shifted to a new block/paddock before they run out of feed.

Forestry systems grazed by goats have their weed control costs significantly reduced (Perera, 1995; Anonymous, 1996) as well as decreased fire risk due to the removal of undergrowth and dead material (Perera, 1995), including pine needles (Anonymous, 1996; Section 3.3.6, p.44).

In New Zealand sheep and cattle systems, goats will not have access to trees on most farms. However, where shelter or conservation trees are present and accessible, care must be taken. The suggestions outlined above should be equally applicable in such cases.

"Goats have serious foot problems"

This refers specifically to footscald and footrot, which are bacterial infections of the skin between the digits and the horn of the hoof, respectively. Both diseases also occur in sheep and the bacteria involved in each disease appear to be the same for both animal species (Thompson, 1987a).

According to Thompson (1987a), factors that make animals more prone to these infections are:

- a warm and wet environment
- muddy yards and poorly drained pasture
- high stock density
- overgrown hooves
- poor hoof conformation

Both diseases can be greatly reduced by addressing the problems listed above and by treating animals in a footbath, typically containing 10% zinc sulphate (Smith and Sherman, 1994). Unlike footscald, footrot can be eradicated from the farm, because the bacteria that cause it do not persist in the environment for more than 2-3 weeks (Thompson, 1989a).

Breeding can also play an important part in minimising these problems. An ongoing study commissioned by Meat New Zealand and WoolPro is attempting to obtain a pool of Angora bucks that are less prone to these infections. A report containing preliminary results recommends the following as key criteria for good feet (Woodward, 2000):

- good air gap between the digits, from the front to the back of the hoof

- no membrane at the rear, as this may result in compacted soil and faecal material being retained between the digits
- natural removal of hoof nail without the need for artificial trimming.

In the same report it was also recommended that animals that require trimming should be culled. This is particularly important for breeding animals, so that the traits that make them susceptible are not passed on.

The goats which were used in Experiments 3 and 4 of the present study had a variety of foot conformations. Footrot was not present, but some animals were affected by footscald, particularly in wet periods, and had to be treated in footbaths. Observations corroborate the report mentioned above in that animals which had a considerable gap between the digits were never seen with scald or limping for any reason. Interestingly, the hoof walls of these animals seemed either to grow much slower than others or to wear out more easily, as they required no trimming.

In summary, none of the issues discussed above (namely worms, fencing, trees, and foot problems) are prohibitive to the integration of goats with other livestock for weed control, particularly with cattle. Many New Zealand goat farmers have no problems with containment of goats, debarking of trees, feet infections (particularly footrot), and even with worm burdens, which is an indication that all of these problems can be conquered. Worms are a greater challenge, but they are only a serious problem in intensive goat systems, particularly due to their high goat stocking rates and lack of sufficient cattle, which are used for destroying their infective larvae and forming a "safe pasture" (Thompson, 1987b). Frequent drenching and drench resistance are also much more common in specialised, intensive goat farming systems (Scherrer *et al.*, 1990). As a permanent weed control tool, goats would be integrated with sheep and/or cattle at relatively low stocking rates compared to specialised goat farms, which should greatly reduce the problems above.

Note that goats are little affected by fly-strike (Yerex, 1986; Thompson, 1988c) and facial eczema (Thompson, 1987c), which are serious problems in sheep and in sheep and cattle, respectively.

7.3. QUESTIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Although many of the following point have already been briefly mentioned earlier, suggestions for future research will now be discussed together.

7.3.1. Feeding behaviour of goats

7.3.1.1. Foraging theory

The most widely accepted explanation for foraging decisions made by animals is the optimum foraging theory (OFT), especially after the work carried out by MacArthur and Pianka (1966). As argued by Laca and Demment (1996), OFT is in fact a body of hypotheses based on the axiom that animals that forage more efficiently have greater productive output (fitness), thus present-day animals forage optimally as a result of natural selection.

The theory predicts that the choices made by animals are those that allow them to obtain the maximum of a given "currency" (e.g. net energy intake). Thus, researchers have been measuring optimality by choosing a currency and checking the importance and consistency of the search for it in face of an array of constraints affecting animal choices (Krebs and McCleery, 1984).

Assuming OFT is valid for explaining the feeding behaviour of goats in the present study, it is difficult to think of a currency that they attempted to optimise, given the fact that they selected a wide range of plant organs and species within a relatively short span of time, including organs of contrasting physiological stages. If goats were trying to maximise net energy intake, for instance, why would they compete for, and even fight over, a dead thistle plant when they had plenty of other options around with much better digestibility that could be selected without the need to compete for them? When they entered a new paddock, why did they give preference to seed-heads and only moved on to grass leaves after these were no longer available or had been fully explored? Grass seed-heads have lower energy value than green grass leaves (Thompson and Poppi, 1990).

Why spend time and energy (a) clearing the pasture with their horns and feet in order to have access to a thistle rosette or (b) conditioning a flowering thistle plant by rubbing their horns up and down in order to break the buds and make them easier to be removed while plenty of other options were available without physical restrictions? Why select a seed-head and walk several metres, going past plentiful and highly digestible pasture, in order to select another seed-head of the same species? Why select dead and dry pine needles from the ground while they could be selecting something much more digestible? All these observations make it difficult to accept that the foraging decisions of goats can be explained simply by an attempt to maximise net energy intake.

It is common to hear from farmers that "goats like variety." Could goats be interested in maximising the variety of their diet? In this study goats did select a varied diet, but they did not seem to be interested in selecting a varied diet *per se*. This is clearly illustrated by the fact that they often moved to a different feeding patch in order to select the same organ and species that they were eating before. They seemed to be interested in a specific target for some time and they pursued it consistently, patch after patch, until they eventually changed to a different target (see Section 3.3.6). This does not seem an attempt to maximise variety.

So, what do they base their feeding decisions on? What, if anything, do they try to maximise? If these could be determined, prediction of the impact of goats on vegetation would be easier, more quantitative and probably more accurate.

7.3.1.2. Consumption of bark

This has not been an issue in this study because trees were not accessible to goats, which is the typical case on most New Zealand farms (i.e. they are usually fenced off or protected individually against livestock). However, on some farms goats will have access to trees. Thus, if the mechanism that explains why they eat the bark of certain trees at certain times of the year becomes known, it might be possible to prevent the damage altogether, including, perhaps, to young pine trees, which are said to be very susceptible (see Section 7.2.3.2, p.176).

If the mechanism is nutritional, for instance, it might be possible to make the element(s) that they look for in the bark available in some other form so they do not need to debark trees. One of the farmers contacted during this study (Section 7.2.1.1, p.139) reported that her goats stopped debarking trees once she started making black tea (*Camellia sinensis*) available to them *ad libitum* (she collects used tea bags, pours hot water in a bucket with the bags, and offers this to the goats after it cools down). This is not a very practical alternative, especially if there are many goats on the property or if they are far from the house. However, if the access to tea does indeed reduce or eliminate (as it was claimed) the debarking of trees, then it is likely to be related to chemicals found in the tea. Could these be its polyphenols, which are chemically similar to tannins (Duke, 1992)? If so, why would goats look for tannins, since these are considered feeding deterrents (Provenza *et al.*, 1990)? Condensed tannins have been shown to have a negative impact on gastrointestinal worm larvae activities and it has been suggested that plants containing condensed tannins might have a role in ruminant diets as a means to reduce dependence upon proprietary anthelmintics (Molan *et al.*, 2000). Could goats look for tannins to inhibit worm activities? Would access to plants like broad-leaved dock, which is rich in condensed tannins (Waghorn and Jones, 1989), also prevent debarking?

7.3.1.3. Experience with weeds

As discussed in Section 7.2.1.5, early experience in life plays an important part in determining dietary preferences in goats. Thus, it might be possible to improve the efficacy of goats as a weed control tool by interfering in the learning process and introducing kids to target weeds in a more intensive way than generally occurs out in the field (i.e. to train them to eat weeds). This could be done by cutting weeds and offering them to goats in a pen, for instance. It might be more effective if the cuttings were offered in tight bunches, hanging from a fence post at about their chest height. This has been tried with the same animals that were used in Experiments 3 and 4 (though not kids) and they did show more interest in hanging cuttings than in those lying on the ground.

If the mothers are known to eat the weed species in question, it would be advisable to have them with the kids, as it has been shown that grazing animals do learn about diet from their mothers (Provenza, 1995); otherwise, they must be separated so that the mothers do not interfere with the process. However, care should be exercised if poisonous weeds are involved, as kids will not have an experienced mother from which to learn (Thorhallsdottir, 1990; Provenza, 1995).

If kids do learn to eat weeds in such a way, will they look for the same species out in the field? Would their interest for weeds be greater than in goats that were not trained?

Would this training result in greater weed intake (relative to grass leaves), thus minimising competition with other stock?

7.3.2. Dry matter production and feeding value of pasture weeds

This issue has been discussed in depth in Section 7.2.2.1. In summary, for minimising competition with other livestock and maximising weed control efficacy, it was argued that goat stocking rate should be based on the above ground weed biomass accumulation (kg DM/ha) and that this is unknown for herbaceous weeds occurring in New Zealand pastures. In addition, it was suggested that their chemical composition should also be quantified to determine feeding value and the possible role of some weeds in nutrient cycling (Section 7.2.3.1, p.171). The above factors should ideally be determined on a seasonal basis (see Sections 7.2.2.1 and 7.2.3.1 for more details).

7.3.3. Breeding goats for weed control

Current goat breeds have been selected to produce quality meat, fibre, or milk, efficiently. However, quantity and quality of their products are not so important where the primary or only purpose for the goats is weed control (see definition of objectives in Section 7.2.3.1).

As pointed out in Section 7.2.3.2, traits such as worm (p.174) and footrot (p.177) resistance have had low priority in goat breeding or have been traded off against traits that affect production and quality more directly. However, farmers who want goats solely for weed control would benefit if there was a breed selected specifically to operate as a weed control tool. In general, this animal should:

(a) be hardy and have low maintenance requirements;

(b) have minimal interest in grass and legume leaves (especially green ones) when weeds and grass seed-heads are available;

(c) respect fences;

(d) not debark trees.

Attributes (b), (c), and (d) are likely to be greatly affected by the environment and little by genotype, like most behavioural traits (Ricordeau, 1981; Blair, 1982). Thus, improvements in those areas are likely to be achieved primarily through management (Section 7.2.3.2), instead of breeding. Nevertheless, differences in grazing behaviour between Angora and the Spanish (meat) goat have been detected and attributed to their long versus short hairs, respectively (Merrill and Taylor, 1981). Ideally, for general weed control, goats should not have long hairs (see the reasons in Section 7.2.3.1, p.168). Note that attribute (b) was expressed by goats in the present study (Chapter 3), though it seems that it can be enhanced through management (Section 7.3.1.3).

Traits that determine hardiness and low maintenance requirements are transmittable genetically (Ricordeau, 1981), thus, out of the four points above, (a) is the one which offers the greatest scope for selection. The ideal goat selected for weed control should need as little attention as possible (e.g. no drenching and no foot treatment), which would make management much easier and reduce their running costs even further, i.e. the net benefits (Section 7.2.1.4) would be greater. Additionally, if they required no anthelmintic drugs, they could be immediately incorporated into organic farming systems (goats are probably the best weed control option for organic systems, provided the drenching issue is addressed).

It could be argued that feral goats already offer a lot of what is being suggested. However, feral goats have no breed; instead, they are a mixture of several breeds with various sizes, coat characteristics, foot architectures, degrees of disease resistance, etc.

(Section 7.2.3.2, p.175). While some individuals do present traits linked to the desirable attributes mentioned earlier, others do not (Yerex, 1986). So, even if a uniform group of individuals with only desirable phenotypic traits were picked from a feral mob, they would still produce offspring with a range of characteristics because of their genotype.

While feral goats are a serious problem outside farm land (Section 7.2.3.2), it should be noted that, on the other hand, they are probably the richest pool of domestic goat genes in the world, especially for traits linked to hardiness. Thus, they are an ideal source of genetic material for a hardy, weed-control-specialist breed. Unfortunately, hunters have to shoot the leader first, i.e. the dominant goat, in order to make the whole mob stop and become easier to be shot at or caught (DOC, 1998). Thus, the animal that is most unlikely to escape hunting is, ironically, the strongest, hardiest, and fittest.

7.4. CONCLUSIONS

The present study has improved the understanding of feeding behaviour of goats in pastures containing no woody species. The overall conclusions are:

- Diet selection of herbaceous species was strongly influenced by seasonal variations in botanical composition and the physiological stage of plants. This should always be taken into account when considering patterns of selection or impact to vegetation caused by goats. With the exception of pennyroyal, goats selected all the species studied in this project, during at least one season of the year.
- Dietary choice did not necessarily reflect preference. The large amount of time spent on grasses, for instance, was largely explained by their dominant place in the vegetation cover. Unlike cattle, goats are anatomically equipped to prehend the exact component they aim for and in this study they made strong efforts to find the vegetation components they wanted.

However, if these were not found during a short walking search, they stopped, lowered their heads, and grazed what was available. Most of the time these were leaves of grass species.

- Contrary to popular belief, goats did eat thistle rosettes, provided these were sufficiently exposed. Thus, rejection was not related to any chemical or physical deterrent to grazing and it could be minimised through grazing management by using other stock to clear the pasture around the rosettes before introducing the goats to eat them. Under these conditions, the chances of any rosette not being grazed by goats were very low.
- Given the choice, goats took most bites at a height greater than 10 cm above ground level. However, claims that they "graze pasture from above" (i.e. "start from the top and work their way down") appear incorrect as the whole vegetation profile was explored. In fact goats explored the top of the vegetation in only 30% of the feeding patches, irrespectively of whether the organ they prehended was reproductive or not.
- Goats were strongly attracted to flower-heads in general and if managed properly they prevented seed formation altogether. However, if flower-heads do form, goats can still be used to minimise seed rain. On average, goats will destroy more than 90% of the viable seeds they ingest.
- Seeds that were not destroyed during digestion took up to 72 hours to be excreted.
- Replacing sheep by cattle, goats, or combinations of the two species under the same grazing management resulted in very similar increases in white clover contents of the pasture. Thus, the increase in white clover following the introduction of goats that is often reported may be largely attributed to the removal of sheep from the system, as opposed to the effect of goats *per se*.
- Compared to swards grazed by goats, cattle pastures were less uniform more open due to lower tiller density, more gaps in the canopy, and lower

leaf area index. These factors combined made pasture less competitive against weed invasions.

- These differences in sward structure were attributable mainly to the lower pressure exerted on the soil by goats combined with less body movement (walking, fighting, etc.) at times when soil is more vulnerable to disturbance (i.e. wet and with low herbage cover).
- If both cattle and goats were present in the same system, the greater the proportion of goats (i.e. the smaller the cattle:goat ratio), the more competitive the pasture and the greater its overall feeding quality. However, once the proportion of goats in a mixture with cattle rises above 50% of the total stock units, increasing the proportion of goats any further will probably not cause any further significant improvement in pasture competitiveness.
- Competition with other stock for herbage can be greatly minimised through grazing management, such as by means of a leader-follower rotational system, typically with goats as followers, but possibly also as temporary leaders when weed and/or grass flower-heads are abundant.
- Goat stocking rates should be based on weed growth (kg DM/ha/year) and feeding quality instead of total grazing area. However, no such information is yet available for herbaceous species occurring in New Zealand.
- The success of the integration of goats into grazing systems as a weed control tool depends as much on the farmers as it does on the goats themselves. Goats cannot simply be added to the system and forgotten. Knowledge of goat husbandry and grazing management is essential for more efficient and profitable weed control.
- Finally, some of the benefits offered by goats will only be realised where goats are used as a permanent component in a grazing system as opposed to a transient control measure.

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