MIXED GRAZING OF SHEEP AND CATTLE USING CONTINUOUS OR ROTATIONAL STOCKING

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by S.M. Kitessa

Two consecutive experiments were conducted to test a hypothesis that mixed grazing outcome is influenced by the type of stocking system applied. The objective of both experiments was to investigate the influence of co-grazing with sheep on cattle liveweight gain (LWG) under continuous (C) and rotational (R) stocking, where sheep weekly liveweight change under the two stocking systems was kept similar. In experiment I nine yearling heifers (266 ± 4.5 kg liveweight) and 27 ewe hoggets (54±0.9 kg liveweight) were continuously stocked for 19 weeks on an irrigated perennial ryegrass-white clover pasture (2.95 ha) maintained at a sward surface height (SSH) of 5 cm by adding or removing additional animals in a fixed ratio (1:1 $W^{0.75}$ cattle:sheep). An equal area of pasture was rotationally stocked by a similar group of animals where they received a new area of pasture daily and also had access to the grazed area over the previous 2 days. The size of the new area provided daily was such that the weekly liveweight change of rotationally co-grazed sheep was equal to that of those continuously co-grazed with cattle. Similar groups of animals were used in the second experiment with additional group of 9 heifers grazed alone on C and R pastures.

Liveweight of animals was recorded weekly and final fasted weight was determined after 24-hour total feed restriction. SSH on both treatment swards was recorded daily. There were three intake measurement periods spread over the trial period. Organic matter intake (OMI) was predicted from the ratio of N-alkanes in faeces and herbage. Diet composition was determined by dissecting oesophageal extrusa samples. Grazing behaviour (bite rates and grazing time) were also recorded.

The mean SSH for C pasture was 5.1±0.09 cm. Overall pre- and post-grazing SSH for R pasture was 15.9 ±0.12 and 5.6 ±0.07 cm, respectively. As determined by the protocol average daily LWG of sheep was similar between C and R (147 (±5.8) vs 138 (±6.7) g day^{-1}; (P>0.05). In contrast, cattle continuously stocked with sheep grew 200 g day^{-1} slower than those rotationally stocked with sheep (800 (±41.6) vs 1040 (±47.7) g day^{-1}, P<0.01). R heifers achieved 30 kg higher final fasted liveweight than C heifers (350 vs 381 kg; P<0.01). Overall LWG per ha was also 6 % higher under R than C stocking (674 vs 634 kg ha^{-1}). The OMD of both sheep (73.5 vs 75.8 %) and cattle (75.8 vs 78.0 %) diets was similar under continuous and rotational stocking.

There was no significant difference OMI data also concurred with the LWG data (Cattle: 7.94 vs 6.31 (±0.32) kg day^{-1} (P<0.05); sheep: 1.40 vs 1.44 (±0.04) kg day^{-1} for R and C treatments, respectively). There was no difference in clover content of cattle diet under C and R treatments. C heifers had higher number of bites per minute than R heifers (62 vs 56; P<0.05). Proportion of heifers seen grazing (every 15-minute) during four 24-hour observations was greater on C than R pasture (0.44 vs 0.31 (±0.03); P<0.05). The similarity coefficient between sheep and cattle diet was 0.61 and 0.76 under C and R stocking, respectively.

The lower daily LWG of C heifers was attributed to (a) the lower SSH under C than R stocking and/or (b) the inability of cattle to compete well with sheep where there is small, continual renewal of resources (C) in contrast to a large periodic renewal under R stocking. This experiment showed that the outcome of mixed grazing can be influenced by the stocking system chosen. But it was not possible to apportion the difference in LWG of cattle between mixed grazing *per se* and the difference in mean grazed sward height (5.1 for C vs 10.8 cm for R).

A second experiment was conducted to determine the relative performance of cattle co-grazed with sheep (CS) and grazed alone (CA) under each stocking system. Hence, there were four treatments. CA- continuous stocking (CA-C), CS- continuous stocking (CS-C), CA- rotational stocking (CA-R) and CS- rotational stocking (CS-R). A total area of 4.42 ha was allocated to each stocking system. Under C stocking, 2.95 ha (2/3) was assigned to CS-C and 1.47 ha (1/3) to CA-C, and SSH on both treatments was kept at 4 cm by adding or removing extra animals. Under R stocking, CA-R and CS-R grazed side by side separated by an electric fence. They were given a fresh area daily, the size of which was varied such that the weekly LW change of R sheep was equal to that of the C sheep. CA-R received one-third of the new area though the size was adjusted regularly to achieve the same post-grazing SSH with CS-R. Measurements included: weekly liveweight change, OMI (two periods) and diet composition (using N-alkanes).

The mean SSH of CA-C and CS-C swards was 4.27 and 4.26 (±0.02) cm, respectively. CA-R and CS-R swards had mean pre-grazing SSH of 14.9 and 15.2 (±0.08) cm and post-grazing heights of 4.87 and 4.82 cm (±0.03), respectively. The proportion of areas infrequently grazed was higher for CA-C than CS-C swards (0.30 vs 0.05, P<0.01), but did not differ between CA-R and CS-R swards (0.22 vs 0.17, respectively).

C and R sheep daily LWG: 155 (±0.6) and 147 (±0.7) g, and OMI: 1.96 and 2.04 (±0.11) kg, respectively, were not significantly different. They also had similar diet composition. In comparison, CS-C heifers grew only at 69 % of the daily LWG achieved by CS-R heifers (706 vs 1028 (±72) g; P<0.05). LWG of CA-C and CA-R was 916 and 1022 (±72) g day^{-1}, respectively. The difference in LWG between CS-R and CS-C (D_1) heifers was due to difference in mean sward

height, stocking system and mixed grazing, while D_2 (difference in LWG between CA-R and CA-C) was due to difference in mean sward height and stocking system. D_1-D_2 (the effect of stocking system on mixed grazing) was 216 g and made up 67 % of the total difference between CS-R and CS-C. There was a significant stocking system-species mixture interaction in the final fasted LW achieved by heifers. Final fasted LW was significantly lower for CS-C than CA-C heifers (283 vs 323 (±9.7) kg), but did not differ between CS-R and CA-R (332 vs 330 (±9.7) kg, respectively). The digestibility of diet OM was similar for both continuously and rotationally stocked sheep (84.4 vs 83.2 %, respectively). Cattle diet OMD was 76.5, 74.7, 79.4 and 77.8 for CA-C, CS-C, CA-R and CS-R respectively (P>0.05). Differences in OMI followed a similar pattern to daily LWG. Mean daily OMI was 8.98, 6.24, 8.80 and 9.45 (±0.40) kg for CA-C, CS-C, CA-R and CS-R, respectively. Clover content of the diet of CA-C heifers was three times higher than that of CS-C heifers (30.7 vs 10.4 % OM; P<0.05); there was no difference in clover content of diets of CS-R and CA-R heifers (21.5 vs 23.9 % OM, respectively). In both stocking systems LWG per ha was higher on CA than CS treatments.

These results suggested that the disadvantage of selective clover grazing by sheep outweighed the advantages of sheep grazing around cattle dung patches under continuous stocking. Under rotational stocking, rapid diurnal changes in sward conditions probably limited selective grazing by both sheep and cattle such that there was no disadvantage to CS cattle. The results do not provide a basis for recommending grazing cattle with sheep rather than cattle alone, but do provide some basis for recommending co-grazing of sheep and cattle using rotational rather than continuous stocking.

Key words: *Cattle, continuous stocking, diet composition, frequently grazed areas, grazing behaviour, infrequently grazed areas, intake, liveweight gain, mixed grazing, N-alkanes, perennial ryegrass, rotational stocking, sheep, stocking system, sward surface height and white clover.*

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ANOVA: Analysis of variance.
AFRC: Agriculture and Food Research Council.
BW: Body weight.
CA: Cattle alone.
CA-C: Cattle alone, continuously stocked.
CA-R: Cattle alone, rotationally stocked.
C.I. : Confidence interval.
C:S: Cattle:sheep ratio.
CL: Clover.
CS: Cattle-sheep mixture.
CS-C: Cattle-sheep, continuously stocked.
CS-R: Cattle-sheep, rotationally stocked.
CV: Coefficient of variation.
d: day.
DDMI: Digestible dry matter intake.
DH: Dead herbage.
DLWG: Daily liveweight gain.
DM: Dry matter.
DMI: Dry matter intake.
DOMI: Digestible organic matter intake.
Expt.: Experiment.
GC: Gas chromatography.
GL: Grass leaf.
GLC: Gas-liquid chromatography.
GS: Grass stem.
GSH: Grass seedhead.
hd: Head.
HFRO: Hill Farming Research Organisation.
LAI: Leaf area index.
LSD: Least significant difference.
LW: Liveweight.
LWG: Liveweight gain.
MLP: Maximum likelihood programme.
OE: Oesophageal extrusa.
OF: Oesophageally fistulated.
OM: Organic matter.
OMD: Organic matter digestibility.
OMI: Organic matter intake.
PM: Pasture mass.
PVI: Pasture value index.
RHM: Residual herbage mass.
s.d.: Standard deviation.
s.e.d.: Standard error of difference.
s.e.m.: Standard error of the mean.
s.e.p.: Standard error of prediction.
SSH: Sward surface height.
vs: Versus.

CHAPTER 1

1. Introduction

Broadly speaking, any pasture or grassland is grazed by more than one herbivore species at any one time (Wright & Connolly, 1995). However, mixed grazing commonly refers to the practice of simultaneous (co-grazing) or sequential (leader-follower) grazing of more than one domestic animal species, or more than one class of the same domestic species on the same pasture/grassland. The latter, co-grazing of different classes of the same species, is mainly a contrast of difference in size and/or physiological drive. In contrast, mixed species grazing involves a more complex pasture/animal interaction of species which have evolved different grazing strategies and may consequently occupy different ecological niches. In this thesis, unless stated otherwise, mixed grazing refers to mixed animal species grazing.

Mixed grazing has been and is a feature of many agricultural systems where communal ownership of pasture and grasslands, lack of technical expertise, financial incentives, or a combination of these and other factors has excluded livestock enterprises specialised in one product. Even in specialised systems, it is unlikely that the grazing practised is purely mono-species grazing where more than one enterprise is run on the same property. For instance, in New Zealand more than 80 % of beef is produced from farms which also run sheep, deer or all the three species, and therefore mixed grazing may occur more commonly than indicated in published literature. Recently, however, some more biological (Nolan & Connolly, 1977, Collins, 1989), social and ecological (Nolan & Connolly, 1992) arguments have been suggested for using mixed grazing. These have resurrected interest in mixed grazing in countries with well developed beef, sheep, deer and goat production systems. Consequently, there have been conferences (Nolan & Connolly, 1980) and workshops (Baker & Jones, 1985) devoted solely to this topic. It has also been a component of other conferences such as the IVth International Symposium on the Nutrition of Herbivores (Wright & Connolly, 1995). This study explores one of the biological grounds for mixed grazing

Various biological advantages have been claimed for mixed grazing, but the main ones are: (i) reduction in gastro-intestinal parasite burden of companion species, (ii) better matching of seasonal pasture supply and demand over mono-species grazing (e.g. selling finished steers to free pasture for autumn flushing of ewes), (iii) predation control (e.g.

bonding sheep to cattle to offset sheep losses from coyote predation (Hulet *et al.*, 1987), and (iv) increased animal performance and improved overall resource capture arising from complementarity between the grazing behaviour of the species involved (Nolan & Connolly, 1977, 1989; Collins, 1989). The last of these claimed advantages is considered for further investigation in this thesis, because the use of pasture resources by more than one species (as opposed to mono-grazing) has not always led to improved animal output per unit area. The following review explores some of the factors that have led to equivocal reports in the literature.

CHAPTER 2: LITERATURE REVIEW

This review is organised into two sections covering: (1) scenarios which provide an opportunity for complementary use of pasture resource by co-grazing species and (2) an appraisal of mixed grazing results and factors responsible for variable mixed grazing results in the literature.

2.1. Complementary resource use by ruminants

Each ruminant species has evolved a grazing strategy which defines the way in which it derives its nutrient intake from a given pasture. This involves identifying a landscape, plant community, choice of a patch within a community and a degree of selectivity within the patch. In relation to mixed grazing and complementary use of a pasture resource, it is difference among ruminants in patch selection and degree of selectivity within a patch that is of particular interest. Recent studies tend to suggest that the driving variable for both manipulation of intake rate with decreasing availability (Illius and Gordon, 1987; Gordon *et al.*, 1996) and degree of selectivity (Gordon & Illius, 1988) in ruminants is the incisor arcade breadth. These studies have shown that animals with small incisor arcade breadth have greater capacity both in adjusting intake rate to declining availability and selection in fine-grained mixtures.

Species are considered to complement each other when each performs its preferences with some beneficial effect on its companion species, and the performance of at least one of the species increases without any significant consequence to the performance of its companion species. A decrease in the performance of one or both species under mixed grazing relative to mono-grazing is an indication of competition in resource use.

Although estimates vary, it is claimed that co-grazed sheep and cattle may produce the same output per unit area on 10-20 % less pasture resource than that required if each species grazed alone (Nolan & Connolly, 1977, 1989; Collins, 1989). This has been attributed to increased efficiency of utilisation of the pasture resource arising from complementary use of resources. How do species complement one another? There are two possible scenarios:

(1). They may differ in the patches of pasture and pasture horizons they select to graze- *spatial complementarity* and/or,

(2). They may differ in the botanical components (species and/or plant part) they select within a patch or horizon- *botanical complementarity*.

These categories are not very distinct, as the choice of a patch or a horizon is related to the components that constitute it. The aim here is to illustrate possibilities for complementary and competitive resource use. These two scenarios and the likely mixed grazing response are schematically presented in Fig. 2.1. This model implicitly assumes that: (1) species do not compete for a space (patch or horizon) unless their diets overlap, i.e. no spatial competition without competition for botanical components, and (2) species that complement each other in space also complement each other in their choice of botanical components, but there may be botanical complementarity without spatial complementarity (Fig. 2.1).

A negative response refers to a situation where output per unit area from mixed grazing is less than the combined output from each species grazing an equivalent area on their own; the converse is true for a positive response. As shown in Fig. 2.1, a negative response to mixed grazing occurs in situations where two animal species compete for the same diet as well as space, while situations where animals exhibit complementarity in botanical, or botanical and spatial preference induce a positive response to mixed grazing. A positive response to mixed grazing can arise under competition from redistribution of resources in favour of one of the species, such as grazing one ahead of the other. This is less relevant to the study under consideration, which explores improved utilisation through complementary interaction between co-grazing species. Perhaps the most important point in this scheme is that a particular animal species combination can result in a positive, a negative or no response to mixed grazing depending on the level of pasture diversity and stocking density.

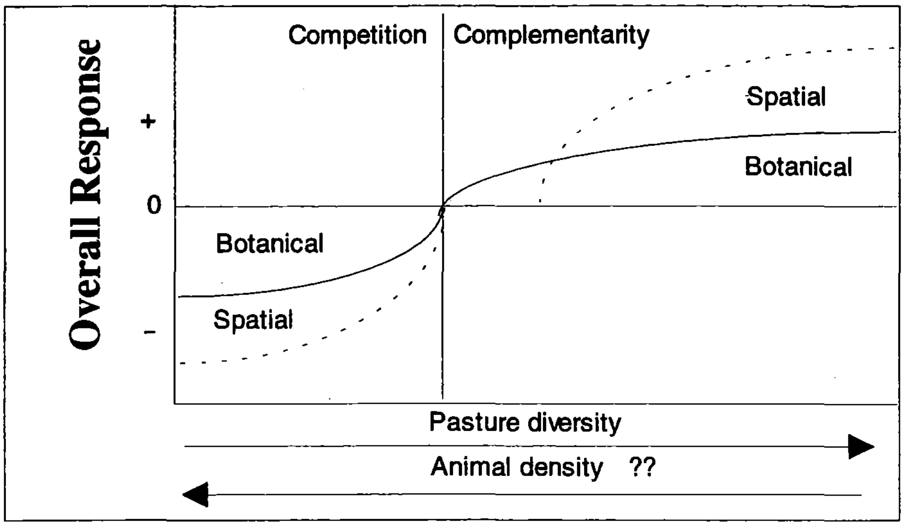

Fig. 2.1. A schematic view of competition, complementarity and overall response to mixed grazing.

Theoretically, sheep and goats co-grazing on gorse infested New Zealand hill country may fall on the far right of this scheme while the same species co-grazing on a fresh growth of a mono-culture sown pasture may fall on the far left. Experimental data are presented in later sections.

In general, most empirical data from mixed grazing studies support the above scheme that increased positive response to mixed grazing accrues with increase in pasture diversity (See also Wright & Connolly, 1995). However, there is one exception which appears to contradict it. Grant *et al.* (1985) reported an increase in dietary non-overlap (decrease in similarity index) between sheep and cattle with progressive depletion of the inter-tussock vegetation on *Nardus* tussock, because cattle increasingly shifted to grazing on *Nardus* leaf. However, one can argue that with further depletion of the inter-tussock vegetation the sheep would have also shifted to grazing on *Nardus* leaf (see Fig. 5 in Grant *et al.,* 1985) with a consequent increase in diet similarity index between sheep and cattle. Alternatively, one can argue that low dietary overlap can also arise through active competition where one species is 'winning' in for selecting quality material desired by both species. As shown in the above example cattle shifted to grazing on *Nardus* although both species preferably grazed inter-tussock vegetation at the beginning. Therefore, low dietary overlap may not always indicate lack of competition.

Regarding animal density, Nolan and Connolly (1989) reported that there was increasing benefit to mixed grazing over mono-species grazing with increase in stocking rate. They argued that the addition of an additional stock unit affects single-species grazing to a greater extent because under mixed grazing the effect is minimised due to the fact that for each species in the mixture, half of the extra stock unit is a species which is unlike itself. This may need to be re-considered in view of the fact that: (1) their conclusion may only be valid within the range of stocking rates considered in their experiment, (2) with increase in stocking rate the diversity of the pasture may be reduced with progressive depletion of some of the vegetation components, and (3) patchiness of swards generally decreases with increasing stocking rate and this may be deemed to minimise the opportunity for different patch choice by the co-grazing species. For instance, Greenhalgh and Reid (1969) estimated that the percent area classified as being rejected by dairy cows due to dung fouling decreased from 34 to 23 % when pasture allowance was decreased from 20.4 to 11.4 kg DM per cow. Further work is required to reconcile these seemingly contradictory opinions. Observations of other mixed grazing studies which include stocking rate were not considered by this author, for they did not have unconfounded species equivalence as argued by Connolly & Nolan (1976) and Connolly (1987). Both reports argue that predicted species equivalence (before experiment) is not usually the same as determined species equivalence (after experiment), with a consequent confounding of effect of change in stocking rate with that of mixed grazing. In the following sections, spatial and botanical complementarity are considered further with examples of mixed grazing studies in the literature.

2.1.1. Spatial complementarity

The most common examples of mixed grazing benefits that can be ascribed to spatial complementarity are those related to differences in reaction of cattle and sheep to dung pats (Nolan & Connolly, 1977; 1989, Collins, 1989), and those related to difference in pasture horizon grazed by grazers like cattle and sheep, and browsers (or intermediate feeders) like goats (Clark *et al.,* 1982; Townsend and Radcliffe, 1990; Radcliffe & Francis, 1988; Collins, 1989, del Pozo *et al.,* 1996). These are considered separately below.

2.1.1.1. Reaction to dung patches

Grazed pastures commonly contain patches of infrequently grazed areas which are composed of herbage growing on or near dung pats of the species grazed (or grazing) on that pasture. This is especially true of pastures under cattle grazing. These areas are estimated to make up 10-47 % of the total area under cattle grazing (Greenhalgh & Reid, 1969; MacLusky, 1960; Tayler & Rudman, 1966). Under rotational stocking, the longevity of dung pats was estimated at 2 to 3 grazings after deposition (Hirata *et al.* 1987).

Forbes & Hodgson (1985) showed the disposition of sheep and cattle to graze around dung pats of the other species, while rejecting herbage around their own dung pats. On temperate pastures, Nolan and Connolly (1989) estimated that about 40 % of pasture fouled by cattle dung pats was refused by cattle but sheep preference for it gave rise to improved utilisation and increased total animal performance.

The importance of these ungrazed, more precisely: infrequently grazed, areas may depend on the amount of dung per defecation (Williams and Haynes, 1995) and climatic factors which influence the rate at which these patches are recycled back to frequently grazed areas. In theory, the importance of dung pats should be less in summer than in winter, and in tropical than in temperate pastures. It can also be inferred that the advantage of co-grazing sheep and cattle may be to a greater extent from sheep grazing around cattle dung pats than the opposite, as sheep dung is usually a dry pellet. There are no published data to substantiate this thesis.

In summary, there may be significant benefit to using sheep to graze with cattle where infrequently grazed areas are not rapidly recycled. Such benefit however depends on the delicate balance between the use of the infrequently grazed areas by sheep and the competition on the frequently grazed areas between sheep and cattle.

2.1.1.2. Choice of pasture horizons

Positive response to mixed grazing of sheep and goats on sown grass/clover pastures has been observed both where the species were co-grazed (Radcliffe & Francis, 1988), when sheep were grazed on pastures previously grazed by goats (del Pozo *et al.*, 1996), and when sheep grazed pasture that was previously grazed by a sheep-goat mixture with a higher proportion of goats (Clark *et al.*, 1982; Townsend & Radcliffe, 1990). For instance, del Pozo and colleagues (1996) report that lamb growth rate was 33 % faster (188 vs 141 g/day) when lambs followed goats than sheep. These studies and others (see also Penning *et al.*, 1996) have all indicated a greater build up of clover in pastures under goat than sheep grazing. Is there a difference in preference for clover between sheep and goats, or is the difference in clover content between swards grazed by sheep and those grazed by goats a reflection of a difference in the capacity to select clover?

There seems to be little ground to suggest that the feeding apparatus of sheep and goats (i.e. mouth parts) has led to different levels of degree of selectivity. Gordon & Illius' (1988) model, based on data on a range of ruminant ungulates, has identified incisor arcade breadth as the driving variable for degree of selectivity in grazing ruminants, i.e. those animals with large incisor arcade breadth are less capable of selective grazing than those with small incisor arcade breadth. Since the estimates for a 50 kg sheep and a 36 kg goat were 31.9 and 33.6 mm, respectively, and the degree of protrusion of their arcade was similar (0.047 vs 0.053, see authors for detail), it may be deemed that both species have similar capacity for selective grazing. This leads to the conclusion that either sheep have greater preference for clover than goats or their diet composition is dictated by the horizon they choose to graze. This is difficult to untangle due to the fact that some authors have observed unwillingness of goats to graze deep into the pasture horizon (Collins, 1989) and clover is almost always found in the lower horizon in a grass/clover mixture. Penning *et al.* (1997) reported that there was no significant difference between sheep and goats in their preference for clover (time spent grazing clover:total time spent grazing), albeit the estimated preference values were 74 and 59 % for sheep and goats, respectively. Until further evidence emerges, the complementarity between sheep and goats on grass/clover pastures may be interpreted as much in terms of difference in choice of pasture horizons as difference in preference for clover. In any case, there is scope for complementary use of resources by sheep and goats on a grass/clover pasture. The advantage of this complementarity is best captured when growing lambs follow goats as demonstrated by both New Zealand (Townsend & Radcliffe, 1990) and UK workers (del Pozo *et al.,* 1996).

2.1.2. Botanical complementarity

2.1.2.1. Selection of pasture species

Various examples of botanical complementarity through selection of different species have been observed between sheep and goats on scrub-pastures (Clark *et al.,* 1982; Prigge *et al.,* 1989; Townsend & Radcliffe, 1990) and between cattle and sheep on native vegetation communities (Squires, 1982; Grant *et. al.,* 1985, 1987). Clark and colleagues (1982) and later Townsend and Radcliffe (1990) observed that the proportion of gorse on hill country pasture decreased as the goat:sheep ratio increased. On high scrub vegetation, Prigge *et al.* (1989) reported that the selection index for forbs and shrubs for goats was nearly four times that for sheep (3.0 vs 0.8), where an index of 1.0 means proportion in diet equals proportion on offer.

Regarding cattle and sheep, Grant and colleagues (1985) reported that across three different native hill vegetations, sheep diets generally contained more fine-leaf grasses and forbs than cattle diets. The seasonal range of similarity indices for sheep and cattle diets from various studies are summarised in Table 2.1. Similarity coefficient is a measure of the proportion of botanical components common to two swards, or a diet and a sward, or diets of two animals. Accordingly, an index of 1.0 indicates 100 % similarity (Holecheck *et al.*, 1984). Similarity coefficient between sheep and cattle diets appears to show significant

Table 2.1. Similarity coefficients of cattle and sheep diets. (An index of 1.0 indicates 100 % similarity).

Plant community	**Coefficient (seasonal range)**	**Authors**
Agrostis-Festuca	0.60 (July) - 0.78 (Sep.)	Grant *et.al.*, 1985
Nardus	0.58 (June) - 0.80 (Oct.)	
Blanket bog	0.50(July) - 0.62 (Sep.)	Grant *et al.*, 1987
Calluna moor	0.56 (May) - 0.84 (Oct.)	
Artemisia spp., *Artiples* spp., *Chrysothamnus* spp.	0.19-0.46	Olsen & Hansen, 1977

fluctuation from one season to the next and across different vegetation communities (Table 2.1). This is probably a reflection of variations in spatial distribution of the species across seasons as well as different vegetation communities, and change in the chemical composition and structure of that species with season. In some cases (e.g. at fixed animal numbers per ha) seasonal changes in similarity coefficients may also arise from change in relative stocking rate. This tends to suggest that the use of natural vegetation requires a strategic introduction of multispecies grazing in order to maximise complementarity and minimise competition.

2.1.2.2. Selection of plant parts

In this area, the most commonly noted observations are that : (i) sheep select leaves in preference to stems (Dudzinski & Arnold, 1973; Mulholland *et al.*, 1977), green to dead matter (Dudzinski & Arnold, 1973; Mulholland *et al.*, 1977; Collins & Nicol, 1987;) to a greater extent than cattle, (ii) sheep discriminate against reproductive parts, such as grass seedheads, to a greater degree than cattle or goats (Table 2.2), and (iii) goats avoid dead matter more than sheep or cattle perhaps because they usually do not graze deep into the pasture canopy (Table 2.2). Any advantage in dietary non-overlap between grazing species in terms of plant parts is most likely to be greater later in the season when most of the botanical components (reproductive stems, seedheads and dead matter) assume a significant proportion of the total biomass. Since sheep selectively graze more nutritious parts such as leaves and green matter, there is limited scope for improvement in mixed grazing response due to botanical complementarity in terms of selection of plant parts. That is, greater consumption of leaf by sheep would not have an apparent advantage to cattle.

Table 2.2. Percentage of botanical components in total g OMI/kg $w^{.75}$ in cattle, sheep and goat diets (*Adapted from Collins, 1989*).

	Grass seedhead	Grass leaf	Grass stem	Clover	Dead matter	Total Green
Cattle	21	13	15	40	11	90
Sheep	4	22	14	54	6	96
Goats	19	15	16	48	2	99

In summary, difference in grazing strategy of ruminants provides scope for complementary use of resources. This scope is also shown to vary with vegetation type and season. Aspects of co-grazing that lead to competitive resource use by co-grazing species have been dealt with in great detail by Nicol (1997). In broad terms, it can be stated that situations that minimise complementary resource use result in competition between species. The remaining part of this review considers why using pasture/rangeland resources by more than one species did not always lead to improved animal performance per ha than mono-species grazing.

2.2. Factors affecting mixed grazing outcome

As indicated in Fig. 2.1, responses to mixed grazing are largely determined by the diversity of the vegetation on offer. Even with the same vegetation species mixture, particular diversity is a difficult variable to re-produce. Miles (1985) in reference to native plant communities, stated that one of the generally applicable rules is that no two vegetation communities are alike. This may also apply, though probably to a lesser extent, to sown pastures. Hence, there is a great scope for mixed grazing studies to be situation specific (Wright & Connolly, 1995). Perhaps this is one of the reasons why most reports from mixed grazing studies have not been concordant. Lambert and Guerin (1989) presented an exhaustive summary of mixed grazing reports. Table 2.3 presents data extracted from their summary.

Table 2.3. Summary of the outcomes of mixed grazing studies on cattle and sheep (*Adapted from Lambert and Guerin, 1989*).

Observation	**Number**	**Proportion**
Studies involving cattle and sheep	12	1.00
No response in cattle or sheep	2	0.17
No effect on cattle, + response in sheep	5	0.42
+ Response in both cattle and sheep	5	0.42
+ Response in cattle, no response in sheep	0	0.00

(+ response means species LWG under mixed grazing higher than under mono-grazing; no effect means equal LWG under mixed and mono-grazing).

Some interesting points emerge from Table 2.3. There were more positive responses in sheep than in cattle LWG. Less than half of the studies cited found positive response in both sheep and cattle liveweight gain; about 17 % found no response in LWG of either species. There are numerous factors that may lead to such different conclusions from different mixed grazing experiments. These factors can be broadly classified into two major categories: (1) variables related to the grazing animals chosen and (2) variables related to the design and conduct of experiments. The former include: species ratio, species mix, age of animals, breed and sex of animals, and physiological state of animals. Variables related to the conduct of an experiment and its artefact include: species equivalence, method of grazing, and stocking system applied. The effect of the stocking system chosen on mixed grazing outcome (the subject of this thesis) will be covered in detail after a brief review on the significance of other factors listed above. The significance of stocking rate has already been dealt with in section 2.1. There are varying levels of information on each of the other variables.

2.2.1. Animal related variables

2.2.1.1. Species ratio

Evidence from many experiments and reviews seems to suggest that the liveweight gain advantage of a species in mixed grazing is inversely related to its proportion in the mixture (Van Keuren, 1970; Hamilton, 1976; Boswell & Cranshaw, 1978; Dickson *et al.*, 1981; McCall, *et al.*, 1986; Nolan & Connolly, 1989; Townsend & Radcliffe, 1990). For instance, the rate of sheep liveweight gain improved by 22 % when the proportion of sheep in a sheep:cattle mixture was reduced from 80 to 60 % (McCall *et al.*, 1986). Similarly, lamb growth rates increased from 169 to 203 g day^{-1} when the ratio of sheep to goats decreased from 3 ewes:1 goat to 3 ewes: 3 goats (Townsend and Radcliffe (1990). This is not surprising because as the ratio of a species in mixed grazing increases, it progressively becomes closer to single-species grazing for that species and therefore the difference between the performance of that species under mixed and single species grazing should progressively disappear. The interesting question would be whether the response to change in ratio would affect the two companion species differently.

The solution to this question requires that any data used to compare change in ratios is not confounded by a latent change in stocking rate due to the use of erroneous substitution rates. So far, the only published reports that had overcome such limitations by using response equations to determine the 'true' species substitution rate are those from Ireland (Nolan, 1986, Nolan & Connolly, 1989). Some of these data are summarised in Figure 2.2, which shows the percentage change in liveweight gain of co-grazing sheep and cattle (in relation to their mono-grazing counterparts) in response to changes in sheep:cattle ratio. The data plotted in Fig. 2.2. are average improvements in LWG of co-grazed animals calculated from values found in different reports. See Appendix 2.1 for details on data set. These data seem to suggest that sheep and cattle liveweight gains are affected differently by change in sheep:cattle ratio.

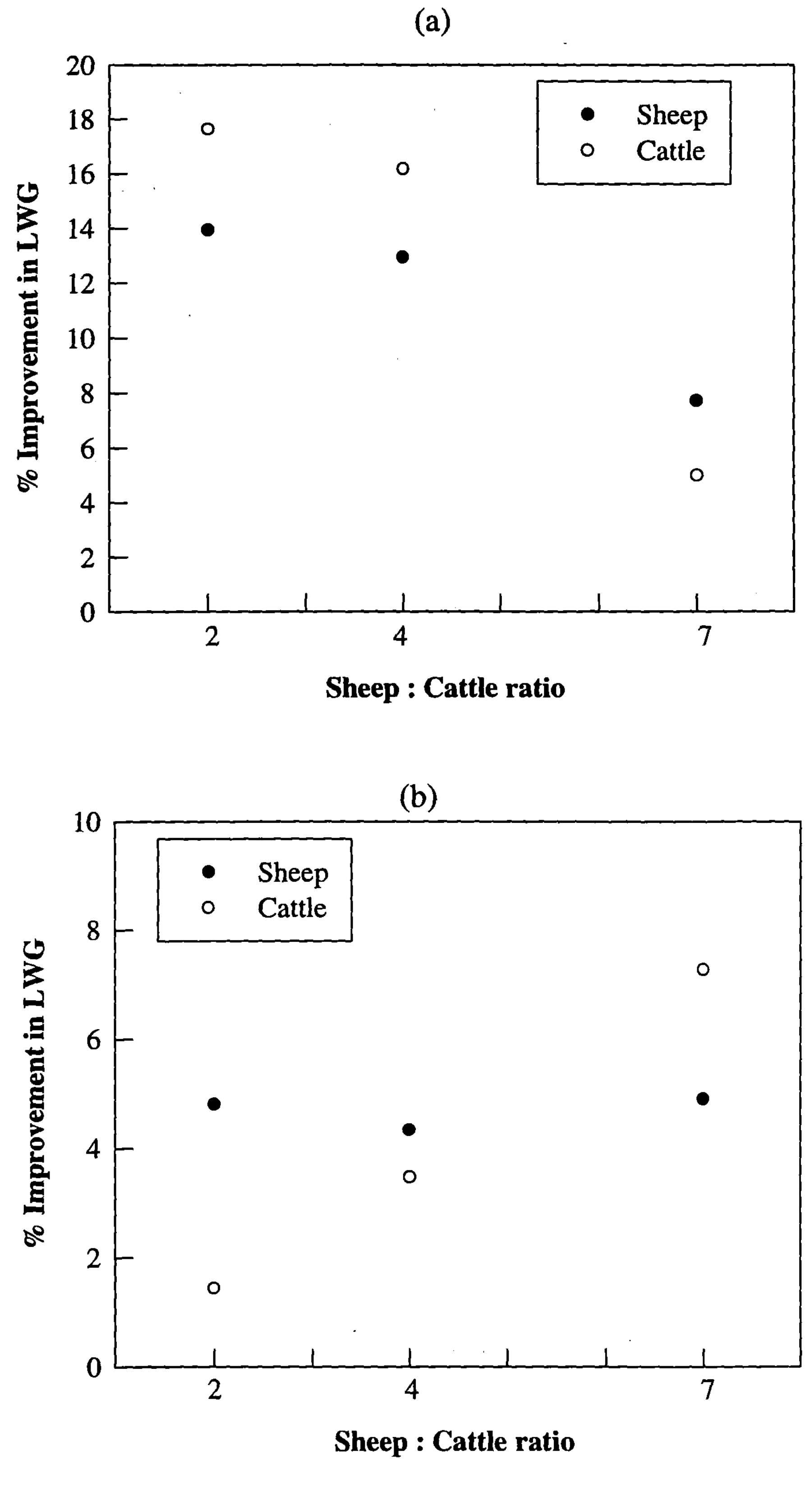

Fig. 2.2. Percent change in liveweight gain (LWG) as compared to mono-grazing in response to change in species ratio at (a) low and (b) high stocking rates. (*Adapted from Nolan, 1986, Nolan & Connolly, 1989*).

The response of sheep liveweight gain to changing ratio seems highly dependent on stocking rate. At low stocking rate, sheep co-grazed with cattle preformed increasingly better than their mono-grazing counterparts with decease in sheep:cattle ratio (Fig. 2.2a). At high stocking rate, the response of sheep liveweight gain to change in sheep:cattle ratio was so inconsistent that it is difficult to draw any pattern (Fig. 2.2b). On the other hand, liveweight gain of cattle co-grazed with sheep seems to improve with increase in sheep:cattle ratio at high stocking rate (Fig. 2.2b).

An interesting pattern emerges from the response of cattle liveweight gain to change in sheep:cattle ratio at low stocking rate. From these data there is no evidence to support the authors' conclusion that cattle liveweight gain increases with increase in sheep:cattle ratio. In fact, cattle appear to perform better when their proportion in the mixture increases (Fig. 2.2a). The possible argument for lack of, or minimal, response to mixed grazing at high stocking rate is presented in section 2.1. Further discussion is centred on the response of cattle LWG at low stocking rate which seems to defy early conclusions (see Nolan & Connolly, 1989).

Theoretically, the direction of response of the two species to changing ratio will only be the same if cattle draw equivalent nutrients from pasture that is rejected by sheep, as sheep would from pasture that is rejected by cattle. There is no information that shows this to be the case. It would be interesting to see if the pasture value index (PVI) generated by Wright and Connolly (1995) can be used to interpret the pattern of response by sheep and cattle to change in their ratio. The description of PVI by Wright & Connolly (1995) is re-stated here. "Assume an environment in which there are n components of vegetation (for simplicity assumed to be different plant species) on offer which may contribute to the diet of an animal species. For the *ith* plant species,

W_i is the biomass(kg per unit area) on offer,

D_i is the edible contribution (kg per unit area) of the *ith* species, i.e. the quantity the animal species would eat,

q_i is the quality of feed of the ith species. This is defined on some scale and may have a very broad meaning, including multidimensional chemical attributes.

Then, $W_iD_iq_i$ is the value of that pasture to the animal species. " Another quantity they used was f_i which is the proportion of the *ith* species in the edible portion of the vegetation in relation to its proportion in the vegetation, and is used to approximate preference for a plant species or plant part. The authors suggested that if the ratio of preference for two plant species provides a reasonable approximation to the ratio of their f_i values and the contribution of the different species to the standing herbage (W_i) is known, then under certain assumptions, a PVI can be estimated to compare a number of different pastures for different animal species. Accordingly, a value greater than 1 indicates preference. The authors used this concept to see the preference of sheep, cattle or goats to savanna vegetation previously grazed by any one of the other two species. Some values are extracted into Table 2.4.

Table 2.4. Pasture value indices[α] for cattle (C), and sheep (S) for plots of semi-arid savanna grazed over two years (*After Wright & Connolly, 1995*).

		PV index for	
Plot	species	Cattle	Sheep
1	C	1.06	1.15
2	C	1.50	2.28
3	S	0.95	0.52
4	S	0.59	0.31

[α] Preferences in plots grazed by a particular species were used in calculating the pasture value index for plots not grazed by that species.

Although there was variation between plots, the data were consistent in their indication of low PVI of pasture grazed by sheep for cattle, and high PVI of pasture grazed by cattle for sheep (Table 2.4). For sheep, pasture grazed by cattle had a mean PVI of 1.72 while pasture grazed by sheep had a mean PVI of 0.77 for cattle. This means, by selectively removing highly nutritious parts of the vegetation, sheep leave behind a pasture of inferior quality than cattle, which are less capable of selective grazing. Therefore, mixed grazing of sheep and cattle is more likely to benefit sheep than it does cattle. This fits well with the summary given in Table 2.3, where there was more positive response in sheep LWG to mixed grazing than in cattle LWG. It can be inferred that the PVI for sheep of a sward previously grazed by cattle will depend on grazing pressure. Therefore, it is very possible that the lack of response in sheep LWG to changing cattle:sheep ratio at high stocking rate shown above was because the PVI of cattle pasture for sheep is low at high stocking rate. This needs to be experimentally confirmed.

In full awareness of the limited data presented here, one can at least conclude with some confidence that not only are there no grounds to suggest that the rate of cattle liveweight gain will improve as sheep:cattle ratio increases, but also that there is limited scope for cattle to benefit from their association with sheep.

Then, how can one explain reports of improved cattle performance under mixed grazing, and the trend implied in Fig. 2.2a of increase in rate of liveweight gain of cattle as their proportion in the mixture increased? For most sown pastures, it can be stated that the selective grazing by sheep of such components as grass leaves and clover has no benefit to cattle and complementarity is mainly through better use of dung fouled pasture. Hence, the utilisation of dung fouled pasture may have played a greater role in those experiments which reported cattle response to mixed grazing than in those which did not. Alternatively, the answer may also lie in the "giants vs dwarfs" analogy of Connolly (1986) rather than complementary use of pasture resources. That is, due to their larger size cattle would capture a greater proportion of the feed resource in a given time than sheep, and this effect may increase as their proportion increases (Fig. 2.2a). The logic why this works in the reverse direction in Fig. 2.2b remains unclear. In conclusion, all the empirical data presented here suggest that sheep, but not cattle, liveweight gain increases as the ratio of that species in the mixture decreases.

2.2.1.2. Species mix

A mixed grazing response has the chance to be greater when the companion species differ widely in their feeding habits and degree of selectivity. In theory, complementarity should be greater between browsers (feeding predominantly on woody species) and grazers (feeding predominantly on graminoids) than species combinations of similar feeding habits. This may be the reason why Collins (1989) reported that compared to mono-grazing cattle, organic matter intake decreased by 18.7 % when cattle grazed with sheep, but increased by 24.4 % when they grazed with goats. Collins (1989) explained these in terms of difference in the grazed horizon, i.e. goats were grazing fresh growth on the surface horizon while both sheep and cattle grazed deep into the horizon and hence there was greater competition between cattle and sheep than between cattle and goats. Though goats are not exclusively browsers, their habit of searching for leaves and young shoot when feeding on shrubs and forbs may have come through to limit their grazing of pastures to the top horizon. The PVI reported by Wright & Connolly (1995) seems to lend some support to the premise that there might be greater competition between cattle and sheep than between cattle and goats. For cattle, the mean PVI of pastures grazed by sheep was 0.77, while that grazed by goats was 0.86. Further, Squires (1982) reported that on a semi-arid woodland dietary overlap was greatest between sheep and cattle and least between sheep and goats.

As seems to be the case for most statements about mixed grazing, there are experimental observations that contradict the above generalisation. Norton *et al.* (1990) and Collins (1989) recorded greater dietary overlap between cattle and goats than between cattle and sheep, and suggested that goats are more like cattle than sheep in their feeding habit. This also contradicts the incisor arcade breadth and degree of selectivity relationship postulated by Gordon & Illius (1988), which would suggest goats to be more like sheep than they are like cattle because of the similar incisor arcade breadth stated earlier (see section 2.1.1.2). Perhaps Norton and colleagues' (1990) observation may have been confounded by the fact that animals were starved for 1 hour prior to each introduction to the test pasture, and tests were based on oesophageal samples of 15 minute grazing repeated six times a day (may not reflect long-term feeding habit). It also appears as if there was considerable interference and the three species may have been differentially affected by handling. Collins (1989) compared the similarity of cattle and goat diets on a declining pasture resource, which probably gives a different outcome to cases where the two species are compared on a fairly steady state in pasture condition.

To summarise, there are grounds for variable mixed grazing responses based on different species combinations. Complementarity and positive response to mixed grazing is deemed to be higher between species that have evolved with different feeding habits.

2.2.1.3 Age of animals

Zoby and Holmes (1983) were first to show that increasing stocking rate (declining height and mass of herbage) had a greater effect on the grazing intake of adult cattle than that of young cattle. In spring, they recorded 40, 15 and 9 % decrease in herbage intake per kg $W^{0.75}$ of animal groups with mean liveweight of 631, 439 and 164, respectively, as stocking rate was increased from 6.0 to 12.0 animals ha^{-1}. Note that each stocking rate had equal number of animals from each size group grazing together. Other studies have also shown greater resilience of intake of suckler calves than cows (Baker *et al.*, 1981) and suckler calves than steers (Aiken & Bransby, 1992) with increase in stocking rate. Zoby and Holmes (1983) concluded: as stocking rate increased, smaller animals were better able to modify their grazing behaviour (bite rate and grazing time) to maintain greater level of herbage intake than medium or large animals. They attributed the underlying reason to difference in growth potential. However, it may also have been due to difference in incisor arcade breadth per unit body weight (Illius and Gordon, 1987). If we assume that all size groups are capable of similar number of jaw movements per day and similar capacity to extend their grazing time as pasture allowance decreases, large animals will have to compensate for greater reduction in bite size than smaller animals. This is well supported by Illius and Gordon's (1987) theory that smaller animals are able to subsist on shorter swards than larger animals (due to the allometric relations of bite size and metabolic requirements to body size).

In a separate experiment, Nicol and Souza (1993) took this further and examined if co-grazing with sheep would have different effects on young and adult cattle. They found that with progressive decline in pasture mass on offer, the digestible dry matter intake of cows (450 kg LW) and calves (160 kg LW) grazed with lambs (34 kg LW) declined at the rate of 27 and 15 g per kg $LW^{0.75}$ per t DM/ha, respectively. The basis for the greater competitiveness of calves with sheep may be a combination of their proximity to sheep in terms of incisor arcade breadth per unit body mass and their greater physiological drive as growing animals over adult cows. In conclusion, co-grazing sheep and cattle may lead to different conclusions due to the age of cattle in the mixture There is no information on whether grazing with lambs or adult sheep will have a significantly different effect on cattle..

2.2.1.4. Breed, sex and physiological state of animals

There are no published experimental data to indicate whether or not mixed grazing responses will differ due to differences in breed, sex, or physiological state of one or both species in mixed grazing. Theoretically, the opportunity to pick up response to mixed grazing should be greater when animals of greater productivity or growth potential (fast growing breeds, or lactating dairy cows) are used to exploit the complementary use of resources than when animals of lesser potential are used. On the other hand, it may also mean that mixed grazing of animals of high physiological drive (lactating ewes and dairy cows, growing lambs and steers) may lead to greater competition than when mature breeding stock are grazed in common (e.g. dry ewes and dry cows). This is yet to be demonstrated experimentally.

2.2.2. Design and conduct of experiment

2.2.2.1. Equivalence of species (substitution rate)

In order to set up an experiment to measure the response to mixed grazing *per se*, it is critical that the effective grazing pressure is equated under single and mixed grazing by using an appropriate species equivalence (substitution rate). The problem in achieving this is that the true substitution rate can only be known at the end of the experiment and it is thought to be peculiar to that experiment (Wright & Connolly, 1995). Therefore many early mixed grazing reports were based on trials where species equivalence (substitution rate) was pre-determined using such parameters as livestock unit, liveweight, or metabolic body weight per ha, none of which has been proven to equate grazing pressure when applied across species. Connolly and Nolan (1976) proposed the use of response equations based on large-scale experiments with a range of stocking rates and species ratios. In this case, animal species substitution rate is determined at the end of the experiment rather than at the beginning. For instance, in one experiment that lasted over four grazing seasons, it was observed that the addition of one steer affected the performance of lambs by the same amount as the addition of 2.86 ewes with their lambs (20/7 , Equation 1).

$$\mathbf{LWGL = 323 - 7.0E - 20C} \qquad \textbf{Equation (1)}$$

$$\mathbf{LWGC = 1812 - 40E - 191C} \qquad \textbf{Equation (2)}$$

where, E= Ewes and lambs ha^{-1}, *C= Steers* ha^{-1},

LWGL = Liveweight gain of lambs,

LWGC = Liveweight gain of steers. (See Connolly, 1987 for more details).

On the other hand, the addition of 5 ewes and their lambs had the same effect on steer performance as adding one steer (191/40, Equation 2). While such an approach has overcome the confounding factors suffered by other authors, as Wright and Connolly (1995) pointed out, its implementation requires large-scale field experiments to generate response curves, the logistics of which falls beyond the limited funding currently available in grazing research.

Collins (1989), used equal daily disappearance of pasture mass (EDDPM) in comparing pasture intake and diet selection under single and mixed grazing of cattle, sheep and goats on sown grass/clover temperate swards. This was also useful in overcoming some of the limitations, but the labour intensive nature of the technique makes it unattractive for use in long-term experiments where the desire is to measure output per animal or per unit area. The technique employed in this study is described in Chapter 3.

2.2.2.2. Method of Grazing

As outlined in the definition, animals in mixed grazing are grazed either concurrently or sequentially (leader-follower) on the same pasture. These two methods of grazing exhibit different levels of complexity. In sequential grazing, the effect of each species on the vegetation as well as the output from each species can easily be modified by the operator; neither of these can as easily be accomplished under concurrent grazing. Generally, the species grazing first will have advantage over the one grazing second. It is commonly used to give advantage to growing animals such as lambs grazing ahead of ewes as often practised by New Zealand farmers.

Although dependent on the grazing intensity in effect, competition between grazing species appears to be greater under simultaneous than under sequential grazing (Table 2.5). Boswell and Cranshaw's (1978) work shows that there was greater benefit to cattle when they were rotated ahead of sheep (mean +31 %) than when both species rotationally grazed the pasture concurrently (mean -6 %) (Table 2.5). Predictably, sheep LWG was lower when sheep were rotated behind cattle rather than grazed together.

Table 2.5. Percent change in daily liveweight gain (LWG) of cattle and sheep under two methods of razing. (*Adapted from Boswell and Cranshaw, 1978*).

Grazing Method	**Species$^{\beta}$ ratio(C:S)**	**% increase in LWG$^{\alpha}$**	
		Cattle	Sheep
Simultaneous	66:33	-12%	+133%
Simultaneous	33:66	+6 %	+120 %
Sequential	66:33	+17 %	+38%
Sequential	33:66	+45 %	+2 %

$^{\alpha}$ % increase = $\frac{\text{(LWG mixed grazing) - (LWG mono-grazing)}}{\text{(LWG mono-grazing)}}$

$^{\beta}$Ratio based on liveweight to liveweight basis.

However, it is interesting to note that even those sheep that were rotated behind cattle had superior rate of liveweight gain than those which grazed on their own (Table

2.5). From the limited data presented here, the method of grazing chosen in mixed grazing (sequential vs concurrent) may play a role in minimising or intensifying competition. In single season studies, the decision on sequential vs concurrent grazing of species is more relevant to rotational than continuous stocking systems.

2.2.2.3. Choice of stocking systems

It may help to address contemporary views on stocking systems under single species grazing before presenting arguments for considering the effect of choosing one stocking system over another on mixed grazing outcome.

2.2.2.3.1. Continuous vs rotational stocking: single species studies

Despite various terminologies in the literature, there are essentially two forms of grazing: continuous and intermittent stocking. Continuous stocking is a management where animals are continuously stocked on an area of land over an extended grazing period (a few weeks to a whole season). In this system the aim is to balance the daily growth and regrowth of pasture with the amount that is removed daily by animals. Intermittent stocking, on the other hand, involves alternating periods of defoliation and regrowth. In this system, the pasture is subdivided into paddocks and each subdivision is stocked at such a rate that the harvestable regrowth is removed over a short period of time, from 24 hours to as long as 7-10 days. Due to the close monitoring required to run the system it is sometimes referred to as controlled-grazing (McMeekan, 1960) and often as rotational stocking. The discussion of stocking systems in relation to mixed grazing here is mainly limited to the distinction between grazing without spell (continuous) or with spell (rotational), rather than details of the variants of each system.

The intention here is not to resurrect the age-old argument on respective merits of rotational vs continuous stocking, which went on for decades but failed to show unequivocally the superiority of one system over the other either in pasture production or animal performance (Parsons, 1988; Parsons *et al.*, 1988). It is questionable whether a true comparison of the two systems is possible without using response curves based on large-scale experiments which include continuous stocking at different heights versus rotational stocking across a range of pre- and post-grazing heights over a number of grazing cycles, all replicated over time and space. Even where such a huge undertaking is affordable, the final response curves will probably be peculiar to the specific vegetation type. Therefore, as Ernst *et al.* (1980) put it, the question should be: "Under what circumstances can more forage be grown and/or more animal products obtained under one particular stocking system as opposed to the other?" Some of these circumstances are more obvious than others.

(A) Rangelands

In fragile ecosystems and in pastures that have low persistence under continuous stocking, rotational stocking has generally been advocated as the only 'sustainable' option. Even in such circumstances, the literature is not without contradiction. For example, O'Reagain and Turner (1992) challenge the notion that rotational stocking has less detrimental effect on rangelands than continuous stocking. They cite an example where out of 22 comparisons, more than 50 % (14 cases) found no real difference; rotational stocking was better in 5 cases and continuous stocking in 3 cases. One needs to balance such comparisons against the possible vast difference in 22 rangeland properties in their edaphic, topographical, climatic and stocking rate differences. All things being equal, the spelling period provided by rotational stocking may play a significant role in minimising rangeland deterioration, especially at medium to high stocking rates. Detailed discussion of rangeland management is not relevant to this thesis.

(B) Intensively managed pastures

The literature is replete with comparisons of rotational and continuous stocking systems on intensively managed temperate pastures. Despite the many efforts over the decades, this comparison still remains a contentious issue. However, important progress has been made in understanding the grazing management of temperate pastures. In order to demonstrate some of the progress made in this area, the comparison of rotational vs continuous stocking is considered in two sections: early animal production comparisons driven by stocking rate and the recent approaches of comparing grazing management options at equivalent sward state.

(i) Stocking rate driven comparisons

Most of the early comparisons of rotational and continuous stocking were based on designs that operated at a single fixed stocking rate. Such experiments failed to produce a common ground by leaving open the option of experiments with different stocking rates leading to different conclusions. McMeekan (1952, 1956) stressed the importance of stocking rate in grazing experiments, and showed how it can influence the outcome of rotational versus continuous stocking comparisons (McMeekan, 1960). He showed that not only was milk production per ha greater under rotational stocking at high stocking rate, but also the highest stocking rate at which production per ha started to decline due to further depression of production per animal was higher for rotational than continuous stocking. Conway's (1963a) work with beef animals also agreed with the above.

Conway's comparison of rotational vs continuous stocking at low, medium and high stocking rates (6 treatments) had additional notable features (Table 2.6). The results indicated that the effect of increasing stocking rate from medium to high on the relative difference between rotational and continuous stocking depended not only on the number of animals but also on their liveweight (Table 2.6). In addition, the difference between the two systems was smaller when all treatments were stopped when animals on the high stocking rate treatments stopped growing (1962 in Table 2.6), rather than continuing each treatment until the animals on that treatment stopped growing (1961 in Table 2.6). This concurs with his suggestion that the difference between rotational and continuous stocking becomes more important later in the season when pasture growth rate slows down. His results showed no significant difference between systems during the early part of the grazing season. At low stocking rates, animal productivity was either similar on both continuously and rotationally stocked pastures (McMeekan, 1960) or better on continuously stocked pastures (Conway, 1963a).

Table 2.6. Percent change in production per animal or per area due to stocking rate increase from medium to high *(Adapted from Conway, 1963a).*

	Liveweight gain per head		Liveweight gain per ha	
Animals	Rotational	Continuous	Rotational	Continuous
Young, light: 1960	-3	-20	+38	+14
Old, heavy: 1961	-30	-63	-1	-47
1962	-30	-40	+0.5	-15

From the foregoing and other research results (McMeekan and Walshe, 1963; Hull *et al.,* 1967), there seems to be strong evidence that at high stocking rate, animal productivity is greater under rotational than continuous stocking. Such observations led to the illusion that rotational stocking is intrinsically a more efficient system than continuous stocking. However, further examination of stocking rate as a driving variable in understanding the plant/animal inter-relationships in pastoral systems has revealed otherwise.

(ii) Sward state driven comparisons

In 1985 John Hodgson presented a paper to the XV'th International Grassland Congress in which he contended that "stocking rate cannot be considered as a primary determinant of either herbage production or animal performance, since its influence is mediated *via* effects upon a range of sward characteristics which collectively define the state of the sward" (Hodgson, 1985a). By using a plant tissue turnover relationship model on grasslands (Fig. 2.3), Hodgson (1985a) demonstrated the insensitivity of the rate of net herbage production under ostensibly contrasting grazing managements and emphasised the risk of confounding the effects of treatment and of sward state on estimates of both herbage production and consumption. It was indicated that it is necessary to understand the plant tissue turnover relationships in the pastoral system (Fig. 2.3) in order to discern grazing treatment effects on herbage production from that caused by sward state. The author proposed the use of sward canopy/surface height as an alternative variable to stocking rate on the basis that: (i) it has been shown to be the characteristic that rationalises herbage production responses over sites, years and seasons (Parsons *et al.*, 1983), and (2) it is the variable to which the ingestive behaviour of animals grazing temperate swards is most sensitive (Hodgson, 1985b). Subsequently, the comparison of rotational and continuous stocking systems was re-visited to see if either system was intrinsically superior over the other at equivalent sward states.

Perhaps the most significant contribution to the understanding of the plant/animal relationships on temperate pastures was made by work based on leaf area index (LAI) and sward height which identified the compensating changes in tiller populations and production per tiller, the associated changes in sward structure and photosynthetic efficiency of leaf populations (Grant *et al.,* 1983; Parsons *et al.,* 1983) and how these operate under different patterns of defoliation by grazing animals (Bircham and Hodgson, 1983). This work has led to the development of a model for grassland photosynthesis and other associated processes (Fig. 2.3).

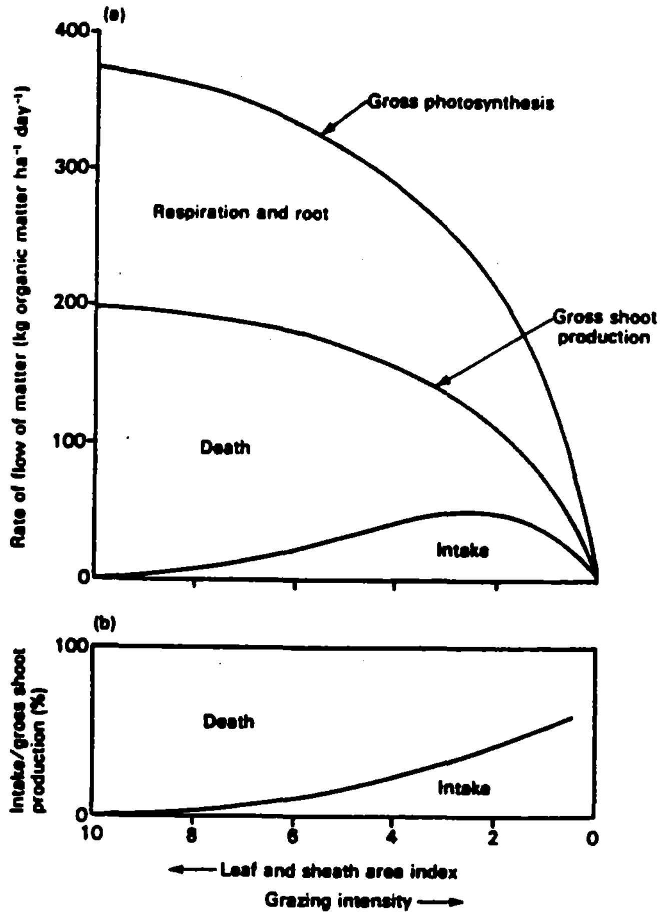

Fig. 2.3. The effect of the intensity of continuous stocking on (a) the components of the production and utilisation of grass and (b) on the amount harvested as animal intake as a proportion of gross shoot production (*Reprinted from Parsons et al., 1983*).

Though this model was developed on continuously stocked, all-grass swards, it has proven very useful in showing that there are different processes involved in a grassland system which reach their maximum at different LAI (Fig. 2.3). These include: gross canopy photosynthesis, net accumulation of live matter, loss of tissue to death and harvest of tissue through grazing (Fig. 2.3). The optimum production and utilisation for continuous stocking is believed to be at a height or LAI which strikes a compromise between maximum net accumulation of live matter and maximum harvestable yield of herbage of good nutritional value (Parsons, 1988). This is estimated to be within 10 % of maximum rate of net herbage accumulation and falls at a LAI of 2.5 to 4.5 (Fig. 2.3), or at SSH and herbage mass of 25-65 mm and 900 - 1,650 kg OM/ha , respectively (Bircham and Hodgson, 1983).

Under rotational stocking, the pasture is cyclically grazed down from a higher LAI (or height) to a lower LAI over a short period. During each regrowth, the rate of accumulation of net growth depends, among other things, on (1) good light interception, (2) the amount of youngest category of leaves (photosynthetically efficient leaves) remaining , (3) the amount of oldest category of leaves remaining (which determines tissue death), and (4) the lag between an increase in the rate of gross tissue production and a corresponding rise in the rate of tissue death (Parsons, 1988).

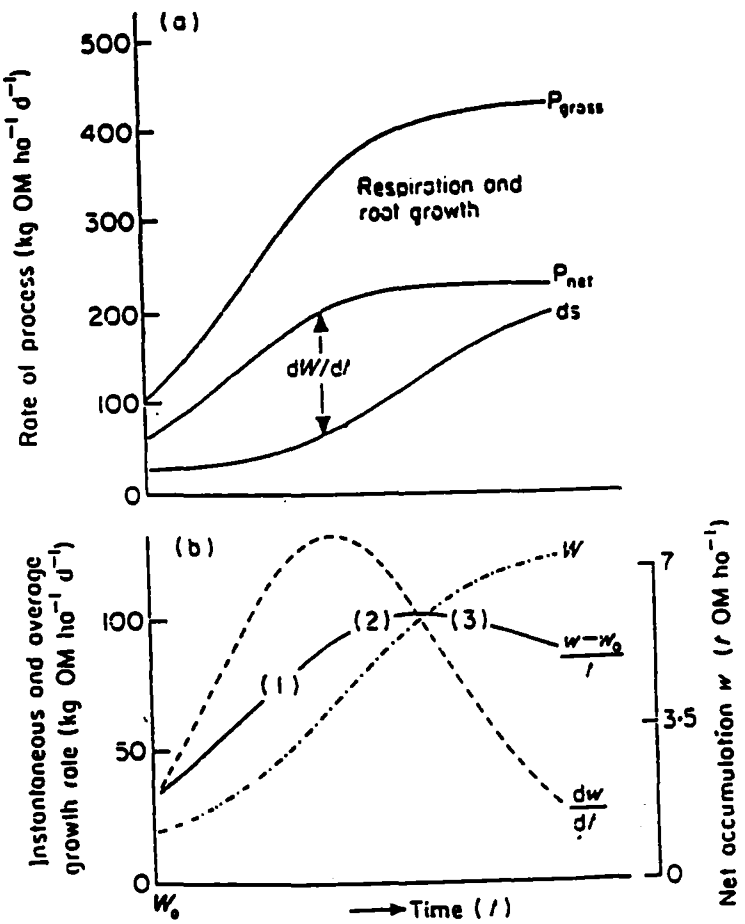

Fig. 2.4. The effect of the duration of regrowth on the major processes in the net accumulation of herbage (a), namely gross photosynthesis (P_{gross}), gross(shoot) tissue production (P_{net}) and death (ds), and the corresponding changes (b) in the instantaneous growth rate (dW/dt), the weight of the crop (W) and the average growth rate ((W-W0)/t). (*Reprinted from Parsons and Penning, 1988*).

The model for the rotational system is essentially similar to that of continuous stocking (Fig. 2.4a). In each regrowth period there are three parameters of interest in deciding the optimum net accumulation of herbage: (i) the instantaneous growth rate (dw/dt), (ii) the average growth rate ($(W-W_0)/t$), and (iii) total herbage accumulated during regrowth (W) (Fig. 2.4b). Short spell periods give near maximum instantaneous growth rate but very low average growth rate and low total net accumulation of herbage (1 in Fig. 2.4b), while longer ones give low and declining instantaneous growth rate (Fig. 2.4b), increased respiratory load and increased rate of senescence (Fig 2.4a). Parsons and Penning (1988) suggested that the rate of production of leaf, of particular importance both in photosynthesis and animal intake, is near maximum between spell periods of 19-23 days. In terms of pasture mass, Harris (1978) estimated that near maximum production of herbage on rotationally stocked pastures can be achieved at average stubble biomass of 1,700 to 2,500 kg DM per ha.

From the above, one can infer, with some reservation, that at the same stocking rate, rotationally and continuously stocked swards can be at different points in relation to the maximum net herbage accumulation possible from each system. Senft and Tharel's (1989) recent simulation model also tends to concur with this premise. This led to the question whether rotationally and continuously stocked swards are different in net herbage accumulation at the same sward state: *average* LAI.

By using their pasture model Parsons and colleagues (1988) clearly demonstrated that at any given average LAI, the yields achieved under continuous and intermittent defoliation are similar. The lag between an increase in the rate of net photosynthesis and in the rate of tissue death, widely advocated for better productivity under intermittent defoliation, lead to only a small (< 20 %) advantage to intermittent defoliation in terms of average growth rate (Parsons *et al.*, 1988). The authors recommended that there was little to be gained from adopting any grassland management other than that which suits the immediate logistics on the farm. Similarly, Parsons' (1988) review which exhaustively examined the physiological basis for optimising production from grasslands concluded that there was little, if any, difference in the overall efficiency or productivity of intermittent and continuous defoliation managements. Are there grounds for difference in pasture or animal output from different forms of intermittent grazing?

(i) infrequent, severe vs frequent, lenient defoliation

Intermittent grazing has had many variations centred on frequent, lenient defoliation or infrequent, severe defoliation. Parsons' (1988) review presents a detailed analysis of how the tiller dynamics of the sward effectively cancels out any difference in pasture production or utilisation that such managements attempt to create. Swards that are subject to infrequent, severe defoliation have the advantage of a longer period of lag between increased rate of plant tissue growth and a subsequent rise in plant tissue death. However, such swards also operate below the optimum LAI for longer periods than swards under frequent, lenient defoliation (Parsons, 1988).

Other authors have looked into the optimum number of paddocks in rotational systems and recommended ≥ 8 paddocks as the break point (Senft and Tharel, 1989). This is a curious concept because, as stated earlier, rest periods of 19-23 days have been recommended as the optimum regrowth period, both from animal intake and pasture production point of view (Parsons & Penning, 1988), and this period can be achieved by any number of paddocks and rotation policies. The recent mathematical model of New Zealand workers (Woodward & Wake, 1995) has also indicated that there is no reason to expect land subdivision to increase productivity.

(ii) close-folding (strip-grazing)

Strip-grazing is a variant of intermittent grazing where animals are restricted to daily or half-daily allowances, and was first introduced in the 1950's, apparently to increase the efficiency of utilisation of pastures on dairy farms (Holmes *et al.*, 1950). However, many authors (Freer, 1959; Kennedy *et al.,* 1960) showed that when operated at equivalent stocking rates, there was no difference in milk production per animal or per ha between rotational (5-7 days shift) and strip-grazing (twice daily shift). This agrees with the results of Conway (1963b) who found no difference between rotational and strip grazing in either liveweight production per animal or per ha. Interestingly, Volesky (1990) has introduced what was called frontal grazing as "forage harvesting of the future."

Frontal grazing is essentially the same as strip-grazing. In strip-grazing, the daily/half-daily strips are provided by the operator by using electric fences, while in frontal grazing the animals themselves attain continuous supply of fresh pasture during each day by pushing a sliding fence in front of them. Besides costs of installation and the training of animals involved, the method is fraught with difficulty on non-meadow pastures (ragged terrain), and in cases where different feeding regimes are part of the experiment. Further more, subsequent work by Volesky and colleagues (1994) failed to show any difference in steer production per ha between this system and rotational or continuous stocking. This is perhaps not surprising in view of Parsons and colleagues' (1983) work on defoliation patterns and tiller dynamics. In conclusion, when evaluated at similar sward state none of the management options seem to provide any ground for recommending one over the other either in terms of pasture production or animal performance.

Earlier reports of superior animal performance under rotational stocking at high stocking rate, usually late in the growing season (Conway, 1963a,b) , may be related to (i) the difficulty in predicting when and what proportion of the grazing area to close off for conservation under continuous stocking (Conway, 1963a, 1963b), (ii) the difficulty in maintaining the average LAI within the required range over the whole season by using a fixed high stocking rate under continuous stocking. In conclusion, the observed early animal production differences between stocking systems may be differences in operational difficulty rather than differences in efficiencies of the options considered here. The following section introduces why there is a need to re-visit the intermittent vs continuous defoliation argument under mixed grazing.

2.2.2.3.2. Continuous vs rotational stocking: mixed grazing studies

Most mixed grazing studies are based on continuous stocking experiments; the few research reports based on rotational stocking experiments are mainly from Ireland. Various reviews (Nolan and Connolly, 1977; Lambert & Guerin, 1989; Wright & Connolly, 1995) have revealed the prevalence of contradictory research results in the mixed grazing literature and addressed some of the factors contributing to these equivocal conclusions. However, in none of these reviews has the use of a particular stocking system been identified as a possible cause of disparity between mixed grazing studies. Are there grounds for variable mixed grazing results due to the choice of different stocking systems?

If there were a good number of mixed grazing reports with adequate data on both LWG and sward height/mass under the two stocking systems, it would have been possible to make some inference as to what the answer could be to the above question. Unfortunately, most of the long-term experiments on mixed grazing under continuous or rotational stocking do not have adequate, in some cases any, data on individual intake, sward height and/or mass. Therefore, the following sections examine grounds for re-considering continuous vs rotational stocking in mixed grazing context from observations under single species grazing.

The current guidelines for production from grass (Hodgson, *et al.*, 1986) or grass/clover (Orr *et al.*, 1990) swards under continuous stocking are based on sward state (LAI or SSH) rather than fixed stocking rate or calculated allowance (Parsons and Johnson, 1986). Animals, on average, remove the equivalent of each daily pasture growth to keep the pasture at the desired height or LAI. This means that, within a season, at a chosen leaf area or sward height, there is likely to be very little, if any, change in grass-clover or leaf-stem proportion of a pasture under continuous stocking management (Orr *et al.,* 1990). Even the proportions of the different categories of grass leaves (growing leaves, youngest fully expanded leaves, and older leaves) at a certain LAI remain fairly constant (Parsons *et al.,* 1988; Orr *et al.,* 1990). Gradual changes arise from the onset of reproductive phase of growth or through differences from one year to the next (Orr *et al.,* 1990).

On the other hand, during defoliation under rotational stocking, the pasture presumably passes through a series of changes in quantity (mass per unit area), quality, and composition (leaf-stem, grass-clover, live-dead matter) as it is grazed down from a high height to a lower one, which may affect the opportunity for selective grazing by one or both species mixed grazed. This diurnal change is best demonstrated by the work of Penning *et al.* (1994) where the defoliation period in rotational stocking was extended to 15 to 18 days to allow measurements of changes in proportions of green leaf and dead herbage (Fig. 2.5a), and changes in leaf area index and leaf:stem ratio (Fig. 2.5b). One can safely assume that similar diurnal changes would prevail if the defoliation period was reduced to daily shifts, with consequent greater diurnal variation in sward state and diversity under rotational than continuous stocking. This is supported by Tayler and Deriaz's (1962) work which found a within-day fall in *in vitro* digestibility of herbage under strip grazing, but no pattern of diurnal variation in digestibility of herbage under continuous stocking.

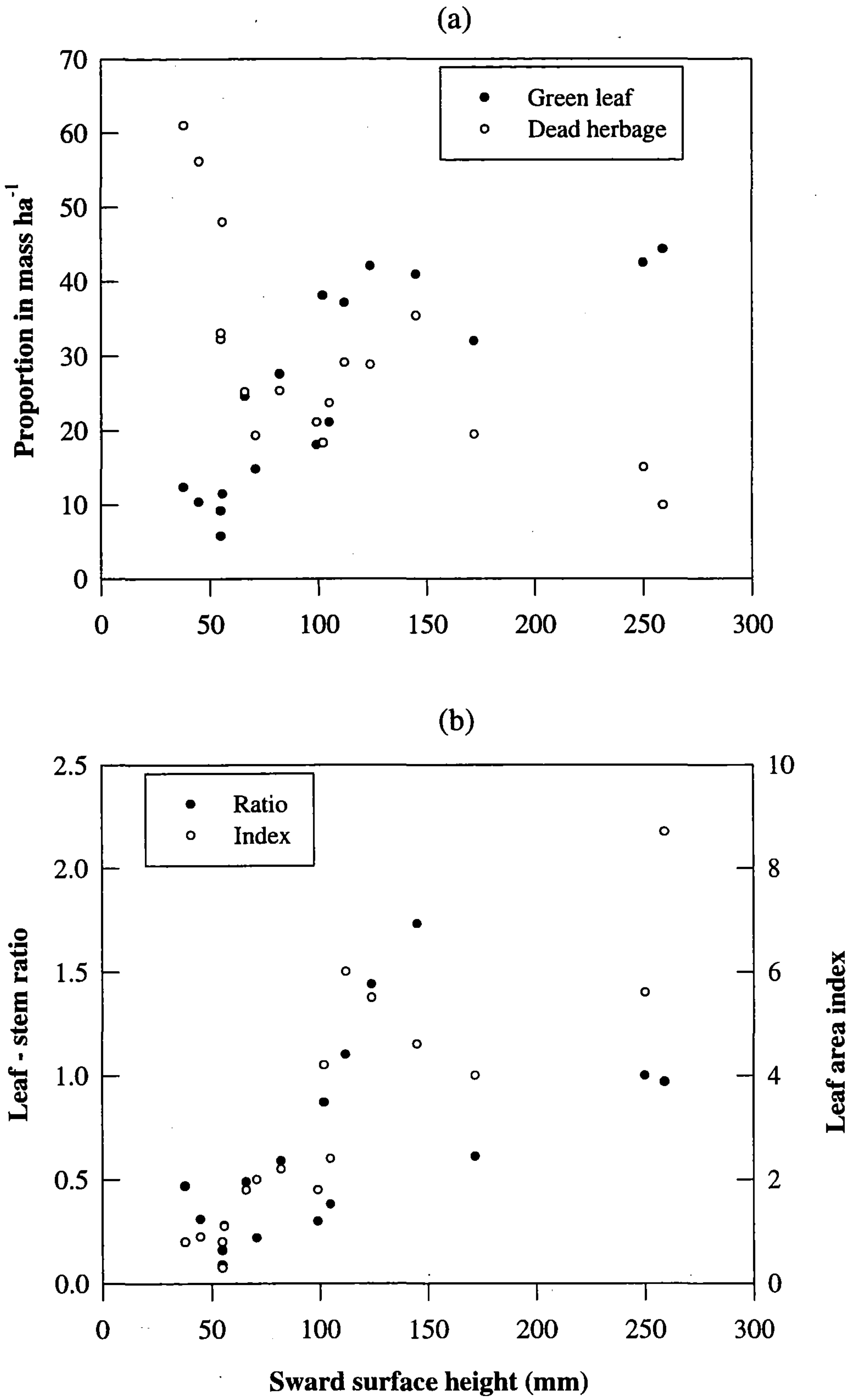

Fig. 2.5. Change in a ryegrass sward composition as it was progressively defoliated by sheep under rotational stocking.
(*Adapted from Penning et al., 1994*)

Where the rate of decline in mass is controlled (Collins, 1989), the extent of changes in quality and composition of herbage per unit change in herbage mass differ depending on the grazing species. For instance, the rate of clover depletion was faster on pastures grazed by sheep than goats or cattle (Collins, 1989). Hence, it is possible that continuous and rotational stocking provide intrinsically different levels of diversity in grazing pasture resource. Given the difference in the recommended optimal pasture height for sheep and cattle grazing (Table 2.7), and the difference in the resilience of their intake to declining pasture mass (Collins, 1989), it seems very possible that the stocking system chosen may play a significant role in the outcome of mixed grazing experiments. The experiments that follow are designed to explore this issue. In order to test this assumption, it is vital that the design of the experiment is based on a certain measure of equivalence to identify difference between the two systems that is due to mixed grazing alone. A novel approach in creating equivalence between continuously and rotationally co-grazed species is introduced in the design of these experiments to overcome the confounding effects of using sward parameters when comparing systems that intrinsically induce different sward characteristics.

Table 2.7. Critical values (C) of sward height required to maintain levels of herbage intake and animal performance close to maximum. *(After Hodgson, 1990).*

	C value (cm)
Continuous stocking	
Ewes and lambs:	
Spring	4-5
Summer	7-8
Beef cows and calves	9-10
Weaned calves	9-10
Dairy Cows	9-10
Rotational stocking	
Ewes and lambs	6-7
Cows and calves	9-10
Weaned calves	11-12
Dairy Cows	9-10

2.3. Summary of literature review

Grazing animals have evolved with different grazing strategies to provide scope for improved utilisation of vegetation through integrated grazing of these resources by two or more animal species. Some progress has been made towards understanding the complex processes involved in mixed grazing. A great deal of this progress was made by Nolan and Connolly who not only presented the first review of this area (Nolan and Connolly, 1977) but also did a series of experiments (Nolan, 1986; Nolan & Connolly, 1976, 1989), overall appraisal of mixed grazing (Nolan and Connolly, 1992), design and analysis of mixed grazing (Connolly and Nolan, 1976, Connolly, 1987) that have made substantial contribution to our understanding of mixed grazing.

Perhaps one of the shortcomings of most of the long-term experiments (Hamilton and Bath, 1970; Hamilton, 1976; Nolan and Connolly, 1989) is that they lack data on pasture height and mass as well as individual animal intake, which makes it difficult to draw any inference on how the response to mixed grazing changes as these variables change. Any future attempt at modelling response to mixed grazing and generating a conclusion that applies to a wide range of vegetation types will require animal performance data with a matching and precise description of the pasture resource. In contrast, most mixed grazing reports have adequate data either on pasture parameters (height, mass, and botanical composition) and their influence on intake, or on animal output (individual and per ha liveweight gain), very rarely on both.

Various factors have been shown to influence the outcome of mixed grazing. Broadly, they relate to vegetation diversity, the animals chosen, and the design and conduct of experiments. There are varying levels of information on each of the factors encompassed in these broad categories. Information on how each of these factors affects the outcome of mixed grazing has been equivocal.

There are sufficient grounds for re-considering the continuous vs rotational argument in a mixed grazing context. To cite a couple: (1) such an investigation will determine which system is more conducive for complementary resource use, and (2) the outcomes may explain if the ambiguity prevalent in mixed grazing reports was due to comparing experiments from contrasting stocking systems.

CHAPTER 3

EXPERIMENT I: Intake, liveweight gain and diet composition of cattle and sheep co-grazed using continuous or rotational stocking

3.1. INTRODUCTION

A review of literature (Chapter 2) has shown that one of the major factors influencing the outcome of mixed grazing is the level of diversity in the pasture resource on offer. The literature also tends to suggest that there is a greater level of variation in pasture diversity under rotational than continuous stocking (See section 2.2.2.3.2). However, it has not been established whether choice of stocking system can lead to significantly different outcomes from mixed grazing experiments. Presumably, any such difference might be easier to detect by comparing continuous stocking to one-day rotations, where the rotationally stocked pasture daily passes through change in height and botanical composition of greater magnitude than a continuously stocked pasture.

If the task of determining whether the productive merits of one stocking system are intrinsically superior over the other under single species grazing is difficult (Ernst *et al.*, 1980), it will probably be doubly so under mixed grazing, for the latter involves an additional variable: animal species interaction. Consequently, the question is whether continuous stocking, which entails, characteristically, relatively steady state conditions or intermittent grazing, which exhibits cyclic changes in sward state (in quantity, quality and composition of herbage), differently influence the level of competition and/or complementarity between co-grazing species and thus affect the results of mixed grazing.

In order to compare stocking systems under mixed grazing, it is vital that the parameter chosen to provide equivalence between the two systems is unconfounded. None of the pasture-based parameters such as pasture height, pasture mass, or rate of disappearance of pasture mass (as in Collins, 1989), or animal-based parameters (like stocking rate) can stand criticism. For instance, at the same pasture height rotationally and continuously stocked pastures may have different quantity, quality, botanical composition, and canopy architecture (important in diet selection). In addition, since there are pre-grazing, post-grazing and average heights under rotational stocking, the decision of which height to use becomes arbitrary. Similarly, rotationally and continuously stocked pastures can reach the same mass per unit area with different botanical composition and nutritive value.

The concept of equilibrating species on daily disappearance of pasture mass (Collins, 1989) can easily be applied to rotational systems. Its application to continuous stocking depends on inference based on estimation of what is removed daily by animals, or on the prediction of daily pasture growth rate using exclosure cages. Both approaches will probably involve a different error of prediction than that under rotational stocking. Problems associated with using stocking rate to provide equivalence of single and mixed grazing species has been thoroughly discussed elsewhere (Connolly & Nolan, 1976; Collins, 1989).

From the above, it is evident that measuring the difference between continuously and rotationally co-grazing animals has operational difficulty. Therefore, a new approach was proposed where treatment effects on the performance of one of the species was measured by keeping the weekly liveweight change of the companion species similar under both systems of grazing. In this case, the aim was to study the effect on cattle of co-grazing with sheep under rotational or continuous stocking at equivalent weekly liveweight change of sheep under both systems.

Accordingly, a grazing experiment was set up with the following objectives: (1) to determine the intake and liveweight gain of cattle when grazing with sheep under continuous and rotational stocking (where sheep in both systems had similar LWG), (2) to compare the diet composition of each animal species in these stocking systems, and (3) to compare the botanical composition of pastures continuously or rotationally co-grazed by sheep and cattle.

3.2. MATERIALS AND METHODS

3.2.1. Experimental site

The trial was conducted in Canterbury, in the South Island of New Zealand (43° 38' S) on the Lincoln University research farm on a Templeton silt loam soil of medium fertility (Olsen P = 18). The area receives a mean annual rainfall of about 650 mm.

3.2.2. Pasture

The paddocks used in this trial had been in perennial ryegrass (*Lolium perenne*. Grasslands Nui)/white clover (*Trifolium repens*. Grasslands Huia) pasture for five years.

Each year the pasture received a single application of 125 kg per ha of superphosphate during April-May. The irrigation schedule of the research farm was a 21-day cycle (50 mls at each irrigation), but during the study period (1 December 1992- 14 April 1993) the area received adequate rainfall during most months (See climatic data in Section 3.3.1). Both treatment pastures were irrigated only once (24 January 1993).

3.2.3. Animals

Twenty Hereford-Angus yearling heifers were bought at a stockyard, fasted for 24 hours, and treated with an anthelmintic (Vetdectin Pouron: 0.5 mg moxidectin per kg LW) before being introduced to the pasture. They had an initial mean fasted liveweight of 188 (±2.77) kg. Sixty-four, two-tooth Corriedale ewe hoggets were drafted from the Lincoln Sheep Breeding Unit. Sheep had a mean initial fasted liveweight of 48.9 (±0.61) kg. They received an oral drench (Vetdectin Oral: 0.2 mg moxidectin per kg LW) as an internal parasite control before being introduced to the experimental pasture. No further anthelmintic treatment was done, as faecal egg counts of both sheep and cattle faeces samples, mid-way through the experiment, were low (<200 eggs per g DM of faeces). When data collection began the mean initial sheep and cattle liveweights (full gut) were 53.9 (±0.93) and 266 (±4.46), respectively. Neither species were mated to avoid the confounding effect of pregnancy on liveweight change measurements.

3.2.4. Experimental design layout

There were two treatments: rotational stocking and continuous stocking. A 6.4 ha pasture was divided into two 2.95 ha treatment areas with a 0.5 ha spare area. Nine heifers and 27 hoggets (1:1, $LW^{0.75}$) were assigned to each treatment as core groups. The remaining two heifers and 10 hoggets were kept on the spare paddock. For the continuously stocked treatment, the core nine heifers and 27 hoggets were continuously stocked on one of the areas at a mean sward surface height (SSH) of 5 cm which was maintained by adding or removing additional animals in a fixed ratio (1:1 $W^{0.75}$, cattle :sheep). Two similar core groups of cattle and sheep were grazed rotationally where they were initially allocated an area of pasture estimated to promote a liveweight gain in sheep similar to that provided by a pasture continuously stocked at 5 cm. At the beginning of the experiment they were given an area deemed to be sufficient for three days and then from the 4th to the 7th day of that week they received one third of the initial area daily with an equivalent grazed area being removed, meant access to any one area for three days. After recording liveweight of all animals at the end of week 1, and each week after that, the size of the new area provided daily to the rotationally stocked group was increased or decreased so that the mean weekly liveweight change of the rotationally stocked sheep was equal to that of the continuously stocked group. The experiment lasted a total of 19 weeks (1 December 1992 to 14 April 1993). For the continuously stocked treatment, when addition of extra stock was insufficient to keep pasture height at 5 cm, part of the paddock was fenced off by using electric fence. This area was recycled back when required after removing excess pasture growth (> 5 cm) by a mob of ewes with their lambs. Similarly, on the rotationally stocked side the same mob of ewes were used to keep the pre-grazing SSH at less than 20 mm. On both treatments, a total of 6 days grazing by a mob of 550 ewes plus lambs was used to remove excess pasture.

3.2.5. Measurements

3.2.5.1. Liveweight

Liveweight of core animals in each treatment was recorded weekly. At the end of the trial (14 April 1993) the fasted liveweight of these animals was determined after 24 hours of total feed restriction. Treatments were compared in terms of the average daily liveweight gain over the whole period. Liveweight gain per ha was calculated from total sheep and cattle grazing days per ha and the respective average daily liveweight gain of each species. Calculation of gain per ha did not include grazing by the mob of ewes stated earlier (Section 3.2.4).

3.2.5.2. Pasture intake

Pasture intake was estimated three times (Table 3.1) during the experimental period using n-alkanes as internal markers (Mayes *et al.*, 1986). In each treatment, eight animals of each species were randomly selected from the core groups for measurement of pasture intake. Animals were dosed with synthetic C_{32} (dotriacontane: $C_{32}H_{66}$) and herbage C_{33} (tritriacontane: $C_{33}H_{68}$) was used as an internal marker.

Table 3.1. Dosing and intake measurement periods (1992/93).

Period	Date started	Date finished	Number of days
I	9/12/92	18/12/92	10
II	13/01/93	22/01/93	10
III	24/03/93	02/04/93	10

Preparation of alkane capsules

Dotriacontane (C_{32}) was directly weighed into a gelatine capsule. The weight of C_{32} in each capsule was labelled on the capsule. For cattle, three capsules each with about 150 mg of C_{32} were wrapped together with a paper and the combined exact weight of C_{32} was recorded on each wrap. When tested in a shaking waterbath (at about 40 °C), the capsules were released from the wrap and dissolved within an hour. For both sheep and cattle, the weight of C_{32} dosed to each animal was recorded during each daily dosing.

Dosing and faecal sampling procedures

A day before the beginning of each dosing period, core animals selected for dosing were marked with stock marker for ease of identification. During each dosing period, animals were dosed once daily at 08:00 hours with C_{32}. Dose rates were 130 mg for sheep and 450 mg for cattle. During Period III, sheep in both treatments were also dosed twice daily with 1 g of Cr_2O_3 per animal.

During the last five days of each dosing period, morning (08:00 hours) and afternoon (16:00 hours) faecal samples were obtained by grab sampling from the rectum or by collecting faeces voided during yarding (provided that these were not contaminated and the animal was clearly identifiable). In the third intake measurement period, four male wethers (same breed and similar size to experimental sheep) fitted with faecal collection harness bags were added to each treatment to determine the total recovery of Cr_2O_3. They grazed with the test animals during the whole intake measurement and were removed afterwards. During the week preceding total faecal collection, the wethers were acclimatised to carrying collection bags. As with grab sampling, total faeces collection was carried out from days 6-10 of dosing. As alkanes were only used for predicting intake, there was no need to measure recovery of the alkanes used in calculating OMI (Appendix 3.1a). See Appendix 3.1c for the recovery value used for calculating intake using Cr_2O_3.

Processing of faecal samples

Morning and afternoon grab samples were frozen as soon as possible and then freeze-dried and ground to pass through 1 mm sieve. Sub-samples of equal volume from each sampling time were then bulked for each animal in each treatment. Morning and afternoon total faecal collections from Period III were weighed to determine fresh weight. Sub-samples were taken for dry matter (DM) and alkane analysis. Sub-samples for DM analysis were weighed fresh and then dried for 48 hours at 70 °C in a forced-draught oven. Subsamples for alkane analysis were treated the same way as faecal grab samples (See above).

Pasture sampling

During each intake measurement period, samples of pasture consumed were obtained from oesophageally fistulated animals (3 heifers and 4 ewes) introduced on day 6, 8 and 10 of dosing (i.e. 1st, 3rd and final day of faecal collection). These animals were kept on the spare paddock (see above) when not in use. At each sampling a minimum of one hour was allowed between fresh daily pasture offer and the introduction of OF animals. OE samples were frozen within two hours and then freeze dried. Each sampling day, half aliquot of the sample from each animal were bulked (i.e. across animals within a day). One aliquot was used for alkane analysis and *in vitro* digestibility determinations. The other aliquot was kept for determination of diet composition to give 9 and 12 samples per period for cattle (3 animals x 3 sampling days) and sheep (4 animals x 3 sampling days), respectively. In addition, 20 random samples (ca. 200 g) cut to ground level with a battery-powered hand piece were collected to characterise the botanical composition of each pasture. In the rotational stocking treatment, pasture samples were taken both from the fresh area given daily and the equivalent area removed from grazing daily. Pasture samples were frozen within two hours and samples from each day were then sub-sampled and dissected into grass leaf (GL), grass stem and pseudostem (GS), grass seed head (GSH), clover leaf and petiole (CL) and dead herbage (DH). OE samples were also dissected into similar components.

Analysis of alkanes in faeces and herbage samples

Sample preparation and extraction of alkanes from faeces and herbage samples was carried out by following the standard methodology of Mayes and colleagues (1986) with some modifications. The modifications include: saving on internal standards ($C_{34}H_{70}$) by calculating faecal ratios of C_{32} and C_{33} directly from the peak areas on the chromatographic trace when estimating intake, use of industrial hexane instead of the more expensive analytical grade n-heptane, and digesting samples in an oven instead of heating blocks (see Kitessa *et al.,* 1995 in Appendix 3.1a for modification and Appendix 3.1b for validation of this modified approach). Freeze-dried and ground faeces (1 g) and herbage (2 g) samples were weighed into Pasteur tubes (70 ml) with screw tops (lined with polytetrafluoroethylene-PTFE). An internal standard containing 0.5 mg C_{34} (tetratriacontane: $C_{34}H_{70}$) in 0.200 g Undecane ($C_{11}H_{24}$) was added to each herbage (but not faecal) sample. Samples were then saponified by adding 10 ml 1.5 M KOH solution per g of sample and digesting in an oven at 90 °C for 3.5 hours. After the first hour, each tube was shaken (to avoid crusting on the wall of test tubes) and the lids tightened to avoid evaporation (Screw tops may initially come loose due to heating).

After removal from the oven, samples were allowed to cool slightly before adding 8 ml of industrial hexane and 5 ml of distilled water to each sample, after which they were placed on a rack attached to a magnetic stirrer and shaken until the contents separated into two phases. The top phase (containing hydrocarbons) of each sample was removed into a labelled vial. Shaking was repeated after adding a further 5 ml industrial hexane to each sample. The top phase from each sample was added to the respective first extract. The solvent from each extract was evaporated by heating in an oven at 90 °C . After adding 2 mls of industrial hexane, impurities from these extracts were removed by washing each sample down a silica gel column (Kieselgel, 70- 325 mesh) prepared in a 5 ml Gilson pipette on a raised rack with Pasteur tubes underneath to collect the eluent. Each sample was eluted five times with 2 ml industrial hexane. The purified extract was dried at 90 °C. Finally, the solutes were re-dissolved in 0.8 ml n-heptane and transferred to GLC vials.

For both faeces and herbage samples, 1 µl of each purified extract was injected (splitless injection) into a gas chromatograph with flame ionisation detector (Hewlett Packard GC, HP 6890 Series) with a BP-1 megabore capillary column (30 m long with an internal diameter of 530 µm and a film thickness of 1 µm). Flow rate for carrier gas (He) was 4.2 ml per minute and for make-up gas (N_2) was 45.8 ml per minute. Injection and detector port temperature was 300 °C. The oven temperature ramp was as follows: 245 °C for 5 minutes, rising 4 °C per minute to 310 °C and held at 310 °C for 5 minutes. After each sample, the oven temperature was raised to, and held at 320 °C for 2 minutes before the next injection. Data acquisition and quantification was done by using Hewlett Packard GC ChemStation software. Identification of individual n-alkanes was based on retention times relative to known standards (Mayes *et al.,* 1986).

Pasture intake was estimated by using an expression derived from that originally given by Mayes *et al.* (1986).

$$Intake = \frac{Dj}{\frac{Fj}{Fi} * Hi - Hj}$$

(Equation 3)

where *Dj* is the amount of C_{32} dosed daily, *Fj* and *Hj* faecal and herbage concentrations of C_{32} and *Fi* and *Hi* are faecal and herbage concentration of C_{33}, respectively. Chromium-based estimates of OMI were obtained by predicting faecal output and estimating the digestibility of OE *in vitro*.

$$Faecal\ output\ (kg) = \frac{g\ Cr_2O_3\ dosed}{g/kg\ of\ Cr_2O_3\ in\ faeces}$$

Equation 4

$$Intake\ (kg) = \frac{Faecal\ output\ (kg)}{1 - digestibility}$$

Equation 5

3.2.5.3. Grazing behaviour

Time spent grazing was indirectly evaluated by recording the number of animals seen grazing by scan sampling every 15 minutes over 24 hours. This was done on four occasions during the total trial period (one at each intake measurement period and one a week after the last intake measurement period). At each observation, recording started at 1145 hours, 30 minutes after a new daily allowance had been allocated to the rotationally co-grazed animals. Bite rates per minute of cattle on both treatments was recorded over two days following each intake measurement period. This was performed visually as well as using a video recorder. Only data based on 30 or more continuous bites were considered for analysis. At the end of the experiment, cattle on rotational stocking were shifted to the continuously stocked pasture and vice versa. Their respective bite rates were recorded after they had stayed 24 hours on the new pasture. They were then returned to their treatment pasture and their bite rates again recorded after 24 hours. Two heifers from each treatment were selected to measure bite weight on turfs dug up from each treatment pasture. Heifers were offered turfs from pasture they had been grazing as well as those from the opposite treatment pasture.

3.2.5.4. Pasture height

On both treatments SSH was measured daily by using an 'HFRO sward stick' (Barthram, 1986). On the continuously stocked pasture, 60 SSH measurements were taken daily by walking through the pasture in a "W pattern". Using a similar pattern, 40 measurements of pre- and post-grazing SSH were recorded on the rotationally stocked area, i.e. the new ungrazed area and the equivalent area removed from grazing, respectively.

3.2.5.5. Pasture mass

Pasture samples for prediction of pasture mass during intake measurement periods were obtained by cutting four quadrats (0.2 m^2) from each treatment on days 6, 8 and 10 of the intake measurement period. Each time quadrats were systematically taken from each paddock in such a way that one quadrat represented a high, two an average, and one a low pasture height as determined visually. The average height in each quadrat was determined by taking 20 SSH measurements. Pasture mass (DM per ha) was predicted by using regression equation of pasture mass and SSH established from the combined data from three-day samplings (12 data points per period, i.e. 3 days x 4 quadrats). See Appendix 3.2 for regression equation. Material harvested from each quadrat was subsampled (*ca.* 20 g fresh weight) and dried at 70 °C for 48 hours to determine DM content.

3.2.5.6. Digestibility

Diet *in vitro* DM and OM digestibilities were determined from OE samples using the two stage pepsin-cellulase assay (Jones and Hayward, 1975). Duplicate 0.5 g freeze-dried and ground (1 mm sieve) samples were digested *in vitro* by following the method of Jones and Hayward (1975) with some modifications (McLeod and Minson, 1978, 1980; Clarke *et al.,* 1982). Samples were incubated in 30 mls of 0.3 % (w/v) pepsin (Pepsin A powder BDH Chemicals Ltd, Poole, England) in 0.125 HCL solution at 50 °C for 68 hours followed by digestion in 30 mls of buffered cellulase (Onzuka 3S cellulase, Yakult and Honsha Co. Ltd) solution (0.025 g cellulase per 0.5 g sample) at 50 °C for a further 48 hours. The average of duplicate samples (corrected for *in vivo* values) was considered the digestibility of each sample unless duplicates differed by more than 5 %, in which case the assay was repeated. A subsample of each sample used for *in vitro* digestibility was dried at 90 °C for 24 hours and then ashed in a furnace at 550 °C for 8 hours to determine OM content of the DM.

3.2.6. Statistical analysis

Average daily liveweight gain (LWG) of each species under the two stocking systems was compared by testing for difference in the regression coefficients (Snedcor and Cochran, 1980) of liveweight on number of days from the start of the experiment. The samples sizes were 180 (9 animals x 20 liveweights including initial weight) for cattle and 540 (27 animals x 20 liveweights) for sheep (see ANOVA in Appendix 3.3a,b for degree of freedom). Differences in mean final fasted liveweights were compared by using a Student T-test (independent samples with equal variance) as well as using analysis of covariance where initial liveweight was used as a co-variate (Appendix 3.3c).

Pasture intake comparisons within an intake measurement period were done by using a T-test (independent samples with equal variance). Levels of pasture intake of cattle and sheep over the whole period were compared separately in a 2 x 3 (stocking systems x period) general linear model (GLM) analysis of variance in SAS (SAS Institute, 1985). For each animal species, there were 48 data points (8 animals x 2 stocking systems x 3 measurement periods). See ANOVA in Appendix 3.4a,b.

Similarity coefficient between animal diet and sward, and cattle and sheep diets was calculated using Kulcyznski's similarity index given by Holecheck *et al.* (1984). Accordingly:

$$S = \frac{(2)(W)(100)}{(A+B)} \qquad \textbf{(Equation 6)}$$

where S is similarity index, W is the sum of the quantity of each plant part/species that the two variables (diet vs sward or diet 1 vs diet 2) have in common, A represents the quantity of all species in variable A, and B represents the quantity of all species/plant parts in variable B.

Change in bite rate of heifers in each treatment on different pastures was analysed using a paired T-test. Bite rates of continuously and rotationally stocked heifers on their respective treatment pasture as well as on opposite treatment pastures were analysed as independent samples using a T-test. The number of animals seen grazing during 24 hour observations was analysed using ANOVA, 4 observation dates x 2 systems, for each animal species . The data was analysed in two ways: (i) considering all 15 minute observations over 24 hours, and (ii) excluding observations during extended rest overnight. All graphic presentations were done by using SigmaPlot (1986).

3.3. RESULTS

3.3.1. Climate

Monthly rainfall and mean daily temperature for the trial period are shown in Fig. 3.1. Only during February did the amount of rainfall considerably fall below the previous ten year average (1982-1991) for the site. All the months over the trial period had cooler mean daily temperature than the long-term average.

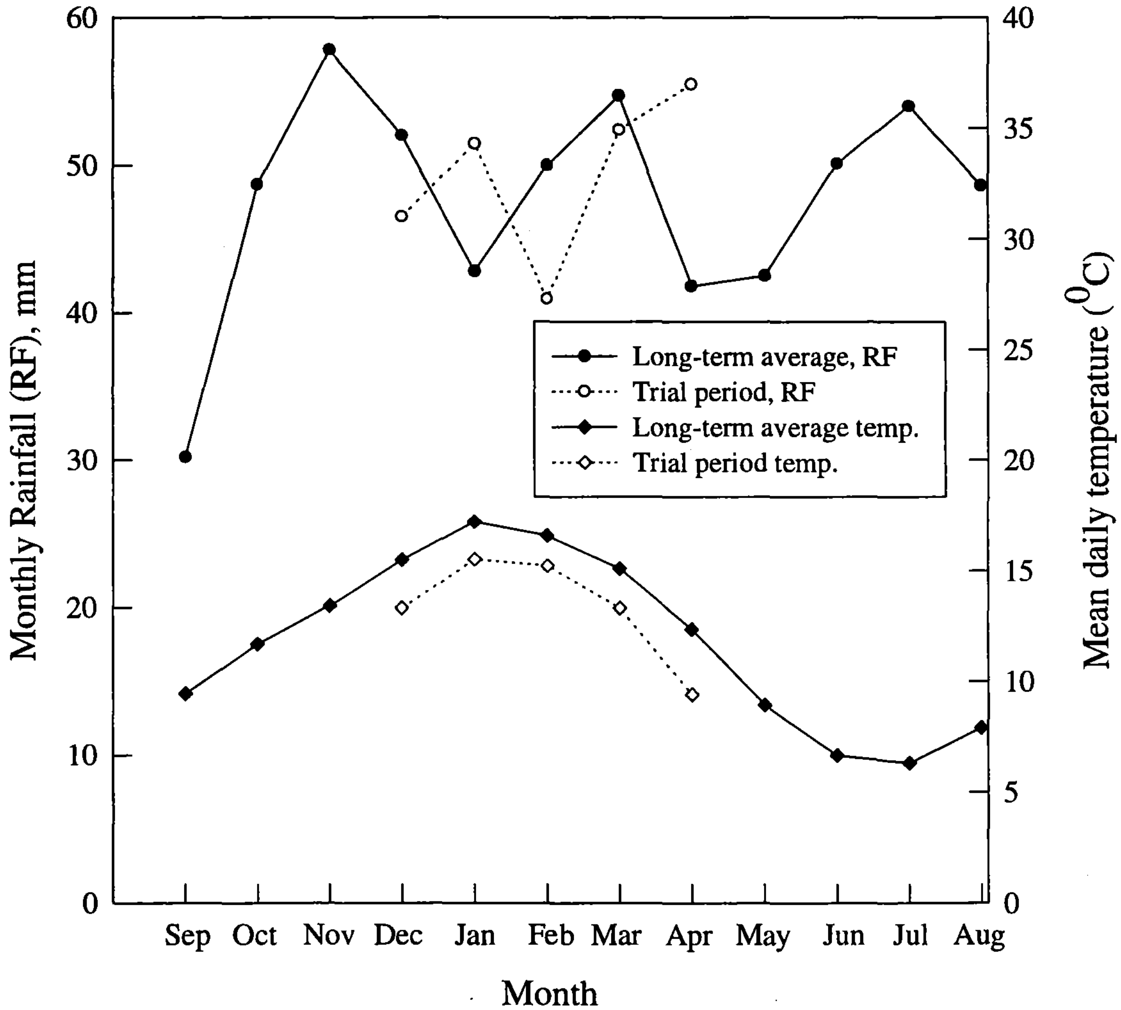

Fig. 3.1. Mean daily ambient temperature and total monthly rainfall during the trial period: December '92 - April '93. (Long-term averages: 1982-1992).

3.3.2. Sward characteristics

Pasture height

On the continuously stocked pasture mean sward height over the whole period (5.1±0.03 cm), as well as during each of the three intake measurement periods (5.0±0.10, 5.2±0.10 and 5.1±0.09, respectively) was very close to the planned 5 cm (Fig. 3.2). Over the whole experimental period, pre- and post-grazing SSH on the rotationally stocked pasture averaged 15.9±0.12 and 5.6±0.07 cm, respectively. During intake measurement periods the mean pre-grazing height was 18.6±0.59, 15.7±0.39 and 16.2±0.35 cm; corresponding values for the mean post-grazing height were 4.7±0.19, 4.3±0.16 and 5.9±0.16 cm, respectively (Fig. 3.2).

Pasture mass

Under continuous stocking, mean pasture mass was 1890±52 kg ha^{-1} and ranged from 1800-2000 kg ha^{-1} at intake periods (Table 3.2). Overall, mean pre- and post-grazing pasture mass for the rotationally stocked group was 4020 and 1990 kg ha^{-1}, respectively (Table 3.2). For both stocking systems, mean overall mass per ha was calculated by taking the mean height over 134 days and fitting the mass-height regression established on quadrat cuts from all the three intake measurement periods. Therefore, the overall value may lie outside the range over the three measurement periods, as in overall post-grazing mass in Table 3.2.

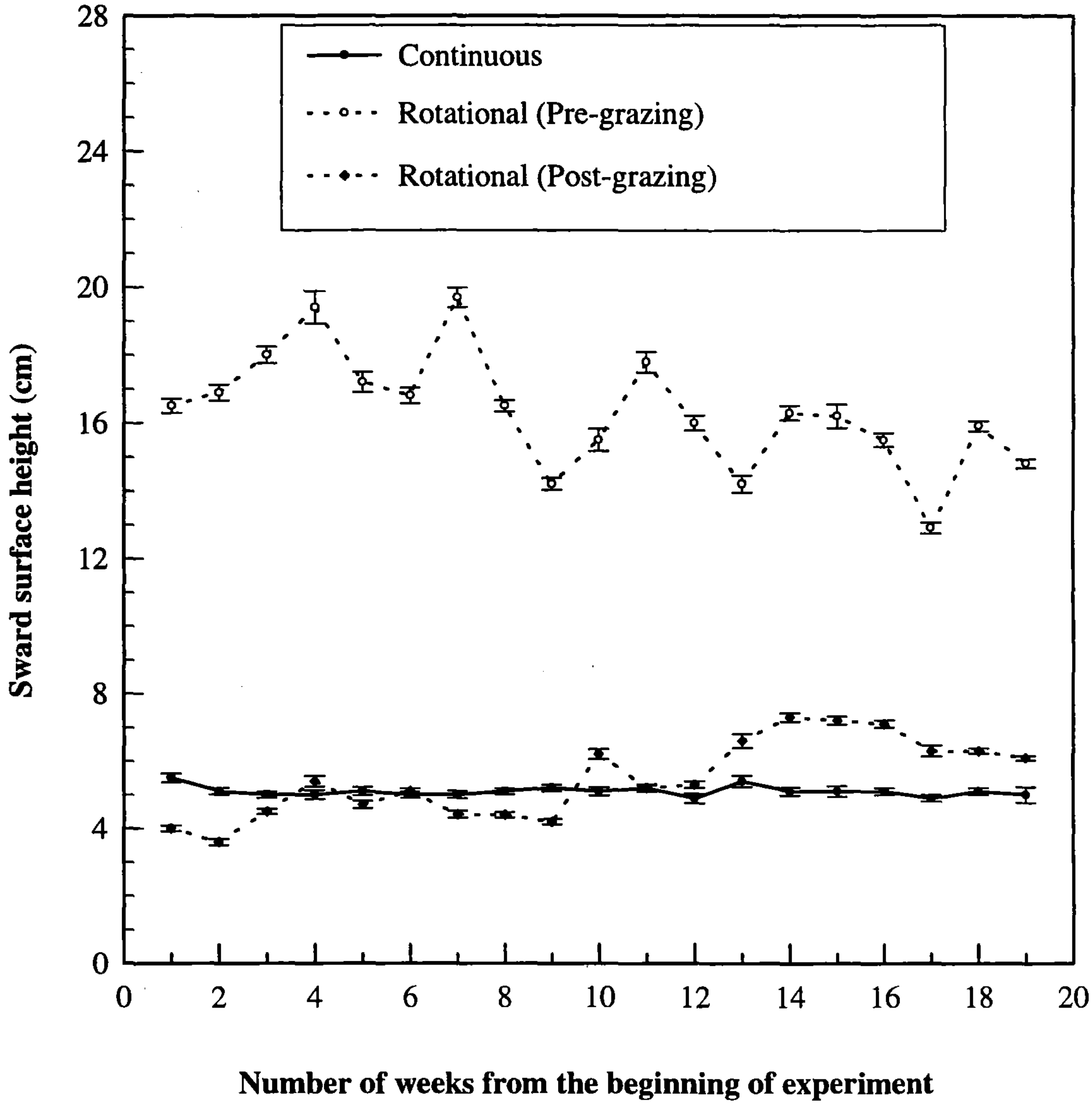

Fig. 3.2. Mean weekly sward height of pasture under continuous or rotational stocking during experimental period.

Table 3.2. Mass and botanical composition of pastures co-grazed by cattle and sheep using continuous or rotational stocking.

		Measurement Period			
Pasture variable	System	Overall	I	II	III
Pasture mass$^{\alpha}$, kg ha^{-1}	Continuous	1890	1875	1992	1765
		(52)	(89)	(100)	(94)
	Rotational:				
	Pre-grazing	4020	4636	4093	3382
		(118)	(123)	(211)	(134)
	Post-grazing	1990	1446	1771	1839
		(119)	(125)	(251)	(214)
Clover (% DM)	Continuous	33.7	35.3	42.7	23.1
	Rotational (pre-)	42.2	46.9	43.1	36.6
Leaf:stem ratio (DM basis)	Continuous	2.2	1.1	1.5	4.1
	Rotational (pre-)	3.9	2.2	3.9	5.5
Dead herbage (% DM)	Continuous	12.7	14.1	14.4	9.7
	Rotational (pre-)	9.7	6.4	14.9	7.7
Grass seedhead (% DM)	Continuous	4.9	4.7	4.4	5.6
	Rotational (pre-)	4.2	10.1	1.5	1.0

$^{\alpha}$ Figures in parenthesis represent standard error of prediction. See Appendix 3.2 for regression equations.

Botanical composition

Percent clover in DM was slightly higher in rotationally than continuously stocked pasture during periods I and III (Table 3.2). In period II, however, the clover content of both pastures was similar (43 %). Over the whole period, clover accounted for 42 and 34 % of the DM in rotationally and continuously stocked pastures, respectively. There was a rise in leaf:stem ratio of pasture under both stocking systems between each successive period (Table 3.2). However, on the continuously stocked pasture there was a greater increase in leafiness from Period II to Period III than from the first interval. On the rotationally stocked pasture, leaf:stem ratio increased by about 1.6 between each period (Table 3.2). Although, this ratio appears higher for the rotational pasture, the parts classified as stem under continuous stocking were mainly leaf sheath and young stems, while stem under rotational stocking was largely composed of well defined and extended stems. The percentage of dead herbage in total DM in continuously and rotationally grazed pastures was low overall (13 vs. 10 % DM, respectively) and did not show any pattern of change with time in either system (Table 3.2). Rotationally stocked pasture had the highest proportion (10.1 %) of grass seedhead (Period I, Table 3.2), but overall mean percent grass seedhead was not different between continuously and rotationally stocked pastures (4.9 vs 4.2 % DM, Table 3.2).

3.3.3. Weekly liveweight

The weekly liveweight of sheep on both grazing treatments are shown in Fig. 3.3. During all (but the first) weekly liveweight measurements, mean liveweight was slightly higher for continuously than rotationally stocked sheep. However, at no weekly observation did the mean liveweight of sheep on the two systems differ significantly ($P<0.05$). The maximum (week 10) and minimum (week 7) differences were 3.66 and 0.06 kg, respectively, in favour of continuously stocked sheep. Weekly liveweight of cattle on the continuously stocked pasture consistently increased over time, while liveweight of those rotationally stocked followed a less consistent pattern until the 11th week (Fig. 3.4). Over weeks 11-19 liveweight of rotationally stocked heifers was consistently higher than those of the continuously stocked group (Fig. 3.4). Details of statistical analysis of daily liveweight gain are presented in the next section. Raw data for sheep and cattle LWG are given in Appendix 3.6a and 3.6b, respectively.

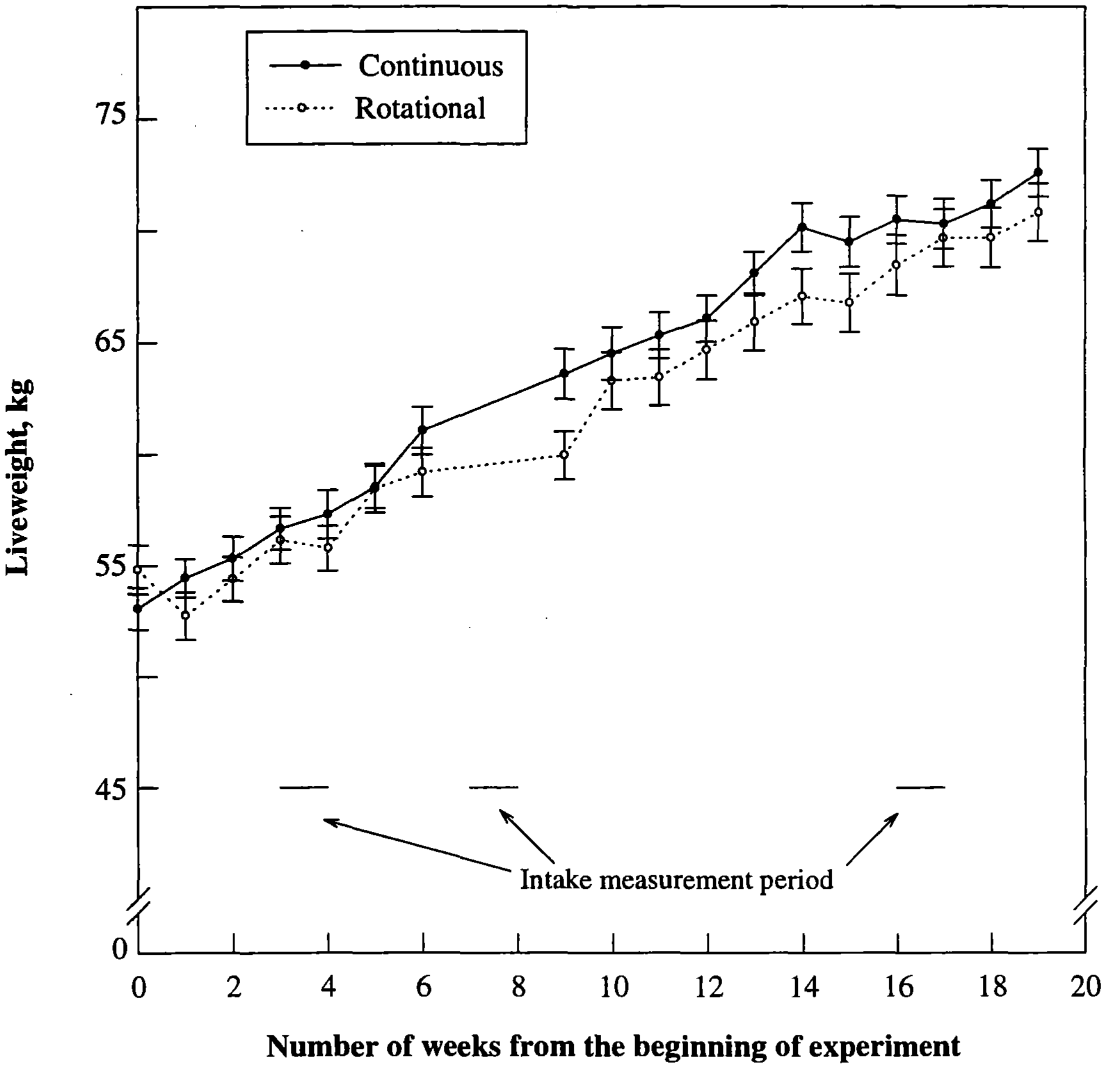

Fig. 3.3. Weekly liveweight of sheep co-grazed with cattle using two stocking systems during the period: Dec.'92 - Apr. '93. (No unfasted weight data for week 8).

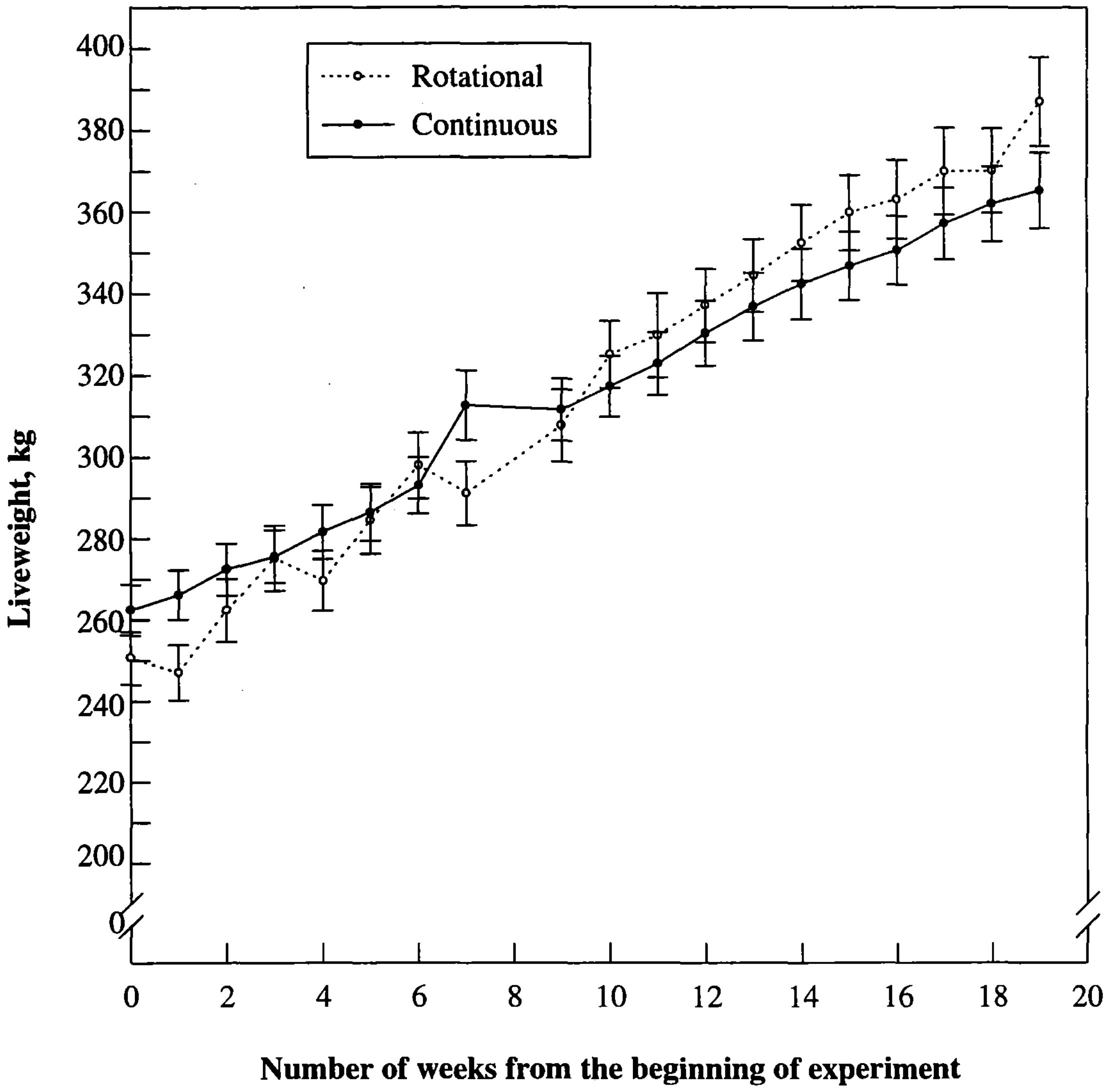

Fig. 3.4. Weeekly liveweight of cattle co-grazed with sheep using two stocking systems. (See Fig. 3.3 for week 8 gap and intake measurement periods).

3.3.4. Daily liveweight gain

Neither the daily liveweight gain nor the final fasted liveweight of sheep was significantly different between treatments (Table 3.3). In contrast, cattle continuously co-grazed with sheep grew about 200 g day^{-1} slower than those rotationally co-grazed with sheep (800 vs 1040 g day^{-1}). Consequently, at the end of the experiment they were on average 18 kg heavier than their continuously stocked counterparts (Table 3.3). Although there was no statistically significant difference between treatments in the initial weight of cattle, the use of initial weight as a covariate to adjust for difference in initial liveweight was significant ($P<0.01$). Final liveweight (adjusted for initial liveweight) showed nearly a

30 kg difference (P<0.01) in final fasted liveweight in favour of the rotationally stocked cattle (Table 3.3).

Table 3.3. Daily liveweight gain (DLWG) and final fasted liveweight of sheep and cattle co- grazed using two stocking systems. (DLWG values are regression coefficients).

	Stocking system			
	Continuous	Rotational	s.e.m.	p[δ]
Initial liveweight, kg				
Cattle	272	261	6.6	ns
Sheep	53.1	54.8	0.99	ns
DLWG, g day^{-1}				
Cattle	804 (41.6)[β]	1039 (47.7)		**
Sheep	150 (5.8)	138 (6.7)		ns
Final liveweight, kg				
Sheep	68.5	65.6	1.15	ns
[ϕ]Cattle (1)	356	374	9.50	ns
Cattle (2)	350	381	2.17	**

[β] Figures in parenthesis represent the standard error of slopes (DLWG).
[ϕ] 1 = Actual liveweight; 2 = Liveweight adjusted for difference in initial liveweight.
[δ] *, Significantly different at P<0.05; **, Significantly different at P<0.01; ns, not significantly different at P<0.05. (For all tables hereafter).

Liveweight gain per ha calculations are summarised in Table 3.4. Since this was calculated as a single value it precluded test for statistical difference. However, the superior cattle performance under rotational stocking was not at the expense of gain per ha. Overall gain per ha was 6 % higher under rotational than under continuous stocking (Table 3.4). The ratio of cattle:sheep gain per ha was 2.1:1 under rotational stocking, but 1.6:1 under continuous stocking.

Table 3.4. Calculated total liveweight gain per ha on pastures continuously or rotationally co-grazed by sheep and cattle for 134 days.

	STOCKING SYSTEM					
	CONTINUOUS		ROTATIONAL		Difference[δ]	
	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
Liveweight gain, g day^{-1}	804	150	1039	138	**	ns
Animals ha^{-1} day^{-1}	3.6	12.3	3.3	11.6	ns	ns
Grazing days ha^{-1}	482	1648	442	1554		
Total Gain, kg ha^{-1}	388	247	459	215	+18 %	-13 %
Overall gain, kg ha^{-1}	**635**		**674**		**6.1 %**	

[δ] Percentage = (Rotational-Continuous)/Continuous.

3.3.5. Pasture intake

Organic matter intake (OMI)

There was no significant difference in daily OMI of sheep under the two stocking systems, either overall (mean of all three measurements) or during each intake measurement period (Table 3.5). For cattle, there was a significant period x stocking system interaction. Cattle that were rotationally co-grazed with sheep had significantly higher OMI per day during the last two intake measurement periods, but significantly lower OMI day^{-1} during Period I (Table 3.5). Consequently, overall mean OMI per day was 26 % higher (6.3 vs. 7.9 kg) for heifers under rotational than those under continuous stocking (Table 3.5). Estimates for overall mean OMI per kg metabolic body weight (mean intake ÷ mean $LW^{0.75}$) were 87.5 and 105.8 g for continuously and rotationally stocked cattle, respectively. The respective values for sheep were 65.1 and 64.4 g per kg $LW^{0.75}$.

Table 3.5. Pasture intake (kg organic matter $head^{-1}$ day^{-1}) of cattle and sheep co-grazed using continuous or rotational stocking.

		Measurement Period			
Species	System	Overall	I	II	III
CATTLE	Continuous	**6.31**	8.22	6.40	4.53
	Rotational	**7.94**	6.68	8.35	8.78
	Difference	*	*	*	**
	s.e.m.	0.32	0.08	0.08	0.08
	CV %	22.1	21.1	21.3	23.6
SHEEP	Continuous	**1.44**	1.38	1.22	1.72
	Rotational	**1.40**	1.43	1.29	1.49
	Difference	ns	ns	ns	ns
	s.e.m.	0.04	0.08	0.08	0.08
	CV %	15.2	15.4	17.2	13.4

Digestible organic matter intake (DOMI)

In both stocking systems, the DOMI of sheep was about 1 kg per day (Table 3.6). The estimated cattle DOMI per day was significantly lower (4.8 vs 6.2 kg) under continuous than rotational stocking ($P<0.01$, Table 3.6). Consequently, calculated DOMI per unit metabolic body weight of continuously stocked heifers was about 30 % lower than rotationally stocked ones ($P<0.05$, Table 3.6).

Table 3.6. *In vitro* digestibility of organic matter (OMD) and digestible organic matter intake (DOMI) of sheep and cattle co-grazed using continuous or rotational stocking.

			$DOMI^{\beta}$	
Species	System	OMD^{α} %	kg $hd^{-1}d^{-1}$	g $(kg.LW^{0.75})^{-1}$
CATTLE	Continuous	75.8	4.8	63.7
	Rotational	78.0	6.2	82.3
	Difference	ns	**	*
SHEEP	Continuous	73.5	1.1	49.8
	Rotational	75.8	1.1	49.8
	Difference	ns	ns	ns

$^{\alpha}$ Based on oesophageal extrusa samples.
$^{\beta}$ DOMI = OMI x OMD.

For continuously stocked sheep, in Period III where both chromic oxide and alkane (C_{32}) were used as faecal markers, alkane-based sheep daily OMI estimates were slightly lower (12 %) than that obtained using chromic oxide (Table 3.7). For rotationally stocked sheep, however, the two techniques provided significantly different estimates of daily OMI; 60 % higher for chromium than alkane-based estimate (1.5 vs. 2.4 kg day^{-1}). In both stocking systems, the techniques had similar coefficients of variation. The conversion of OMI to OMI per unit metabolic body weight did not improve the precision of either technique, as indicated by the CV (Table 3.7). Across the three intake measurement periods the CV with which OMI was estimated was similar for continuously and rotationally stocked sheep (14.9 vs 13.9 %), but slightly higher for rotationally stocked cattle than those continuously stocked (23.4 vs 15.8 %).

Table 3.7. Comparison of alkane and chromium based estimates of OMI during the third intake measurement period.

Variable	System	Alkane	Chromium
OMI, kg day^{-1}	Continuous	1.72 (17)	1.90 (23)
	Rotational	1.49 (18)	2.41 (19)
OMI$^{\alpha}$ (LW$^{0.75}$)$^{-1}$, g day^{-1}	Continuous	70 (17)	73 (21)
	Rotational	63 (17)	102 (16)

$^{\alpha}$ Calculated as the average of each animal's OMI divided by its LW$^{0.75}$.
Figures in parenthesis are coefficients of variation.

3.3.6. Grazing behaviour

Bite rates

Over the 19 week period, heifers that continuously stocked the 5 cm pasture developed a significantly ($P<0.05$) faster bite rate min^{-1} than those on the rotationally stocked pasture (62 vs 56 bites min^{-1}). When introduced to the opposite treatment pasture, both groups decreased their bite rate by 6-7 bites per minute ($P<0.05$). Interestingly, heifers from both continuous and rotational stocking treatments grazed the rotational pasture with a similar bite rate, 56 bites min^{-1} (Table 3.8). When re-introduced to their former treatment pasture, the continuously stocked heifers increased their bite rate back to the previous bite rate, about 60 bites min^{-1}. When re-introduced to their pasture, rotationally stocked heifers grazed at a significantly faster rate than they did before they were taken to the continuously stocked pasture (Table 3.8).

Table 3.8. Bite rates of heifers on their accustomed treatment pasture, on the opposite treatment pasture and after return to their usual treatment pasture.

Treatment heifers	Pasture grazed (in this order)	Bites min^{-1}
Rotational	1. Rotational	56^{c}
	2. Continuous	49^{d}
	3. Rotational	66^{a}
Continuous	1. Continuous	62^{ab}
	2. Rotational	56^{c}
	3. Continuous	60^{bc}
Overall s.e.m.		0.71

Figures with the same letters are not significantly different (P<0.05).

Grazing time

The mean proportion of animals seen grazing per 15-minutes observation period on continuous and rotational stocking treatments was different between heifers (P<0.01) but not between sheep (Table 3.9). On average, the proportion of heifers seen grazing per observation on the continuous stocking treatments was 13 percentage points (0.44 vs. 0.31) higher than their rotational counterparts (Table 3.9). Further analysis of the spread of grazing time over hours of the day for cattle is shown in Fig. 3.5. Heifers in both treatment groups started grazing about the same time (0615 hours) but rotationally stocked heifers often stopped grazing earlier and started waiting (0800-1030 hours) for their daily pasture offering (Fig. 3.5). Both groups of animals started their overnight rest about the same time (2100 hours). Grazing activity between midnight and 0600 hours was less common for the rotational than the continuous stocking group (Fig. 3.5).

Table 3.9. Proportion of sheep and cattle seen grazing every 15 minutes over 24 hours on continuous and rotational stocking treatments. (Values are mean of four 24-hour observations).

		Stocking system			
Data	Species	Continuous	Rotational	s.e.m.	Diff.
1. *All 24 hour*	Cattle	0.44	0.31	0.030	**
	Sheep	0.38	0.35	0.029	ns
2. *Excluding overnight rest*$^{\alpha}$	Cattle	0.49	0.36	0.032	**
	sheep	0.53	0.50	0.033	ns

$^{\alpha}$ For each species, values were excluded where both treatment groups were not grazing.

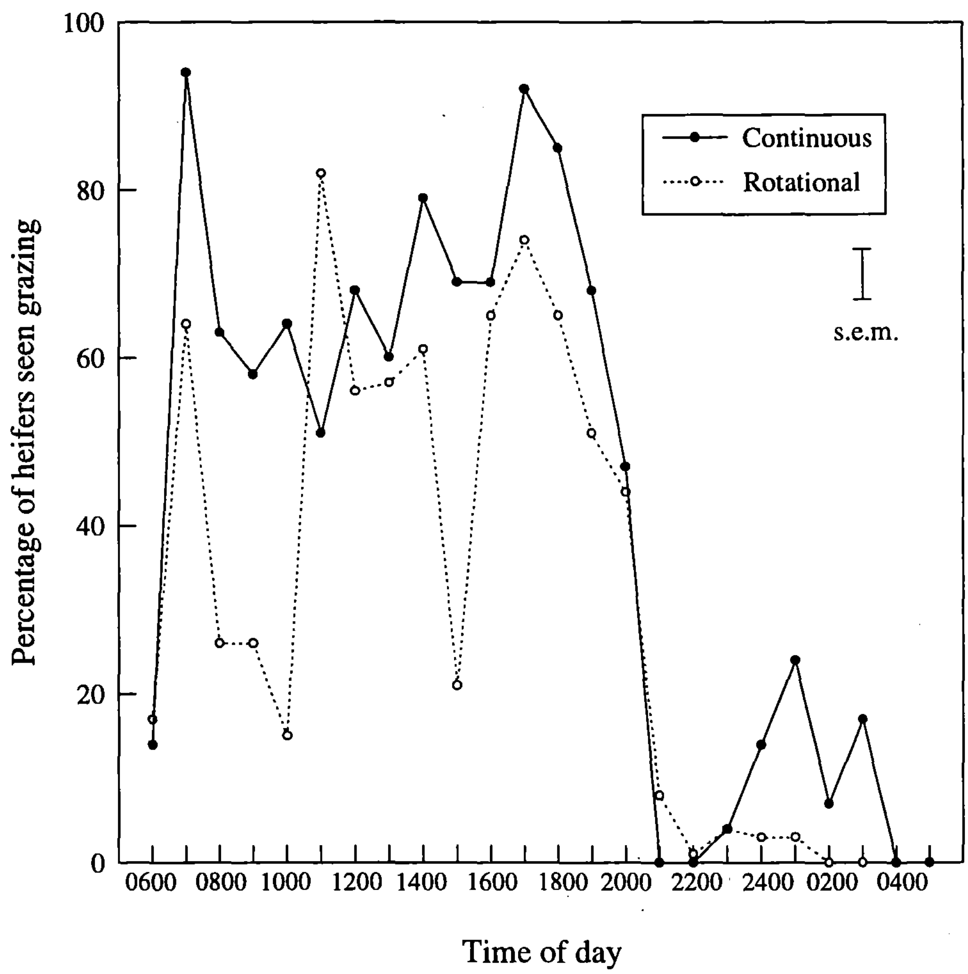

Fig. 3.5. Mean proportion of heifers seen grazing on continuous or rotational stocking treatment pasture during four 24-hour observations.

Bite weight

Attempts at the end of the trial to measure and compare bite weight from turfs dug out from the treatment pastures were unsuccessful because during the acclimatisation period heifers from both treatment groups refused to graze turfs from the continuously stocked pasture. Even after 24 hour total feed restriction both groups refused to graze turfs from the continuously stocked pasture. These turfs had the same SSH as the pasture itself which had been grazed by the continuous stocking treatment heifers for the preceding 19 weeks.

3.3.7. Diet composition

Each botanical component, except grass seedhead, had a greater variance under rotational than under continuous stocking (Table 3.10). However, only the stem and clover were distributed with significantly different ($P<0.05$) variance in the two pasture treatments. Table 3.10 also provides data on within-species, between treatments comparison of the botanical composition of cattle and sheep diet. The diet of continuously stocked sheep contained 20 percentage points less grass leaf (32 vs 52 %) and 13 percentage points more clover (57 vs 44 % DM) than that of rotationally stocked sheep ($P<0.05$). In contrast, cattle diet had 46 and 56 % grass leaf under continuous and rotational stocking ($P=0.07$); the clover content of cattle diet in both systems was about 20 % of DM intake. There was little difference between treatments in other diet components of cattle or sheep. Between species, within treatment comparisons showed greater leaf:stem and lower grass:clover ratio in sheep than in cattle diet under both stocking systems. For instance, the leaf:stem ratio under continuous stocking was 4:1 in sheep diet, but 2:1 in cattle diet (Table 3.10). The respective values under rotational stocking were 13:1 and 3:1 (Table 3.10). Differences in other botanical components in both sward and diet were negligible (Table 3.10).

Table 3.10. Botanical composition (DM basis) of cattle and sheep diet under continuous and rotational stocking.

		Plant parts				
Stocking system	Herbage source	Grass stem	Grass leaf	Clover	Dead herbage	Grass seedhead
Continuous	Sward	0.17	0.32	0.34	0.13	0.05
	s.e.m.	*0.100*	*0.606*	*0.163*	*0.476*	*0.216*
Rotational	Sward	0.10	0.35	0.42	0.10	0.04
	s.e.m.	*0.258*	*0.837*	*0.361*	*0.554*	*0.163*
Continuous	Sheep diet	0.08	0.32	0.57	0.014	0.009
Rotational	Sheep diet	0.04	0.52	0.44	0.006	0.003
	Difference	ns	*	*	ns	ns
Continuous	Cattle diet	0.24	0.46	0.20	0.04	0.09
Rotational	Cattle diet	0.18	0.56	0.22	0.09	0.09
	Difference	ns	*	ns	ns	ns

Similarity coefficients between cattle and sheep diets and the sward grazed in each system are summarised in Table 3.11. The similarity coefficient between sheep diet and sward on both treatments was similar, at about 0.80. Similarity coefficient of cattle diet to sward grazed was higher under continuous than rotational stocking (0.93 vs 0.74). In addition, cattle and sheep diet had a lower similarity coefficient under continuous than under rotational stocking (0.61 vs 0.76).

Table 3.11. Similarity coefficients of cattle diet, sheep diet, and the sward they grazed under two stocking systems.

Stocking system	Variables	Kulcyznski's Coefficient
Continuous	Sward vs sheep diet	0.76
	Sward vs cattle diet	0.93
	Cattle diet vs sheep diet	0.61
Rotational	Sward vs sheep diet	0.82
	Sward vs cattle diet	0.74
	Cattle diet vs sheep diet	0.76

3.4. DISCUSSION

The primary objective of this study was to demonstrate if part of the reason for equivocal reports in the literature on the relative effects of mixed grazing on the intake and LWG of cattle and sheep could be due to differences between experiments in the stocking system applied. This discussion will therefore primarily consider whether the data from this study corroborate this premise. Subsequently, separate discussion on data on each of the variables, i.e. liveweight gain, intake, diet composition and grazing behaviour is presented. Finally, the pros and cons of using similar weekly liveweight change in sheep to provide equivalence between the two stocking systems are considered.

It was evident from this study that under sward conditions which produced similar liveweight gain in sheep, continuously co-grazed cattle grew only at 77 % of the growth rate achieved by their rotationally stocked counterparts, which grew at about 1040 g day^{-1}. This was supported by the lower daily OMI (20 %) of cattle under continuous than rotational stocking. Data on pasture and diet composition of animals also concurs with the observed difference in liveweight gain, because the lower similarity index between sheep diet and the sward under continuous than rotational stocking suggests sheep may have gained advantage over cattle under continuous stocking.

Overall, data from this study lends support to the premise that selection of a stocking system will affect the outcome of mixed grazing, at least that between cattle and sheep. Accordingly, grazing cattle with sheep under rotational stocking provides an opportunity for increased output per ha of about 6 %, apparently at no cost to either cattle or sheep daily liveweight gain. It should be noted that this 6 % difference in LWG per ha is a difference between mixed grazing of cattle and sheep under continuous vs rotational stocking, as opposed to the 10-20 % difference in LWG per ha reported for pastures stocked with each species separately versus that co-grazed with both species.

Perhaps an important question at this point would be: is the difference in growth rate of these heifers a reflection of difference in mean sward height (continuous = 5.1 cm vs rotational = 10.8 cm)? If the difference in growth rate of heifers was related to difference in mean sward height, why did the difference in mean grazing height induce different levels of intake and therefore liveweight gain in cattle but not in sheep? A hypothetical relationship between intake (relative to maximum) and sward height for cattle and sheep is presented in Fig. 3.6. This figure is based on the assumption that irrespective of stocking system, the optimum sward height for maximum intake for sheep and cattle is 5-6 cm and 9-10 cm, respectively. This is only for the sake of argument and it is admitted that this may not be the case in all situations. Accordingly, for sheep, increase in height from 5 cm (continuous stocking) to 10.8 cm (rotational stocking) would not result in significant increase in intake as sheep were already near the height deemed to provide their maximum intake (Fig. 3.6).

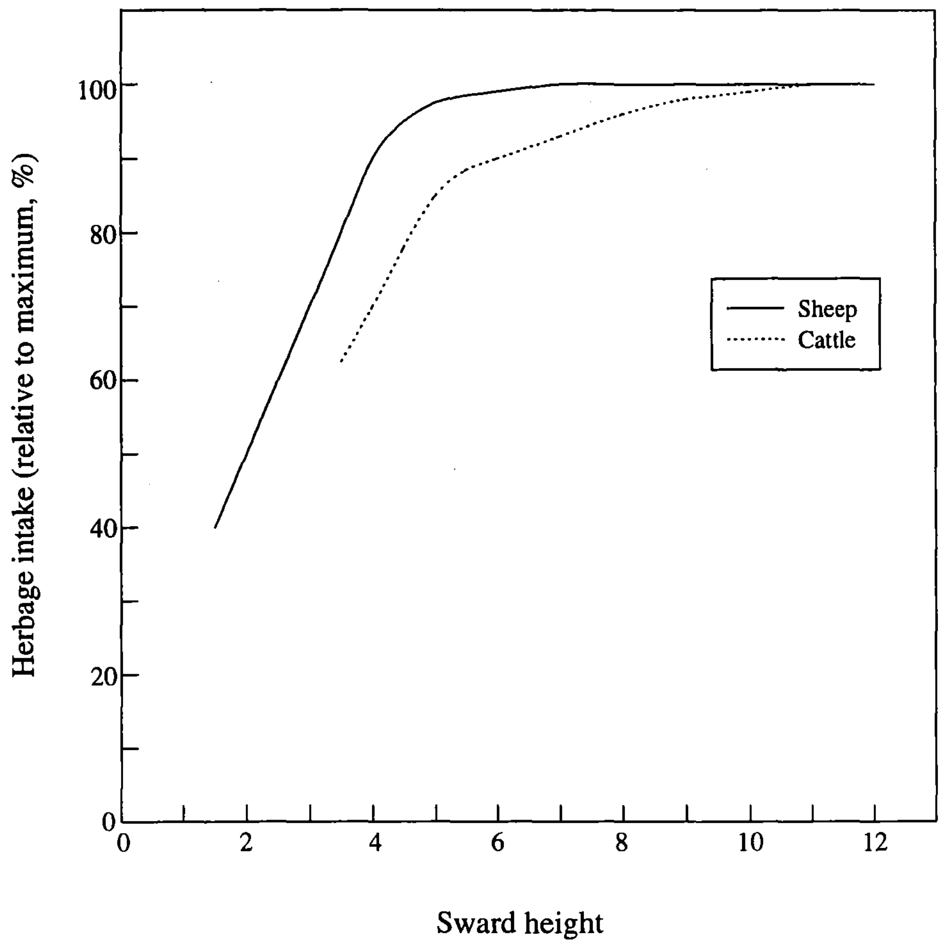

Fig. 3.6. Hypothetical relationship between cattle and sheep intake (relative to maximum) and sward height on temperate pastures (*Adapted from Hodgson, 1990*).

In contrast, mean sward height under continuous stocking was much lower than the sward height deemed to provide maximum intake for cattle, while that under rotational stocking was very close to it. The fact that continuously co-grazed heifers had greater bites per minute and apparently grazed for longer hours per day lends support to this premise that difference in mean height of swards grazed is likely to play a role in the observed difference between growth rate of heifers in the two treatments. Therefore, it is very possible that the difference in LWG between continuously and rotationally co-grazed cattle was a function of both the difference in mean sward height and the interaction between mixed grazing and stocking system. Further study is required to determine the relative importance of these two factors.

In the following sections, data from this study are compared to other published reports. It is worth noting that very few previous studies on mixed grazing of cattle and sheep have adequate data on both liveweight gain and pasture variables (sward height and pasture mass), necessitating some improvisation in discussion of results from this study. Attempts have also been made to compare results from this study to other reports on performance of cattle on pastures of similar sward state to substantiate the role of sward height in the observed difference in LWG of heifers in this study.

3.4.1. Liveweight gain per animal

Due to lack of previous work that has compared mixed grazing under both continuous and rotational stocking to provide any parallel observation, average daily liveweight gain in each treatment, i.e. continuous and rotational stocking, is separately compared to other mixed grazing studies using similar grazing management.

3.4.1.1. Continuous stocking

The growth rate of heifers continuously co-grazed with sheep (800 g day^{-1}) on a 5 cm pasture was greater than that predicted, considering the 9-10 cm height recommended for continuously stocked beef cattle in Table 2.7. Because the heifers were purchased from a hill country farm with a probable restricted winter feeding, there might be some compensatory growth involved. Assuming they had a weaning weight of about 160 kg in April, and considering their initial liveweight of about 190 kg when they were brought to this trial, their liveweight gain over the period May-December period would be about 140 g per day. Therefore, there seems to be some argument for compensatory growth during the experimental period.

Some data from the literature on sward height and liveweight gain of previously non-restricted beef calves, and beef calves previously under restricted winter feeding (i.e. showing compensatory growth) are presented in Fig. 3.7. This data set was selected because observations on both restricted and non-restricted growing beef cattle were done by the same group and under similar environmental conditions. Some of the data in Fig. 3.7 includes calves suckling their mother which may modify the response of LWG to sward height. As shown in Fig. 3.6, LWG data from this study fits better with that observed on previously non-restricted growing cattle than those previously restricted. The animals used in the UK studies were Charolais-cross calves, as compared to Angus-Hereford cross heifers used in this study. Therefore, it is still possible that heifers from this study were exhibiting compensatory growth to attain similar growth rate to that observed in the UK studies.

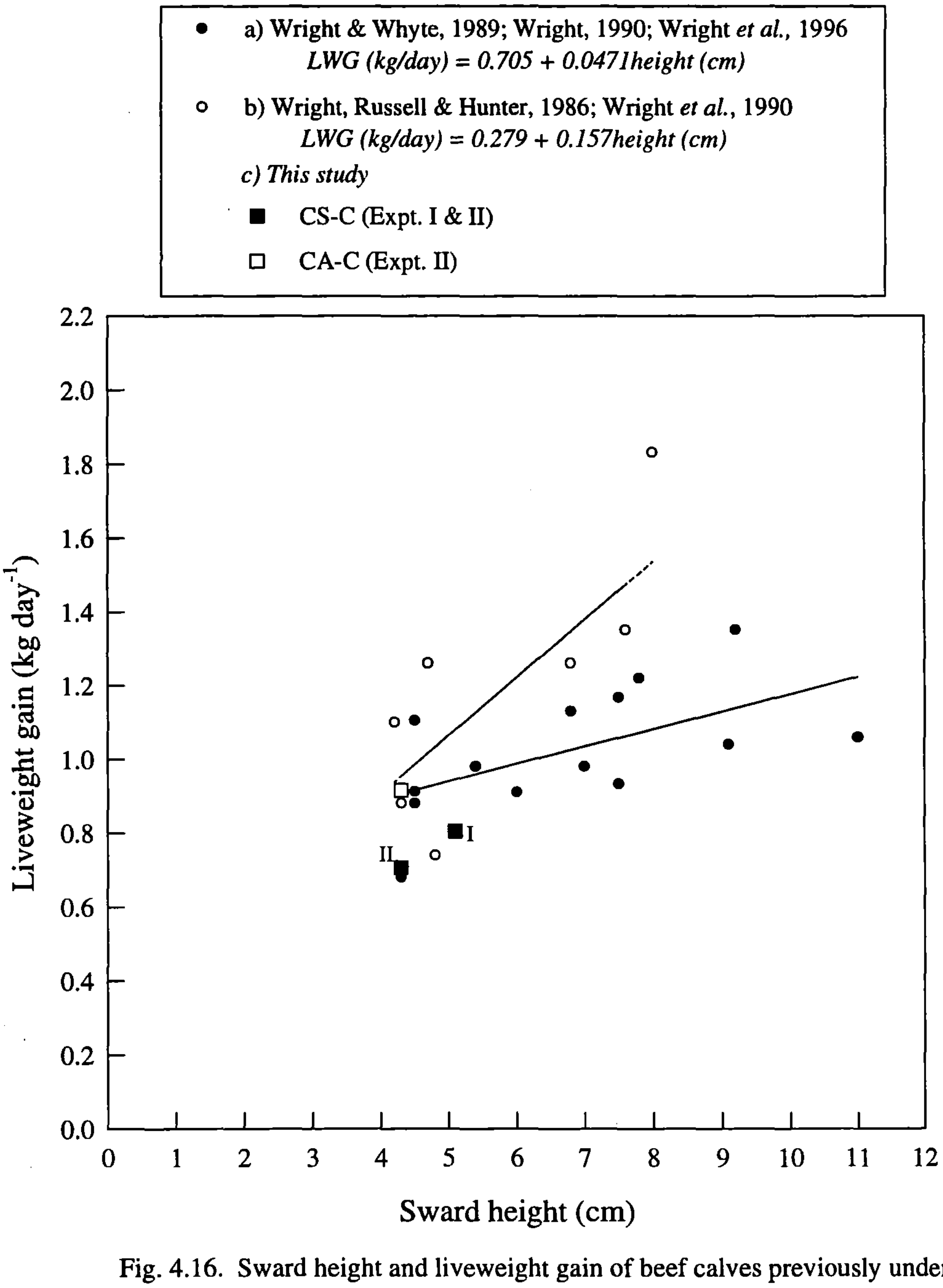

Fig. 4.16. Sward height and liveweight gain of beef calves previously under non-restricted (a), or restricted feeding (b), and cattle from this study (c) under continuous stocking.

Is the critical value for sward height for optimum herbage intake and liveweight gain of cattle different between single and mixed grazing? Unfortunately, previous mixed grazing studies that have presented data on liveweight gain of cattle under continuous stocking (Culpin *et al.*, 1964; Bennett *et al.*, 1970; Hamilton & Bath 1970; Reynolds *et al.*, 1971; Hamilton, 1976) have no data on SSH, making it difficult to make any valid inference.

Comparison of sheep liveweight gain from this study with other published data is constrained by the fact that, in most other studies the sheep LWG data refers to lambs or ewes suckling single (Bennett *et al.*, 1970; Hamilton & Bath 1970; Hamilton, 1976) or twin lambs (Culpin *et al.*, 1964). Nicol and others' (1993) work in the UK, while based on a similar protocol of maintaining sward height at a certain target value, did not include a cattle-sheep combination and is not of relevance. Perhaps, the closest management practice is that of Reynolds and colleagues (1971), where Hereford or Angus steers (initial liveweight, 250 kg) were grazed with crossbred wethers and ewes (initial liveweight = 30 kg). The study had cattle and sheep co-grazed at two ratios, on a pasture maintained (by put-and-take) to provide 500 and 1100 kg ha^{-1} dry *available* (emphasis my own) forage per ha. At the 1:1 ratio both sheep and, to a lesser extent, cattle average daily gain from that report was close to the respective values under this study (Table 3.12).

Table 3.12. Comparison of average daily liveweight gain of cattle and sheep co-grazed using continuous stocking to that reported by other authors.

Experiment	Species ratio (Cattle:Sheep)	LWG (g/hd/d) Cattle	Sheep
This study	*1:1 ($LW^{0.75}$)*	*804*	*150*
Reynolds *et al.*, 1971[α]	1:1 ?	943	152
	1:5 ?	1010	210

[α] Values averaged across residual pasture mass levels of 500 & 1100 kg DM ha^{-1}. No data for each species ratio-pasture mass level combination.

Despite both pasture mass levels (500 and 1100 kg ha^{-1}) being lower than that of the continuous stocking treatment here (1890 kg ha^{-1}), both cattle and sheep average daily liveweight gain from that report at 1 steer:5 sheep ratio were higher than reported here. The fact that 5 month old crossbred wethers and ewes were used in that study, as opposed to two-tooth (18 month old) Corriedale ewe hoggets used in this study, may account for some of the higher growth rate of sheep in that report. Another probable cause may be a difference in estimation of pasture mass per ha. In this study pasture mass per ha referred to total above ground biomass. It is not clear from Reynolds *et al.*'s (1971) protocol how close to the ground they cut the herbage using a sickle bar mower to predict *available* forage per ha.

3.4.2.2. Rotational stocking

Both cattle and sheep daily liveweight gain under rotational stocking, from this study are within the range reported in similar studies (Table 3.13). For both species, average daily gain from this study was slightly higher than that reported by Boswell & Cranshaw (1978), probably a reflection of the higher residual pasture height and mass under this study (Table 3.13). In general, the average daily liveweight gain of sheep in this study (138 g day^{-1}) was lower than that of other studies where sheep LWG refers to lambs grazing with ewes, but comparable to or better than cases where sheep LWG refers to wethers or ewe hoggets (Table 3.13). The average daily gain of cattle in this study was closest to that reported by Nolan and Connolly (1989) at the high stocking rate, at 1:7 cattle to sheep ratio (Table 3.13). As in continuous stocking, most mixed grazing studies with rotational stocking also lack data on pre- and post-grazing pasture height and mass (Table 3.13). Consequently, the basis for difference between experiments remains speculative. In addition, the lack of such information prevents any inference as to the pattern of response in animal performance with changing pasture height or mass under the stocking systems considered here.

Due to lack of mixed grazing data on cattle performance in relation to sward height or pasture mass, it is worth considering cattle performance relative to other cattle alone data under rotational stocking. Even in single species grazing there is a paucity of reports with adequate data on both liveweight gain and sward height (See Commonwealth Agricultural Bureau electronic database, 1987-1997). Fig. 3.8 shows how the liveweight gain of rotationally co-grazed cattle from this study compares to previous reports from New Zealand (Taylor and Scales, 1985) on growing beef cattle grazed on their own. The relationship was from equations relating liveweight gain and post-grazing herbage mass given by Taylor and Scales (1985) for two grazing periods (spring and summer), over two years. The liveweight gain of heifers from this study was higher than that predicted using equations for both grazing periods, i.e. September to mid-December and mid-December to early March (Fig. 3.8). It is unlikely that calves in that study, which were mainly Charolais-cross in the first year and a mixture of Charolais, Murray Grey, Hereford and Friesian-crosses in the second year, were of inferior growth rate potential to the heifers used here. The superior growth rate of heifers from this study may therefore be a combination of mixed grazing effect and compensatory growth by heifers in this study. It is difficult to apportion the difference into each factor. One need to note that the growth rate of heifers from this study may be within the confidence interval of the regression lines, especially the one representing September-Mid-December (Fig. 3.7). Liveweight gain results from this study are also published elsewhere (Kitessa and Nicol, 1995, Appendix, 3.5). The LWG values given by Kitessa and Nicol (1995) were slightly lower than those in Table 3.3, because fasted LW values for week 8 (Figs. 3.3, 3.4) were inadvertently included as unfasted LW when regression of LW on number of days was done for that article.

Table 3.13. Summary of liveweight gain data from some experiments where cattle and sheep were co-grazed rotationally. (PM = pasture mass).

Authors	**Ratio**	**SSH (cm)**		**PM (kg/ha)**		**LWG (g/hd/d)**	
	C:S	Pre-	Post-	Pre-	Post-	Cattle	Sheep[β]
This study	*1:1*	*15.9*	*5.6*	*4020*	*1980*	*1039*	138
Boswell & Cranshaw, 1978	66:33	15-20	3	2800	1100	580	128
	33:66	15-20	3	2800	1100	700	121
Dickson *et al.*, 1981[α]	Low stocking rate (Equivalent to 10 steers ha^{-1})						
	3:1	-	-	-	-	870	*270*
	1:1	-	-	-	-	880	*250*
	High stocking rate (Equivalent to 12 steers ha^{-1})						
	1.5:1	-	-	-	-	670	*200*
	1:1.5	-	-	-	-	820	*200*
McCall *et al.*, 1986[α]	20:80	-	-	-	-	650	67
	40:60	-	-	-	-	560	82
Nolan & Connolly, 1989 *(Average daily LWG to drafting)*	Low stocking rate (Equivalent to 3.86 steers ha^{-1})						
	1:7	-	-	-	-	1154	*229*
	1:4	-	-	-	-	1243	*241*
	1:2	-	-	-	-	1243	*244*
	High stocking rate (Equivalent to 4.94 steers ha^{-1})						
	1:7	-	-	-	-	1062	*210*
	1:4	-	-	-	-	940	*205*
	1:2	-	-	-	-	884	*208*

[α] Values were averages across 3 pasture residuals (1200, 1700 & 2300 kg ha^{-1}) and two land classes (easy & steep). Data not available for each species ratio and residual pasture mass.
[β] LWG of sheep in italics is that of lambs grazing with their dams; others were wethers or ewe hoggets.

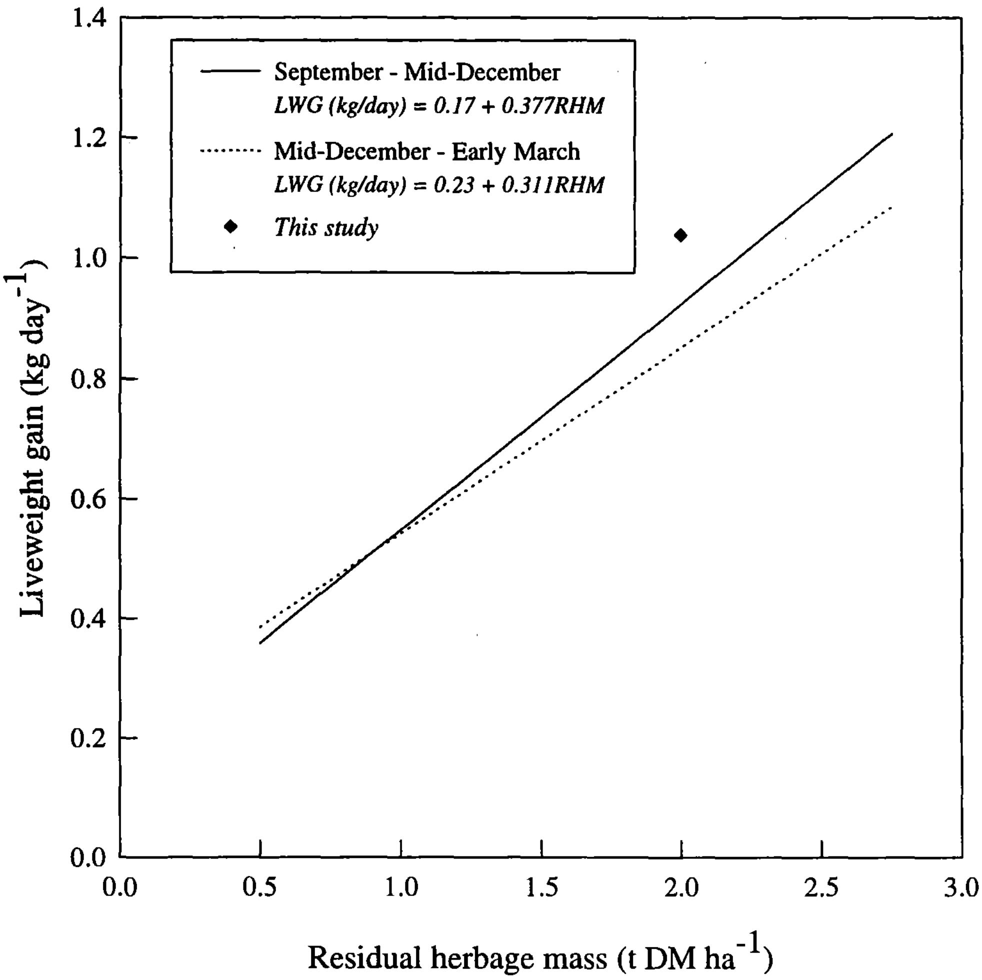

Fig. 3.8. Liveweight gain of growing beef cattle at different residual herbage mass under rotational stocking (Adapted from Taylor & Scales, 1985).

3.4.3. Liveweight gain per ha

The 6 % higher total LWG per ha under rotational than continuous stocking appears to be a result of difference in proportion of cattle gain in total gain under the two stocking systems rather than through provision for a greater number of animal grazing days per ha (see Section 3.4). Increase in total LWG per ha through shifting total gain in favour of cattle gain may be explained by the inherent difference in metabolic efficiency between a large and small animal species (Kleiber, 1965). The total LWG per ha from the continuous stocking treatment was higher than all data from other mixed grazing experiments of similar management listed in Table 3.14. This is to be expected because over all animal number ha $^{-1}$ from this study was higher than that used in those studies.

Table 3.14. Summary of LWG per ha data from some mixed grazing experiments of cattle and sheep.

	Grazing	**Animals ha^{-1}**		**LWG**
Authors	**system**	Cattle	Sheep	**(kg ha^{-1})**
This study	*Continuous*	*3.6*	*12.3*	*630*
Culpin *et al.*, 1964	Continuous	2.5	2.5	180
		2.5	3.7	202
		3.7	2.5	228
		3.7	3.7	240
Hamilton & Bath, 1970	Continuous	1.41	5.63	359
		1.06	4.23	326
		0.54	2.82	240
Reynolds *et al.*, 1971	Continuous	-	-	285
		-	-	264
This study	*Rotational*	*3.3*	*11.2*	*670*
Dickson *et al.*, 1981	Rotational	7.5	5	1420
(2 ewes+twin lambs = 1 steer)		5	10	1400
		7.5	10	1390
		5	15	1470
Nolan, 1986; Nolan &	Rotational	1.24	8.6	600
Connolly, 1989		1.54	7.4	600
(Liveweight gain to drafting)		2.47	4.9	653
		1.65	11.1	754
		2.47	9.9	807
		3.40	6.8	789

Total LWG per ha from the rotational stocking treatment was much lower than that reported by Dickson *et al.* (1981) but within the range of values reported by Nolan (1986) and Nolan and Connolly (1989). Clearly, the high total LWG per ha reported by Dickson and colleagues (1981) was a reflection of the relatively higher stocking rate used in that study. In summary, there is no evidence to suggest that the difference in growth rate of heifers from this study was because rotationally stocked heifers achieved higher growth rate at the expense of gain per ha compared to continuously co-grazed heifers in this study or other similar mixed grazing studies.

3.4.4. Intake and grazing behaviour

3.4.4.1. Herbage intake

OMI data confirm treatment effects on growth rate of cattle and sheep, i.e. they reflect significant difference in liveweight gain of cattle and lack of difference in growth rate of sheep under the two stocking systems The period x stocking system interaction also follows the liveweight of the two treatment groups (Fig. 3.4 vs Table 3.5). Although there was a slightly higher CV for mean OMI per day for rotationally than continuously stocked cattle (4 percentage points), it can be stated that the OMI was estimated with similar precision under both stocking systems for both animal species. There are hardly any other reports on intake of co-grazed cattle and sheep for any useful discussion. As far as the author is aware, Hodgson *et al.* (1985) and Collins (1989) provide the only other reports on intake of co-grazed cattle and sheep, at least on sown temperate pastures. Mullholland and colleagues (1977) have data on intake of cattle and sheep co-grazed on cereal stubbles.

Hodgson and colleagues' (1985) experiment, where cattle and sheep grazed alone or in mixture on a mainly ryegrass pasture maintained at 3.0 and 4.5 cm, was similar to the continuous stocking treatment here. As shown in Fig. 3.9, data from the two studies combine to show some response pattern of OMI to sward height. Compared to cattle and sheep co-grazed at the higher 4.5 cm height treatment in that study, cattle in this study had an extra 3.5 g, while sheep OMI was greater by 4.9 g per kg liveweight (Fig. 3.9). Due to other possible sources of variation (besides sward height) between these two studies, it is not possible to make a valid inference into why the extra 0.5 cm had differential effects on cattle and sheep OMI.

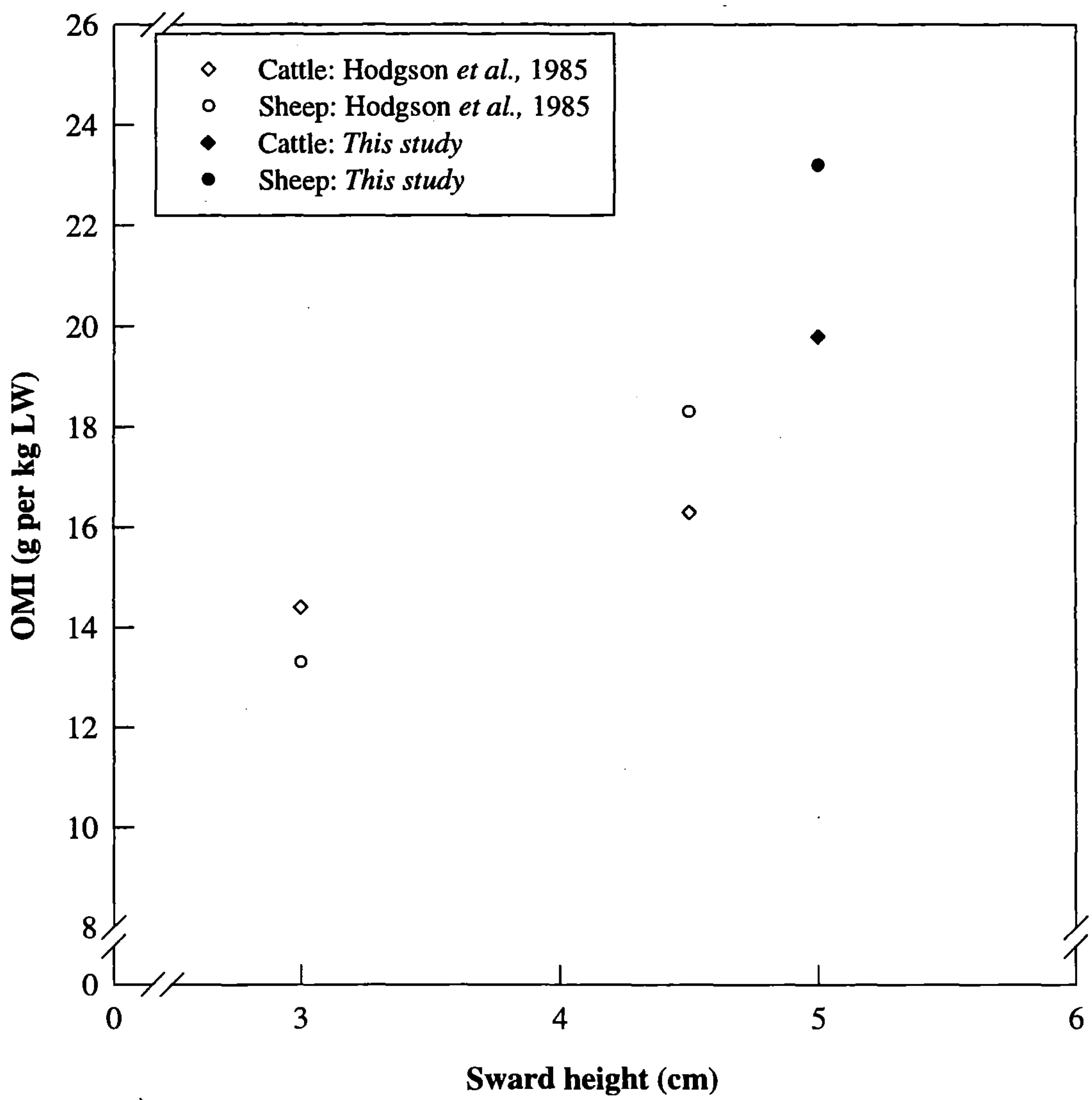

Fig. 3.9. OMI of cattle and sheep at different sward heights from different mixed grazing studies under continuous stocking.

There is no similarly suitable data in the literature for comparing OMI of rotationally co-grazed cattle and sheep. Mean daily digestible OMI (per kg $LW^{0.75}$) values reported by Collins (1989), although based on a system that simulates rotational stocking, were much lower than that recorded here (Table 3.6), ranging only between 10-12.3 g for both cattle and sheep, whether grazed alone or together. This was because the mean OMI estimates reported by Collins (1989) were on swards with controlled declining pasture mass (from about 4,500 to 1,000 kg per ha), whereas OMI estimates from this study were on swards designed to maintain intake over the measurement periods.

In the absence of adequate data in the literature on intake of co-grazed cattle and sheep, examining whether the estimated intake was adequate for the level of liveweight gain as prescribed by feeding guidelines for animals at pasture may provide a useful discussion point. It may also provide an indirect appraisal of the accuracy of the use of n-alkanes as markers for estimating intake at pasture. Interestingly, OMI requirements to meet the daily liveweight gain attained by cattle and sheep, estimated using guidelines presented by Agricultural and Food Research Council, AFRC (1993), were generally lower than marker-based estimates (Table 3.15). This means either the marker-based OMI was exaggerated or the AFRC equations were a conservative estimate. Considering that these equations were based on indoor studies, it is possible that the allowances made for predicting requirements of livestock at pasture may need to be re-considered.

del Pozo *et al.* (1996) have also measured intake of lambs grazing at pasture using alkanes. At their sward height treatment of 4 cm, the closest to that under this study, their estimated DMI for lambs grazing on a pasture previously grazed by goats and growing at 131 g day^{-1} was 1.0 kg day^{-1} (average of two periods). At this growth rate, the predicted requirement (AFRC, 1993) for DMI for these lambs, with initial weight between 27-32 kg, grazing on a pasture with digestibility of 75-80 % range, is 0.70 kg DM per day, only 70 % of DMI measured.

Table 3.15. Comparison of OMI estimates for sheep and cattle to that predicted from feeding standard tables (AFRC, 1993).

		LWG	Estimated OMI (kg day^{-1})		
Stocking system	Species	(g day^{-1})	AFRC$^{\alpha}$	Alkane	% difference
Continuous	Sheep	150	1.10	1.44	27
Rotational	Sheep	138	1.10	1.40	27
Continuous	Cattle	804	5.85	6.31	8
Rotational	Cattle	1039	6.21	7.94	22

$^{\alpha}$Digestibility values used for both continuously and rotationally stocked pastures were:
cattle: 0.70-0.75
sheep: 0.75-0.75
AFRC values are DMI converted to OMI using the OM content of pastures.
% difference = (alkane -AFRC)/AFRC.

OMI of sheep predicted using alkanes was closer to that predicted using AFRC (1993) equations than chromic oxide based estimates (Table 3.16). This was especially the case under rotational stocking (Table 3.16). Considering the similarity in daily LWG, diet composition and the *in vitro* digestibility of OE samples for these sheep it is unlikely that the actual difference in OMI between the two groups was as great as 0.5 kg day^{-1} as predicted using chromium oxide. The large discrepancy between OMI estimates obtained using these techniques under rotational stocking suggests that one of the markers had greater diurnal variation in flow rate under rotational than continuous stocking. Since the alkane method is based on the ratio of dosed to natural alkane rather than absolute concentration, it is very possible that this reflects the more robust nature of the alkane technique (i.e. coping with systems that inherently entail diurnal variation in flow rate) over the chromium method. Other authors have also claimed greater accuracy for using alkanes over other marker techniques (Dove and Mayes, 1991; Malossini *et al.,* 1996). However, there was little difference in precision (as shown by CV %, Table 3.7). Since the accuracy of using alkanes is highly influenced by how well the pasture samples represent what the animals selected (Dove and Mayes, 1991), lack of improvement in precision over the chromic oxide technique may have more to do with not having a representative sample of what the animals ate. How well the samples collected using OF animals in this study represented what the test animals ate is considered under the section on diet composition.

Table 3.16. Comparison of OMI estimates for sheep based n-alkanes and chromic oxide to that predicted using feeding standard tables (AFRC, 1993). (NB this is for period III only).

		Estimates of OMI (kg day^{-1})		
Stocking system	Species	Alkane	Chromium	AFRC$^{\alpha}$
Continuous	Sheep	1.72	1.90	1.22
Rotational	Sheep	1.49	2.41	1.22

$^{\alpha}$ As in Table 3.15.

3.4.4.2. Grazing behaviour

Bite rate of cattle on both treatment pastures was within the range given by Hodgson (1986) for cattle on temperate pastures, which was 20-66 bites min^{-1}. Continuously stocked cattle were grazing at the higher end of this range (Table 3.8). In general, evaluation of the grazing behaviour of cattle showed that continuously stocked cattle had made behavioural adjustments (increased bite rate and increased apparent grazing time) to sustain adequate growth rate on a pasture below that recommended for growing beef cattle (Hodgson, 1986; Wright, 1990). However, these adjustments were not sufficient to enable similar total daily intake to that of rotationally stocked cattle. Although it was not possible to gather data on bite weight, it can be deduced using previous reports

(Black & Kennedy, 1984) that continuously stocked cattle which were grazing a sward with mean height of 5.1 cm would have had a lower bite weight than rotationally stocked cattle-which grazed a sward with a mean height of 10.8 cm ((pre- + post-grazing SSH) ÷ 2). Further, continuously stocked heifers had longer apparent grazing time and lower intake per day than rotationally stocked ones, which substantiates the argument for lower bite weight for the former. As stated by Black and Kennedy (1984), there is limited scope for increase in bite rate and grazing time to compensate for low bite weight and sustain total daily intake, hence the lower OMI per day for continuously stocked cattle.

It appears that although the two pastures promoted similar sheep intake and liveweight gain, the rotationally stocked pasture provided higher bite weight and consequently higher intake for cattle. In the short-term trial (24-hr), cattle previously on rotationally stocked pasture grazed the continuously stocked pasture at a slower rate than they used to graze before, probably due to lack of sufficient time for acclimatisation. In terms of both average sward height (Fig. 3.2) and pasture mass (Table 3.2), the rotationally stocked pasture was higher than the continuously stocked sward, and one would have expected them to increase their rate of biting when grazing a pasture of lower height and mass (Black & Kennedy, 1984).

One significant finding from the turf grazing study was the refusal of turfs from continuously stocked swards by heifers that had been grazing the same pasture for the preceding 19 weeks. This raises an important question about the validity of grazing behaviour reports which are usually based on dug out turfs fed indoors. If the bite weight trial had been done at the beginning of the experiment, it would have led to the erroneous conclusion that the sward height chosen was too low for these cattle to graze. Therefore, there is a need to condition animals to swards before sound inference can be made on grazing behaviour based on short-term trials on swardlets.

3.4.5. Diet digestibility and composition

The greater proportion of grass leaf in the diet of rotationally co-grazed heifers (56 vs 46 % DM) and lower similarity coefficient between cattle diet and sward under rotational than continuous stocking (0.74 vs 0.93) suggests that cattle may have had comparatively greater opportunity to select a diet of higher quality than the sward under rotational than continuous stocking. Further, the closeness of similarity coefficient between cattle diet and sward (0.74) and sheep diet and sward (0.82) under rotational stocking, suggests rotationally co-grazed cattle were equally competitive with sheep under this system. Or it may mean that the system was not conducive for selective grazing for either species. On the contrary, sheep diet had the lowest (0.61) and cattle diet had the highest similarity coefficient (0.93) with the sward under continuous stocking, which suggests that sheep may have gained advantage at the expense of cattle under this system.

The OMD values recorded here for cattle concur with similar studies. For instance, on a ryegrass pasture Le Du and Baker (1981) recorded OMD of herbage selected at 75, 75, and 73 % for milk-fed calves, steers and cows, respectively. OMD values for sheep are close to the 75-86 % reported by del Pozo *et al.* (1996) for lambs grazing grass/clover pasture.

Similarity coefficients between cattle and sheep diets both under continuous and rotational stocking are within the range shown in Table 2.1. The similarity between oesophageal extrusa composition and composition of pasture reported by Collins (1989) on a similar pasture, at 0.76, is similar to that observed under rotational (0.74) but lower than that observed under continuous (0.93) stocking treatments. Interestingly, Collins' (1989) study was a simulated rotational stocking experiment. In contrast, the value recorded for sheep in that study was 0.58, which is closer to that recorded here under continuous stocking (0.61) than under rotational (0.82) grazing. Perhaps this apparent inconsistency may be explained by the opportunity for selective grazing by sheep provided by the three stocking methods: (i) continuous, (ii) rotational (1 day shift) stocking , and (iii) Collins' 15-18 day simulated rotational stocking. That is, (iii) may be closer to (i) than it is to (ii) in terms of the size of diurnal change in pasture resource and its influence on the opportunity for selective grazing by sheep.

There were some concerns with the representativeness of pasture samples collected for diet digestibility and botanical composition data from this study. The refusal of turfs from continuously stocked swards by both previously continuously and rotationally stocked cattle raises doubt on the usefulness of OF animals in sampling continuously stocked pasture. On the rotational stocking treatment, the use of OF cattle and sheep to obtain a sample of what the animals ate during each day was constrained in some ways. First of all, the samples collected represented the pasture grazed over the 15-20 min sampling period. The height, mass and botanical composition of pasture grazed during that period depended on how close that sampling period was to the point when animals were given fresh daily pasture offer. Extending the sampling period was discounted because it would lead to sample contamination from regurgitation (Holecheck *et al.,* 1984), and multiple sampling during a day was not only logistically impractical but also would lead to too much interference, which could make the daily herbage intake during measurement periods unrepresentative of what happened over the whole trial period. Therefore, it is difficult to state whether the provision of a minimum of one hour between fresh daily offer and collection of samples under- or over-estimated diet digestibility and proportion of 'preferred' parts (i.e. grass leaf and clover) in the diet of rotationally co-grazed cattle and sheep. Future studies need to consider this problem in designing sampling procedures to determine diet composition under continuous and rotational stocking.

3.4.6. Use of equivalent sheep liveweight gain

Manipulating the grazing area on rotational stocking to give similar sheep weekly liveweight change between continuous and rotational stocking experimental treatments eliminated the need to equilibrate continuously and rotationally stocked swards by pasture or spelling interval attributes. That is, independent of whether the two stocking systems exhibited significant difference in sward characteristics, the comparison of cattle performance was possible under conditions of equivalent sheep liveweight gain. Over the whole experimental period, the only pasture variable that was manipulated to some extent on the rotational stocking treatment was pre-grazing height, which was kept at <20 mm to prevent the sward developing into rank pasture which would have adversely affected utilisation by sheep (Grant *et al.,* 1985, 1987). Interestingly, the overall post-grazing sward height (5.6 cm) was close to the SSH on the continuously stocked pasture (5.1 cm).

Over weeks 11-19 sheep liveweight, but not liveweight gain under rotational stocking was consistently (but not significantly) below that of sheep under continuous stocking (Fig. 3.3). Over the same period, the converse was true for rotationally and continuously stocked heifers (Fig. 3.4.). Due to limited availability of pasture, it was not possible to further increase the daily pasture offer for rotationally stocked animals without significantly increasing the post-grazing height and the grazed depth (pre-grazing SSH minus post-grazing SSH) from the previous weeks. Therefore, the advantage to rotationally stocked heifers in average daily liveweight gain over this period was most probably a conservative estimate.

Overall, the experimental method of comparing the response of one species at similar response of the companion species, has many features of importance to mixed grazing studies. It is the author's belief that the use of equivalent liveweight gain of a companion species is most probably easier to control, and more easily repeatable than any pasture-based parameters, e.g. pasture height of the same mass, botanical composition and canopy structure. It may also be used over a wider range of vegetation types than any pasture-based parameters. The latter are difficult to measure with adequate precision under extensive, highly heterogenous environments (Holecheck *et al.,* 1984). This approach may enable comparison between mixed grazing on rangelands and intensively managed pastures with less confounding elements than using stocking rate or any pasture parameters. Under farm conditions, the method provides scope for looking into a farming strategy that may allow the introduction/exclusion of additional species or class of stock on to a farm depending on how this affects the target performance set for the existing system.

3.5. SUMMARY AND CONCLUSIONS

This study has shown, for the first time, that mixed grazing outcome is influenced by selection of stocking system. It has also provided a novel approach that enables comparison of the effect of one stock class/species on its companion species under contrasting pasture and management conditions.

Accordingly, the evidence from this study suggests that at equivalent sheep liveweight gain, cattle continuously stocked with sheep grew only at about 77 % of the growth rate achieved by those rotationally stocked with sheep. Cattle rotationally co-grazed with sheep in comparison to those continuously co-grazed had :

(1) higher OMI per day,

(2) higher proportion of grass leaf in their diet, and

(3) diet with lower similarity coefficient with the sward.

All these observations support the supposition made from the review of literature, and have given some basis to the premise that the stocking system chosen influences the outcome of mixed grazing. However, as shown in the preceding discussion, the possibility that difference in mean sward height may have played a significant role in the observed difference in the growth rate of heifers cannot be ruled out. Hence, the lower daily liveweight gain of continuously co-grazed cattle may have been (1) a response (lower OMI day^{-1}) to the lower mean SSH under continuous (5.1 cm) than rotational (10.8 cm) stocking, (2) due to limited opportunity for either cattle or sheep to exercise selective grazing under rotational than continuous stocking, (3) sheep may have had less opportunity to be selective at the expense of cattle under rotational stocking, or (4) a combination of all of the above.

Perhaps a major significant note is that this study has provided liveweight gain data of co-grazing cattle and sheep over nearly 20 weeks with matching data on pasture height, pasture mass and botanical composition under two contrasting grazing management systems. It is the author's belief that whether animals are under single or mixed grazing, pasture height and mass will play a major role in their intake and liveweight gain. These two factors also influence the spatial presentation of botanical components. Therefore, any future attempt at modelling response to mixed grazing will require animal performance data from a well described pasture resource. There are very few, if any, reports on mixed grazing of cattle and sheep that meet this requirement.

The practical significance of this finding is that irrespective of whether it was an effect of mean sward height or not, rotational co-grazing of cattle and sheep allowed for greater proportion of cattle gain without significant reduction in sheep gain per ha, with a net increase in total gain per ha of about 6 %. Therefore, the evidence presented here provides some basis for recommending mixed grazing of cattle and sheep using rotational rather than continuous stocking. It should be noted that the results should not be interpreted as concrete evidence of superiority of one grazing method over another, since the scope for difference in the performance of one of the species was excluded to apply similar weekly sheep liveweight gain. Further, the observed difference may be unique to the set target performance from one of the species.

Finally, to determine the difference between the two stocking systems that is due to mixed grazing *per se*, a further study was subsequently conducted using similar procedures to dissociate the effect of height and stocking system. This study is described in the next chapter.

CHAPTER 4

EXPERIMENT II : Intake, diet composition and liveweight gain of cattle stocked alone, or co-stocked with sheep using continuous or rotational stocking

4.1. INTRODUCTION

The first stage of this study (preceding trial) was designed to investigate if there was any difference in growth rate of cattle that were continuously or rotationally co-grazed with sheep. It has shown that there is a difference in growth rate of cattle co-grazed with sheep depending on the stocking system used. However, the results of Experiment I were confounded to some extent with mean sward height in that it was not possible to categorically state if the difference between continuously and rotationally co-grazed heifers was due to mixed grazing *per se*. Therefore, a further study was carried out in which an all cattle treatment was included in each stocking system to quantify the effect of mixed grazing independently of sward height.

Accordingly, a grazing experiment was set up with the following objectives:

(1) to determine intake and liveweight gain of cattle stocked alone vs co-grazed with sheep under continuous or rotational stocking,

(2) to compare diet composition of cattle and sheep under each treatment combination, and

(3) to compare relative patchiness of swards and their botanical composition when grazed by cattle alone or cattle with sheep under continuous or rotational stocking.

4.2. MATERIALS AND METHODS

4.2.1. Experimental site

The trial was conducted at the same site as Experiment I, with an additional 2.95 ha area from an adjacent paddock of similar pasture included to accommodate the extra treatments.

4.2.2. Pasture

The extra paddock added was also a three year old perennial ryegrass (*Lolium perenne*. Grasslands Nui)/white clover (*Trifolium repens*. Grasslands Huia). Fertiliser policies were as described in section 3.2.2. All paddocks were irrigated once between 5-10 February 1994.

4.2.3. Animals

As in the previous study, animals were yearling heifers (mixture of Hereford and Hereford-Angus) and two-tooth Corriedale hoggets with a mean initial weight of 232±4.4 and 47±0.7 kg, respectively. Both cattle and sheep were treated with anthelmintic (Vetdectin Pouron: 0.5 mg moxidectin per kg LW for cattle; Vetdectin Oral: 0.2 mg moxidectin per kg LW for sheep) at the beginning (9 November, 1993) and near the middle (14 January 1994) of the trial period. Refer to section 3.2.3 for other details on animal handling and management practices.

4.2.4. Experimental design layout

There were four treatments: 2 stocking systems (continuous vs rotational) x 2 species mixtures (cattle alone vs cattle plus sheep) (Fig. 4.1). A group of nine heifers, balanced for breed and initial liveweight, was randomly assigned to each treatment as core animals. Under mixed-stocking these grazed with a core group of 27 hoggets (1:1, $W^{.75}$). Each stocking method was allocated a total area of 4.42 ha. Under continuous stocking, SSH of cattle alone (CA-C) and cattle with sheep (CS-C) pastures were kept near a target height of 4.0 cm by put-and-take; CA-C cattle grazed on a paddock half the size of that under CS-C (Fig. 4.1). On the rotational stocking area, both cattle alone (CA-R) and cattle with sheep (CS-R) grazed side-by-side separated by an electric fence; CA-R received one-third of the total area of daily pasture offer (Fig. 4.1). However, the fence between CA-R and CS-R was regularly adjusted to achieve similar post-grazing height between these two treatments (Fig. 4.2).

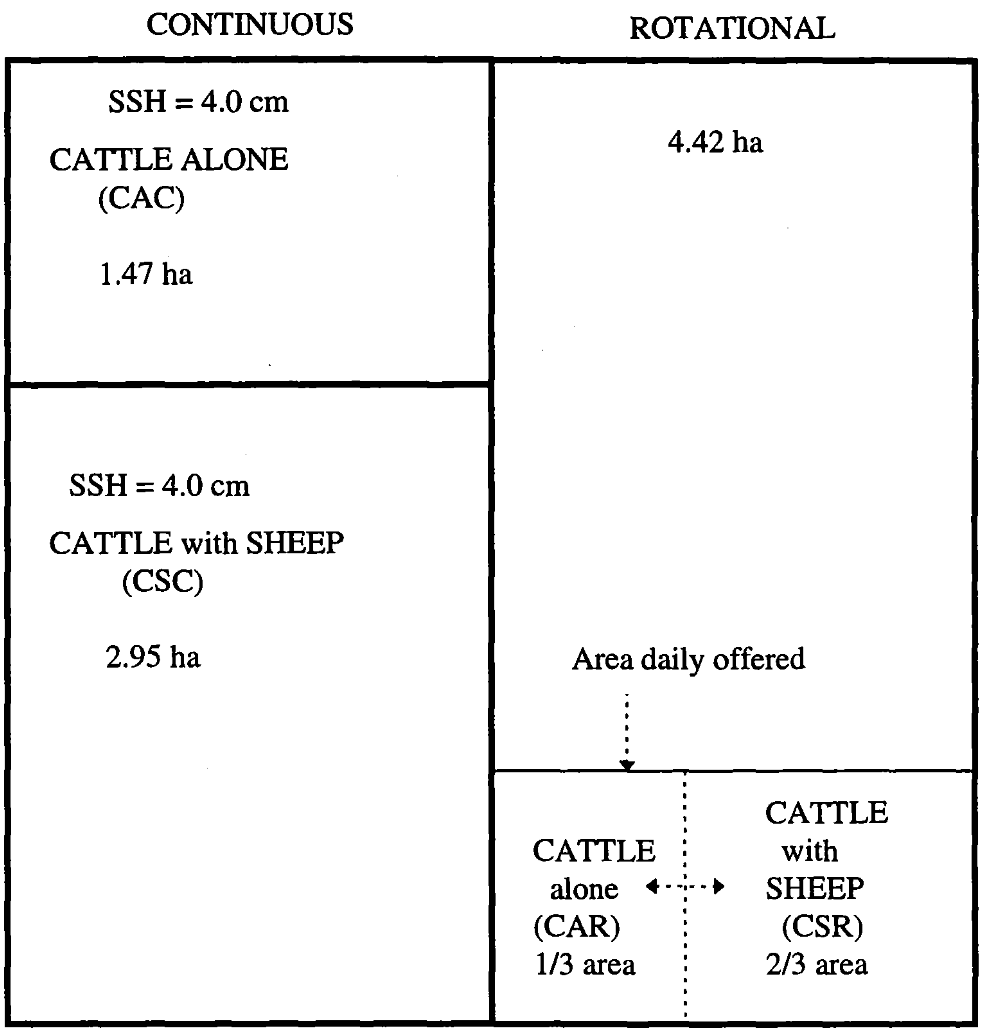

Fig. 4.1. General layout of treatments during Experiment II.

Fig. 4.2. summarises equivalence between treatments and the effects measured through comparison of treatments. Accordingly, comparison of CA-C vs CS-C and CA-R vs CS-R provided mixed-grazing effect under continuous and rotational stocking systems, respectively (Fig. 4.2). The difference between cattle on CA-C and CA-R treatments (D_1) provided the effects of sward height and stocking system, while CS-C and CS-R treatments (D_2) combined the effects of sward height, stocking system and mixed grazing (Fig. 4.2). The variation between the two contrasts (D_2-D_1) was deemed to be difference between continuously and rotationally co-grazed cattle that was due to mixed-stocking *per se*.

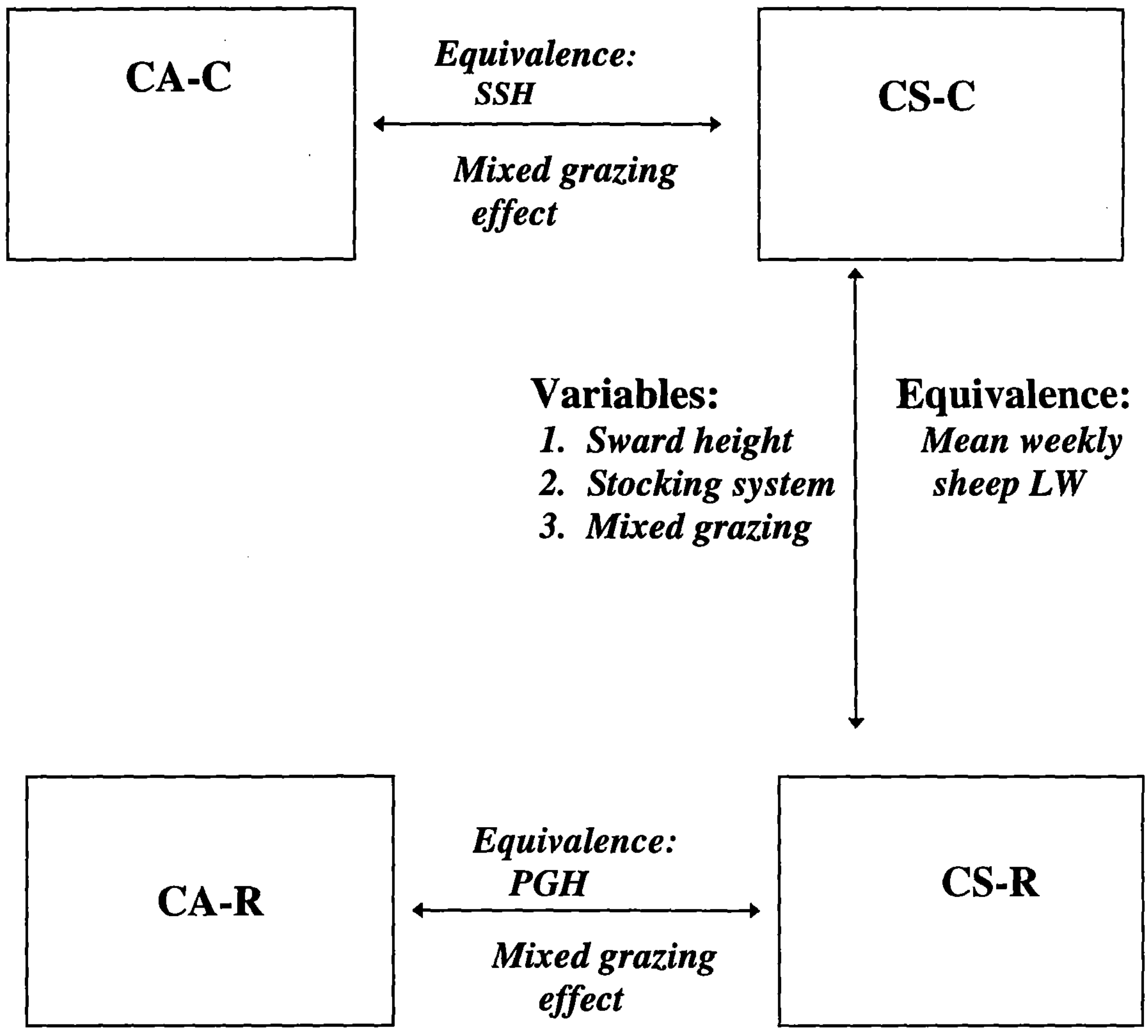

Fig. 4.2. Schematic presentation of variables measured and equivalences used in Experiment II (PGH = post-grazing height; SSH = Sward surface height).

As in Experiment I, the area of pasture offered daily to animals on the rotational stocking treatment was adjusted to promote similar liveweight gain in CS-R sheep to that provided by a pasture continuously stocked at 4 cm. Day to day operations were done as in section 3.2.4. There were four heifers and 12 hoggets used as spare stock for pasture height control on the continuous stocking treatment. Excess pasture from all paddocks was fenced off and grazed by a mob of ewes. Over the whole period, a mob of 125, 325 and 200 ewes grazed for 23, 19 and 4 days, respectively, to remove excess pasture from the area allotted to CA-R and CS-R. On the continuously stocked pasture, 125 ewes were used for 8 days each on CA-C and CS-C pastures. The experiment lasted a total of 126 days (9 November 1993 to 15 March 1994).

4.2.5. Measurements

4.2.5.1. Liveweight

Liveweight of core animals in each treatment was recorded weekly. Final fasted liveweight of all core animals was recorded on 16 March 1994. See section 3.2.5.1 for other details.

4.2.5.2. Pasture intake

Pasture intake was estimated near the beginning and the end of the experimental period (Table 4.1), using n-alkanes as internal markers (Mayes *et al.,* 1986). Animals dosed per treatment, alkanes used as marker, and dose rates were similar to Experiment I. Refer to section 3.2.5.2 for preparation of alkane capsules, dosing and faecal sampling procedures, processing of faecal samples, and analysis of alkanes in faeces and herbage samples. The only difference in analysis of alkanes was that an internal standard (C_{34}) was added to both herbage and faecal samples, because the alkane profile of faeces and herbage samples were used to predict both intake and diet composition in this experiment. Pasture intake was estimated by using the expression in Equation 3. See below for diet composition.

Table 4.1. Dosing and intake measurement periods (1993/94).

Period	Date started	Date finished	Number of days
I	6/12/93	15/12/93	10
II	23/02/94	04/03/93	10

Pasture sampling

Pasture sampling was done following the same procedure as in Experiment I, except that OE samples were not subsampled for diet botanical composition. Diet botanical composition was predicted using n-alkanes (see section 4.2.5.3 below). OE samples were used for determination of OMI (using n-alkanes) and diet OM digestibility. The botanical composition of pasture on offer during intake measurement was determined by collecting 20 samples (snips) at the beginning, mid-way and at the end of faecal collection (days 6, 8 and 10 from the beginning of dosing). On the rotational stocking treatment, samples were also taken from the CA-R and CS-R side of the area removed daily from grazing (immediately after removal) to get an estimate of the botanical composition of post-grazing area. Pasture samples from all treatments were frozen and freeze-dried as soon as possible. Samples from each day were then sub-sampled and dissected into grass leaf (GL), grass stem and pseudostem (GS), grass seedhead (GSH), clover leaf and petiole (CL) and dead herbage (DH). After recording the weight of each component per sample, the material collected for each botanical component during a particular intake measurement period was bulked, ground, and its alkane concentration recorded for use in determination of diet composition.

4.2.5.3. Diet composition

Diet composition of cattle and sheep in each treatment was predicted by using n-alkanes following the least-squares optimisation procedure proposed by Dove and Moore (1995). The alkane profile (C_{25}-C_{36}) of botanical components (see immediately above) from a treatment sward was determined on an organic matter basis (mg per kg OM). The concentration of these same alkanes in the faeces of each animal dosed in that treatment was also determined and corrected for incomplete recovery using recovery values (Appendix 3.1c) from an indoor experiment for sheep, but using reported values for cattle (Dillon and Stakelum, 1988). The alkane profile of botanical components and that of each test animal's faecal sample were entered into a programme developed to determine the optimum combination of botanical components that gave the alkane profile in the faeces (Dove & Moore, 1995). Hence, diet composition was estimated by finding the botanical mixture which minimised the squared deviation between observed and predicted alkane patterns. The procedure uses a non-negative least-squares optimisation routine to avoid negative proportions in the solution (See Dove & Moore, 1995 for mathematical details).

Eight solutions per treatment (per 8 animals dosed) were obtained. The proportion of a botanical component in an animal diet on a particular treatment was the average of 8 values. Alkanes that best discriminate between botanical components were chosen by using canonical variate analysis (SAS User's Guide, 1985). However, C_{32} and C_{34} were not included for selection as they were used for dosing and internal standard, respectively. The clover content of sheep and cattle diet was also predicted using the C_{29}:C_{33} ratio of herbage and faecal samples (Dr. R. Mayes, personal communication).

4.2.5.4. Pasture height

On all treatments SSH was measured daily following the same procedures discussed in Experiment I. On the continuously grazed pasture, 60 SSH measurements on each paddock were recorded daily for CA-C and CS-C pastures. Forty measurements of pre- and post-grazing SSH were recorded on the rotationally stocked area on both the CA-R and CS-R side (Fig. 4.1). On few occasions (n=8 days) each hit with the 'sward stick' was recorded as being from tall, infrequently grazed or short, frequently grazed patches of each treatment pasture. On the rotational stocking treatments, this was done for post-grazing heights only. Proportion of SSH from 'frequently' and 'infrequently' grazed areas was also predicted by fitting a double normal distribution to sward height data (Gibb and Ridout, 1986) using a maximum likelihood programme (Ross, 1987). The test for a double normal frequency distribution of the SSH and the post-grazing height data from continuously and rotationally stocked swards respectively, was made using the computer programme MLP, maximum likelihood programme (Ross, 1987). For each treatment, height data on only every second day was used in fitting the models because the programme had a data limit maximum of 5, 000. The programme provided the fit of a sequence of models to the data in the following order of increasing number of parameters:

(1). Single normal distribution (μ, σ),

(2). Double normal distribution with equal proportion and equal variance (μ_1, μ_2, σ, P),

(3). Double normal distribution with different proportions but equal variance (μ_1, μ_2, σ, P_1, P_2), and

(4). Double normal distribution with different proportions and unequal variance(μ_1, μ_2, σ_1, σ_2, P_1, P_2).

For each treatment, the model which first showed a non-significant chi-square test between predicted values and observed values was accepted. The mean, standard deviation, and the proportion of the frequently and infrequently grazed areas were obtained from the MLP output. Using these parameters, predicted values within each distribution of heights were determined by using the statistical NORMDIST function of Microsoft Excel 5.0 (Microsoft Corporation, 1993).

4.2.5.5. Pasture mass

Quadrat size, days of measurement and pasture sampling procedures were similar to Experiment I. Further, height within quadrats, quadrat sample dry matter content, and height-mass regressions were also done following procedures discussed in Experiment I. However, in this experiment quadrat samples were collected at the beginning and end of each faecal sampling period; i.e. days 6 and 10 of dosing. On the rotational stocking side, four quadrat samples were cut from the pre-grazing area to represent both CA-R and CS-R pastures, but four quadrats each on the post-grazing area. For each treatment, pasture mass per ha for each period and for the whole experimental period was predicted by entering the respective sward height (period-wise) in a height-mass regression for that treatment pasture (8 quadrats x 2 periods).

4.2.5.6. Digestibility

Diet *in vitro* DM and OM digestibilities were determined from OE samples using the two stage pepsin-cellulase assay (Jones and Hayward, 1975). Further details are in section 3.2.5.6.

4.2.6. Statistical analysis

Average daily liveweight gain (LWG) of cattle was analysed in a 2 x 2 factorial design. First, daily liveweight gain was determined for each animal in the treatment from the regression of liveweight on number of days from the start of experiment. This provided 9 daily LWG values per treatment, which were analysed using analysis of variance (9 animals x 2 species mixture x 2 stocking systems) (Appendix 4.2b). Sheep daily liveweight gain in CS-C and CS-R was compared using procedures similar to those in Experiment I (Appendix 4.2a). The samples size was 513 (27 animals x 19 liveweights). Differences in mean final fasted liveweights of cattle were also analysed as above, while that of sheep were compared by using a Student T-test (independent samples with equal variance, n =27 sheep).

Within intake measurement periods, OM intake of cattle was analysed as above. Across both intake measurement periods, OMI was analysed using an 8 x 2 x 2 x 2 factorial design (i.e. animals, period, species mix and stocking system) (Appendix 4.4b).

For sheep, within intake measurement period OMI was analysed using a Student T-test while OMI across both periods was analysed in 8 x 2 x 2 (animals, period, stocking system) analysis of variance (Appendix 4.4a). All ANOVA was carried out using the general linear model (GLM) analysis of variance procedure in SAS (SAS Institute, 1985). All graphic presentations were done using the same software used in Experiment I.

4.3. RESULTS

4.3.1. Climatic data

Total monthly rainfall during this experimental period was on average higher than both the preceding experimental period (see Fig. 3.1) and the long-term average for the months over which this experiment was conducted (Fig. 4.3). Daily mean temperature during the conduct of this experiment was only slightly lower than the long-term average (Fig. 4.3).

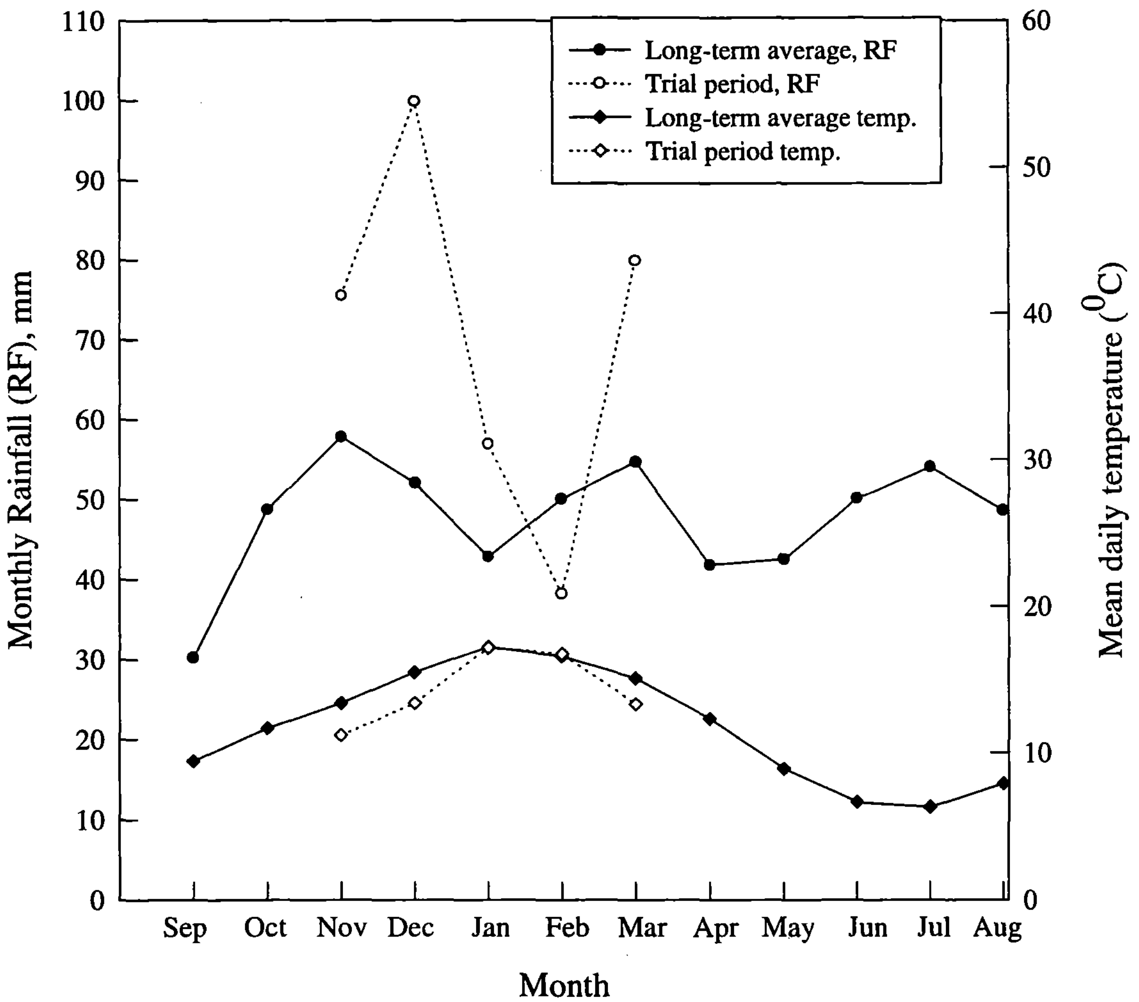

Fig. 4.3. Mean daily ambient temperature and total monthly rainfall (RF) over the trial period, November '93 - March '94. (Long-term averages as in Fig. 3.1).

4.3.2. Sward characteristics

Pasture height

Over the whole experimental period, sward surface height on continuously stocked pastures averaged 4.27±0.02 and 4.26±0.02 cm for CA-C and CS-C treatments, respectively. Weekly means for sward height on continuously stocked pasture and those corresponding to intake measurement periods are given in Fig. 4.4. Sward height was slightly higher than the planned 4.0 cm for both CA-C and CS-C treatments (Fig. 4.4).

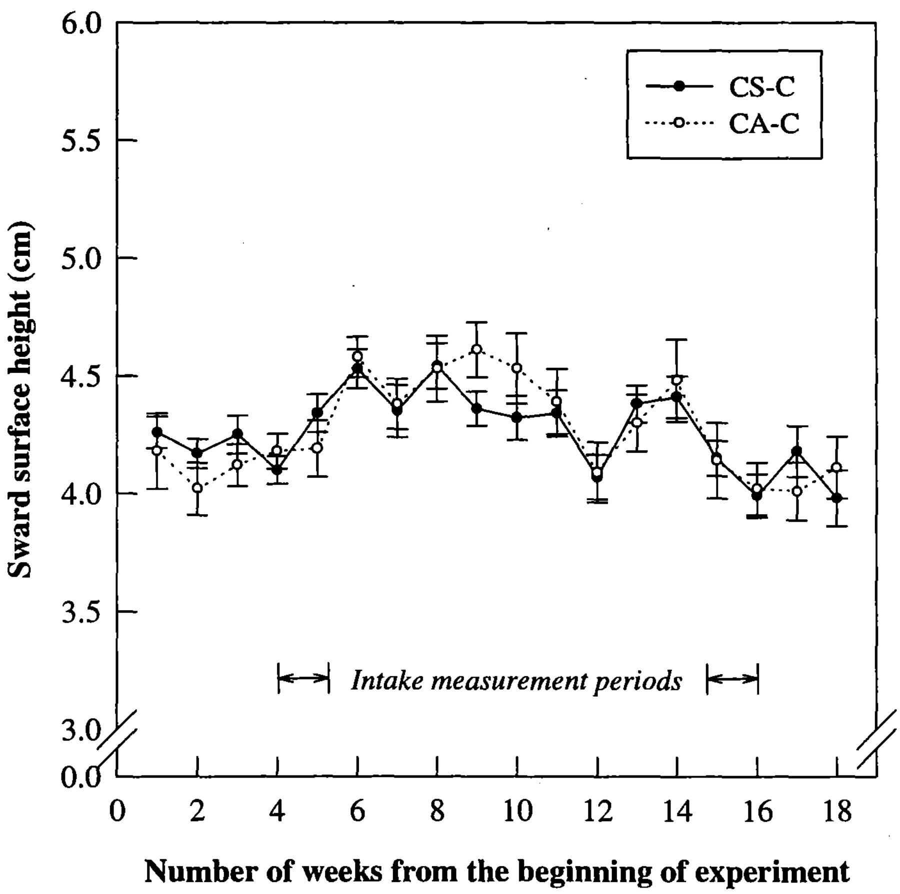

Fig. 4.4. Sward surface height on swards continuously stocked with cattle alone (CA-C) or cattle plus sheep (CS-C).

On rotationally stocked swards, the average pre- grazing sward height for the whole experimental period was 14.9±0.08 and 15.2±0.08 cm for CA-R and CS-R treatments. Corresponding values for post-grazing height was 4.87±0.03 and 4.82±0.03 cm, respectively. Weekly means for sward height on rotationally stocked pastures are shown in Fig. 4.5. As planned in the protocol, average pre- and post-grazing height was similar on CA-R and CS-R swards through out the experimental period (Fig. 4.5). Further, weekly means for pre-grazing sward height were also similar in both CA-R and CS-R treatments. Over the whole period, mean pre-grazing height tended to decline as the grazing season progressed (Fig. 4.5).

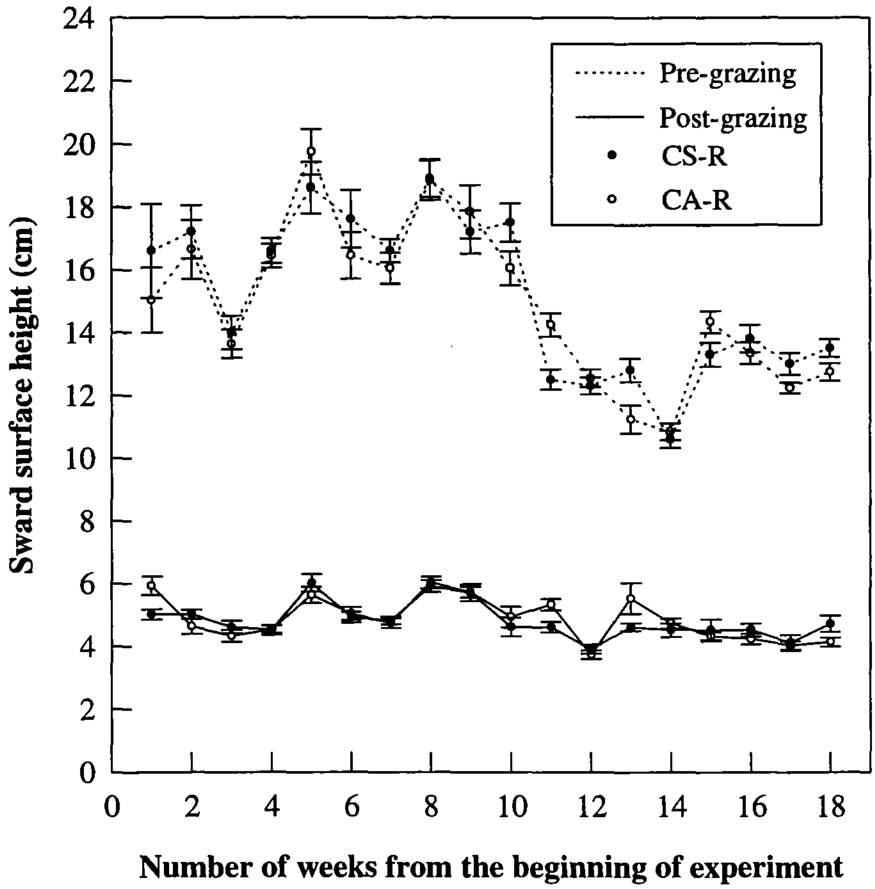

Fig. 4.5. Pre- and post-grazing height of swards grazed by cattle alone or cattle plus sheep using rotational stocking (see Fig. 4.4 for dosing periods).

Pasture mass

Mean predicted herbage mass per ha (from height-mass regression) was not significantly different between CA-C (1653 kg ha^{-1}) and CS-C (1453 kg DM ha^{-1}) treatment swards, as shown by the 95 % confidence interval (Table 4.2). The standard error of prediction for herbage mass on CA-C swards was more than twice that for CS-C swards. On rotationally stocked swards, both pre-grazing (*ca.* 3,000 kg ha^{-1}) and post-grazing (*ca.* 1650 kg DM ha^{-1}) pasture mass were similar on swards grazed by cattle alone or cattle plus sheep (Table 4.2). Note that pre-grazing pasture mass for the two treatment swards was predicted using the same height-mass regression equation (Appendix 4.1). The 95 % C.I. for post-grazing pasture mass on CA and CS swards on rotationally stocked pasture overlaps with the respective intervals for total biomass under continuous stocking (Table 4.2).

Table 4.2. Total herbage mass per ha on swards grazed by cattle alone or cattle plus sheep using continuous or rotational stocking.

Treatment sward	Predicted herbage mass (kg ha^{-1})	95 % C.I. for mean predicted value	Standard error of prediction (n=16)
CA-C	1635	(1412, 1857)	131
CS-C	1453	(1332, 1574)	56.3
CA-R: Pre-grazing	3063	(2912, 3213)	70.2
post-grazing	1751	(1604, 1898)	68.4
CS-R: Pre-grazing	3102	(2952, 3253)	70.1
Post-grazing	1602	(1365, 1840)	111

(N.B. Values are for whole experimental period; see Appendix 4.1 for individual intake measurement periods).

Botanical composition

The botanical composition of swards on offer during the two intake measurement periods is shown in Fig. 4.6. Percent clover on all swards at the beginning of the experiment was 20.5 % DM. On swards continuously stocked by CA, percent clover increased to 42 % by period I (4 weeks), with a further increase to 48.4 % DM in Period II (15 weeks). In contrast, clover constituted 17.2 and 16.4 % DM in periods I and II on CS-C swards (Fig. 4.6). On rotationally stocked swards, percent clover did not show such marked contrast between CA and CS swards, and remained at about 20 % DM across periods in both treatments.

Proportion of grass stem in total DM was slightly higher on rotationally stocked swards during period I (Fig. 4.6), but there was little difference between swards during period II (Fig. 4.6b). In all swards, except CA-C, grass leaf constituted *ca.* 50 % of total herbage dry matter on offer during both periods (Fig. 4.6). Proportion of grass seedhead ranged between 1.1 and 4.7 % DM on rotationally stocked swards; the highest value on continuously stocked swards was 0.4 %, which was on CA-C swards. Generally, there was more dead herbage in total biomass during period I than period II (Fig. 4.6); CA-R sward had the lowest proportion overall (6.8 % DM).

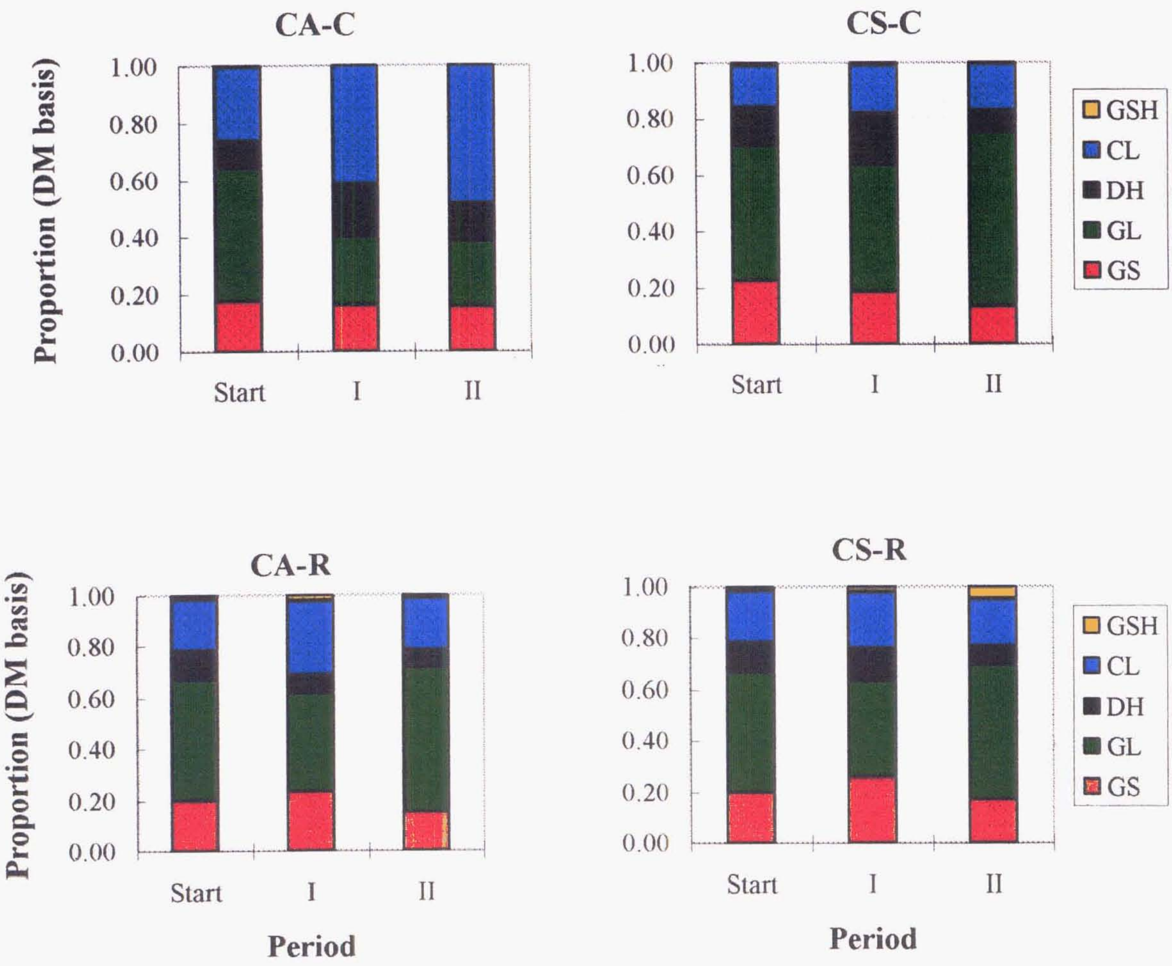

Fig. 4.6. Botanical composition of swards on offer for cattle alone (CA) or cattle plus sheep (CS) under continuous (C) or rotational (R) stocking, during Period I and Period II. Abbreviations for botanical components in section 4.2.5.2.

Botanical composition of post-grazing pasture mass (average of two periods) for rotationally stocked swards is presented in Fig. 4.7. The values for pre-grazing pasture mass are the average of those in Fig. 4.6 and are included in Fig. 4.7 for contrast. On both CA and CS swards, the proportions of leaf decreased, and that of stem and dead herbage in total biomass increased after grazing. The mean proportion of clover in residual mass was 17.9 % for CA-R, but 14 % of total residual DM in CS-R swards.

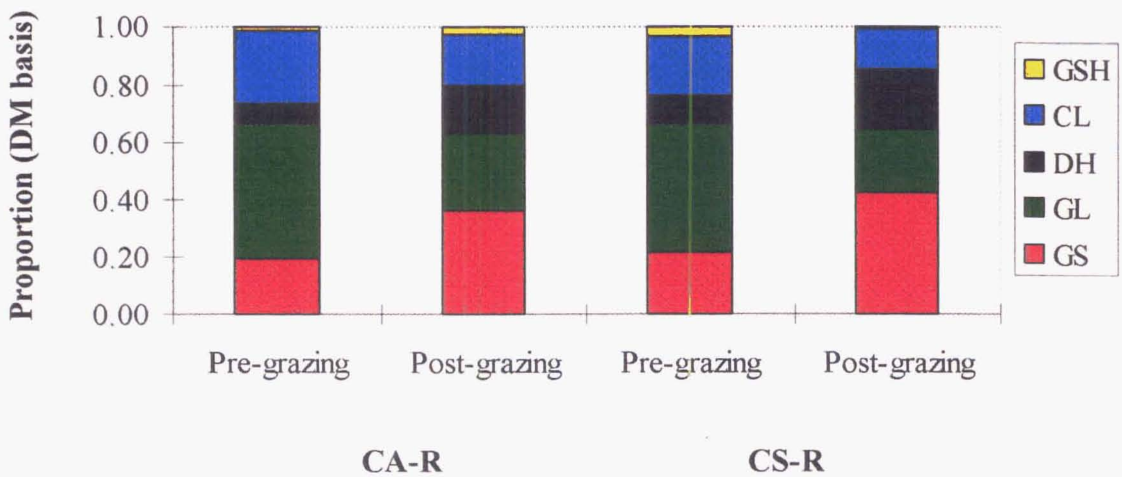

Fig. 4.7. Botanical composition of rotationally stocked swards before and after grazing by cattle alone (CA-R) or cattle plus sheep (CS-R).

Frequently and infrequently grazed areas

Distribution of frequently and infrequently grazed swards were analysed after disregarding data over the first week (which had no effect on the overall mean height of all treatment swards). As shown in Table 4.3, there was agreement between the proportion of the sward subjectively classified as being infrequently grazed and that predicted using the maximum likelihood programme. Parameters from the fitted double normal distributions, including the overall mean heights, for each treatment are summarised in Table 4.4.

Table 4.3. The proportion of swards subjectively classified as infrequently grazed and that predicted using MLP(Maximum Likelihood Programme).

Swards	Subjectively Classified	MLP Predicted	Difference (P<0.05)
CA	0.20	0.17	ns
CS	0.08	0.05	ns

N.B. This is a subset of the data used in Table 4.4. (See Materials & Methods).

The main feature of Table 4.4 is that the effect of species mix on sward height distribution was only significant under continuous stocking, where at similar mean sward height the proportion of the infrequently grazed heights was six times higher in CA than CS swards (0.30 vs 0.05). The mean SSH on frequently grazed areas only differed by 0.5 cm (12 % higher on CS than CA) (Table 4.4). Although there were similar trends on rotationally stocked swards, neither the difference in the proportion of frequently and infrequently grazed areas, nor the mean sward height of these areas differed significantly between CS and CA swards (Table 4.4). In each treatment, a double normal distribution better fitted the data than a single normal distribution. All treatments showed equal variances for the mean sward heights of the frequently and infrequently grazed areas, except CA on continuous grazing, which showed unequal variance.

The frequency distribution of observed and fitted sward heights of continuous stocking treatments are illustrated in Fig. 4.8. The observed data show a skewed distribution irrespective of the animal species mix. CS, the less skewed of the two treatments (Fig. 4.8), still showed a significant lack of fit to a single normal distribution (P>0.001). Frequency distributions of sward heights from rotationally stocked pastures are not presented.

Table 4.4. Parameters of the frequency distribution of sward height on pastures grazed by cattle alone (CA) or cattle plus sheep (CS) using continuous or rotational grazing.

	CONTINUOUS		ROTATIONAL	
Parameter	CA	CS	CA	CS
Overall mean (cm)	4.27	4.26	4.87	4.82
s.d.	1.80	1.32	1.96	2.03
Mean height of frequently grazed area (cm)	3.63	4.10	4.09	4.20
s.d	1.14	1.04	1.08	1.26
Mean height of infrequently grazed area (cm)	5.83	7.23	7.46	7.73
s.d.	1.19	1.04	1.08	1.26
Proportion of area infrequently grazed (p)	0.30	0.05	0.22	0.17

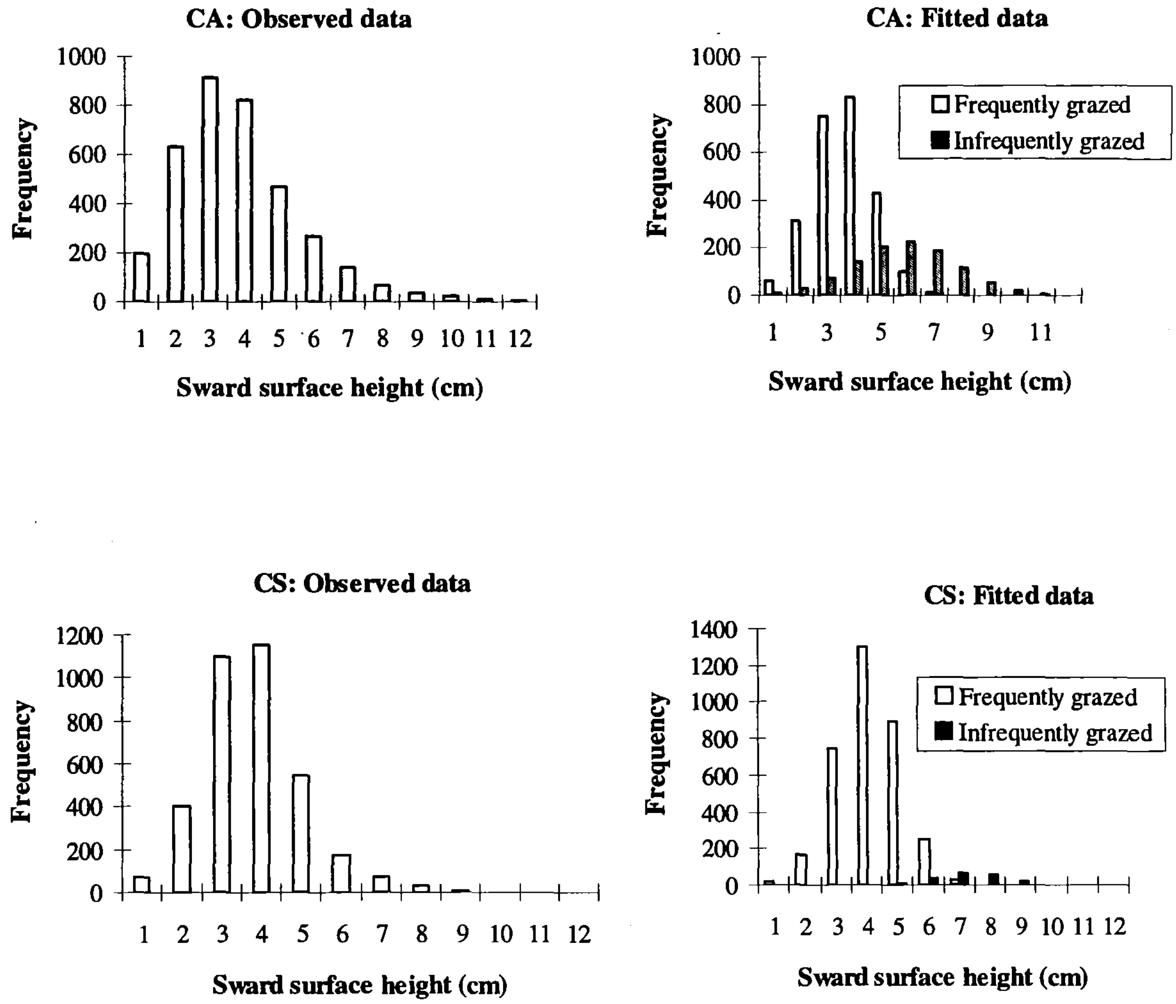

Fig. 4.8. The frequency distribution of observed and fitted (double normal) pasture heights on swards continuously stocked by cattle alone or cattle plus sheep.

4.3.3. Animal performance

4.3.3.1. Weekly liveweight

Sheep

The weekly liveweights of sheep on both continuous and rotational stocking are shown in Fig. 4.9. Mean liveweight at each week was not significantly different between the two treatments (P>0.05). The difference between the two groups ranged between 0.01 and 2.81 kg. On both treatments, liveweight of sheep showed a slight decrease from the preceding week during intake measurement periods, especially during period I (Fig. 4.9). Sheep liveweight raw data is given in Appendix 4.6a. The R^2 for the linear regression of mean weekly LW of sheep on days from the beginning of experiment was 0.97 and 0.93 for CS-C and CS-R sheep, respectively.

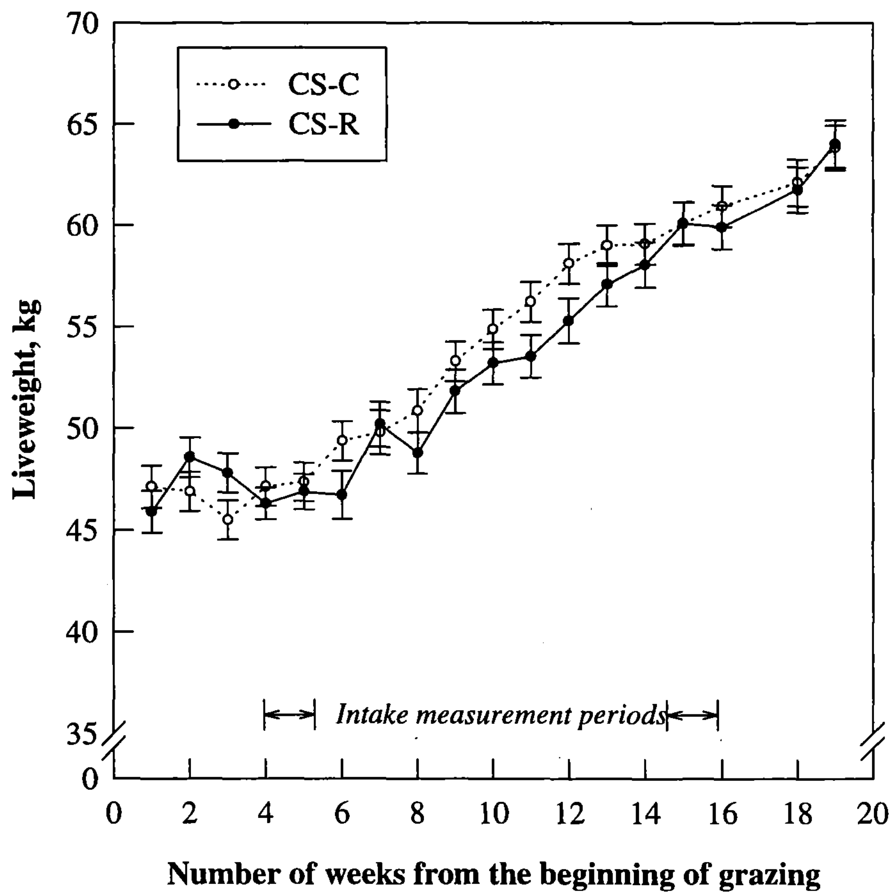

Fig. 4.9. Weekly liveweight of sheep co-grazed with cattle using two stocking systems during the period: Nov. '93 - Mar. '94. (No weighing on week 16).

Cattle

On continuously stocked pastures, the difference in liveweight of cattle co-grazed with sheep and those grazed alone increasingly became greater with time (Fig. 4.10a). Under rotational stocking, there was virtually no difference in the weekly mean liveweight of CA and CS cattle (Fig. 4.10b). On both stocking systems, mean weekly liveweight during the first intake measurement period was slightly lower than the preceding week for all species mixtures (Fig. 4.10a,b). Mean weekly LW of CA-C was similar to that of cattle under rotational stocking treatment. (Fig. 4.10a vs 4.10b). Cattle livweight raw data for each treatment is given in Appendix 4.6b. The R^2 for the linear regression of mean weekly cattle LW on number of days from the beginning of experiment was 0.93, 0.96, 0.98 and 0.97 for CS-C, CA-C , CS-R and CA-R treatments, respectively. All linear fits were significant ($P<0.001$).

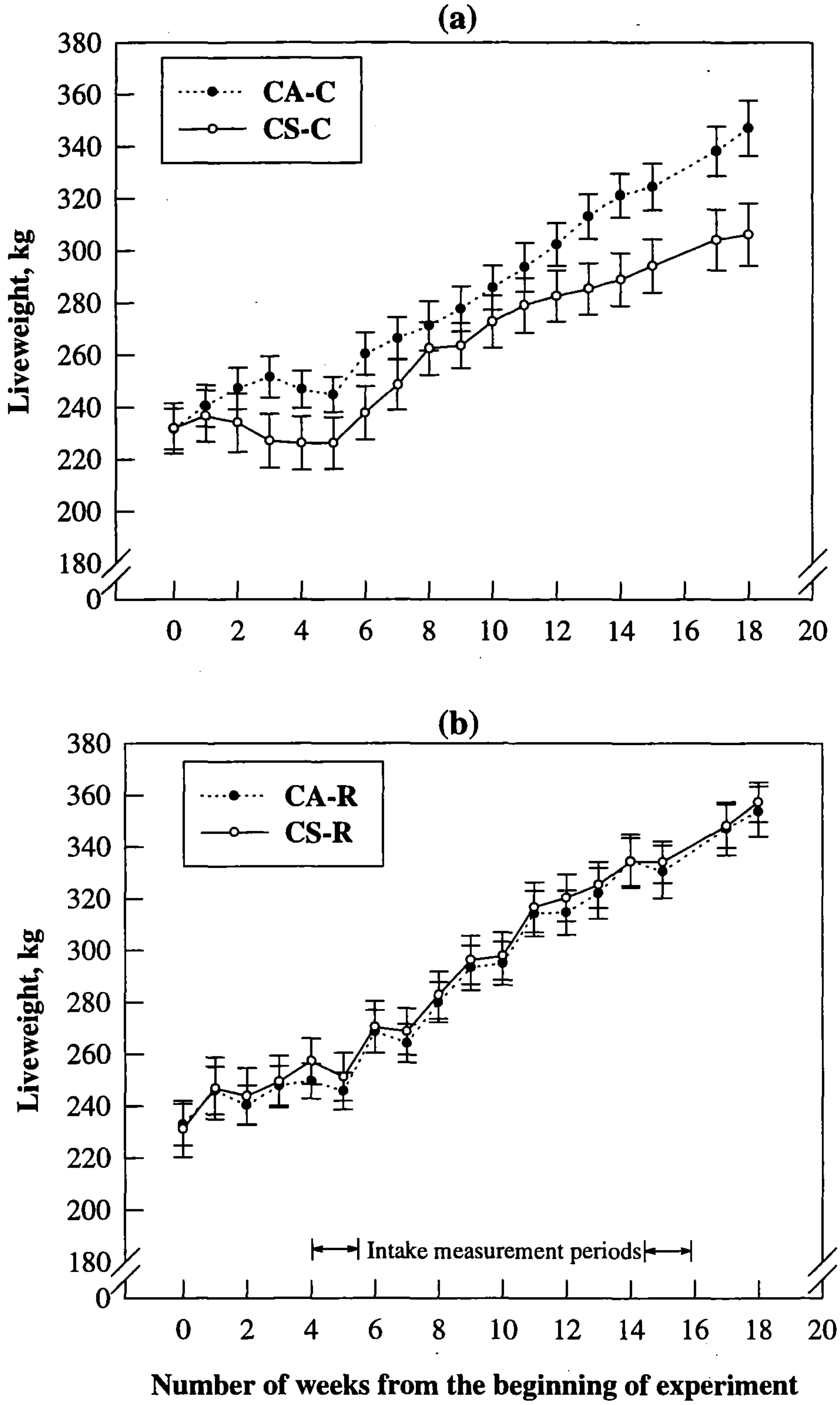

Fig. 4.10. Weekly liveweight of cattle grazed alone (CA) or grazed with sheep (CS) using continuous (a) or rotational(b) stocking.

4.3.3.2. Average daily liveweight gain

Sheep

The average daily LWG and final fasted mean liveweight of sheep over the trial period is shown in Table 4.5. There was no significant difference (P>0.05) in the daily LWG achieved by continuously and rotationally stocked sheep (155 vs 147 g day^{-1}, respectively) (ANOVA in Appendix 4.2a). The final fasted liveweight achieved by sheep in both treatment groups was also similar (Table 4.5).

Table 4.5. Average daily liveweight (regression slope of LW on days) and mean final fasted liveweight of sheep either continuously or rotationally co-grazed with cattle.

	Liveweight gain$^{\alpha}$		Final LW	
Stocking system	(g day-1)	s.e$^{\beta}$	kg	s.e.m.
Continuous	155	0.64	60.5	1.08
Rotational	147	0.67	60.4	1.08
Difference	ns		ns	

$^{\alpha}$ LWG n = 27 animals x 126 days; Final fasted weight n = 27 animals.
$^{\beta}$ Standard error of regression slope (LW on days from beginning of experiment).

Cattle

The mean daily LWG of cattle (average of individual regression slopes of LW on days) in each treatment is given in Table 4.6. Across species mixture, there was a significant difference between stocking systems (P<0.01) in both daily LWG and final liveweight, but no difference between species mixture overall for either daily LWG (P=0.17), or final liveweight (P=0.06) (Table 4.6) (Appendix 4.2b). As shown in Table 4.6, CS cattle on continuously stocked pasture had a significantly lower (P<0.05) average daily LWG and lower final liveweight than their rotationally stocked counterparts. They only achieved 69 % of the growth rate attained by those under rotational stocking (706 vs 1028 g day^{-1}). There was no significant difference between continuously and rotationally stocked CA cattle (Table 4.6), in either rate of growth (916 vs 1022 g day^{-1}) or final liveweight (322 vs 330 kg). Within stocking system, none of the differences between CA and CS treatments was significant (Table 4.6), although CA grew 30 % faster and achieved significantly greater final liveweight than CS cattle under continuous stocking (see also

Fig. 4.10). Although the trends were in different directions, i.e. CA > CS under continuous and CS > CA under rotational, the interaction of stocking system and species mixture was not significant for daily LWG (P=0.15), but it was for final liveweight (P<0.05) with CS-C being lower than all other three treatments (Table 4.6). Inclusion of initial LW of cattle as a covariate (as in experiment I) in ANOVA did not change the magnitude of difference between treatments; group means for cattle LW were within ±2.0 kg at the beginning of data collection.

Table 4.6. Mean daily LWG of cattle either grazed alone or co-grazed with sheep using continuous or rotational stocking.

Comparison		**n**	**LWG (g day^{-1})**	**Final LW, kg**
1. Across stocking system:	CA	18	969^{a}	326.4^{a}
	CS	18	867^{a}	307.4^{a}
	s.e.m.		*51*	*6.84*
2. Across species mixture:	Continuous	18	811^{b}	303.0^{b}
	Rotational	18	1025^{a}	330.8^{a}
	s.e.m.		*51*	*6.84*
3. Stocking system x species mixture:				
Continuous:	CA	9	916^{ab}	322.8^{a}
	CS	9	706^{b}	283.2^{b}
Rotational:	CA	9	1022^{a}	330.0^{a}
	CS	9	1028^{a}	331.6^{a}
	s.e.m		*72*	*9.67*

^{a,b} Figures with the same superscript are not significantly different (LSD P<0.05). (Ditto all tables hereafter).

When regression coefficients of the linear relationship between LW and time for CA and CS cattle under continuous stocking were compared (n = 9 animals x 126 days) independently of the rotational stocking treatments, the difference between their average daily gain was significant at P<0.05 (Appendix 4.3). Similar comparison of regression coefficients of LW on time for CA and CS cattle under rotational stocking still showed no difference in daily LWG (Appendix 4.3); nor did it show for CA under continuous versus rotational stocking.

4.3.3.3. Gain per ha

Total calculated gain per ha for each treatment is given in Table 4.7. In both stocking systems, gain per ha was higher (*ca.* 30 %) on pastures grazed by cattle alone than those grazed by cattle plus sheep (Table 4.7). Within stocking system, CA produced 26 % and 38 % higher LWG per ha than CS under continuous and rotational stocking systems, respectively. Within species mix, LWG per ha from CA-R was 33 % higher than that from CA-C (970 vs 731 kg ha^{-1}). Similarly, LWG per ha from CS was 21 % higher under rotational than continuous stocking (704 vs 580 kg ha^{-1}). The ratio of cattle:sheep LWG per ha in the total LWG per ha, in CS treatment was 1.4:1.0 and 2.1:1.0 under continuous and rotational stocking, respectively.

Table 4.7. Calculated total LWG per ha on pastures grazed by CA or CS using continuous or rotational stocking.

			CS-C		CS-R	
Variable	**CA-C**	**CA-R**	Cattle	Sheep	Cattle	Sheep
LWG, g day^{-1}	916	1022	706	155	1028	147
Animals ha^{-1} day^{-1}	6.33	7.53	3.81	12.3	3.69	12.2
Grazing days ha^{-1}	798	949	480	1550	478	1537
Total gain ha^{-1}, kg	731	970	339	241	478	226
Overall total, kg	**731**	**970**	**580**		**704**	

4.3.3.4. Pasture intake

Organic matter intake (OMI)

Sheep

The mean OMI was 1.96±0.11 and 2.04±11 kg day^{-1} for continuously and rotationally co-grazed sheep, respectively (Table 4.8). Overall mean daily OMI of continuously and rotationally co-grazed sheep was not significantly different (P=0.63); there was no period x system interaction (ANOVA in Appendix 4.4a). Between the two intake measurement periods mean OMI of sheep, across treatments, increased from 1.72 to 2.29 kg day^{-1} (Table 4.8).

Table 4.8. Mean OMI (kg day^{-1}) of sheep co-grazed with cattle using continuous or rotational stocking over two intake measurement periods.

Stocking system	Overall	Period I	Period II
Continuous	**1.96^{a}**	1.82a	2.10^{a}
Rotational	**2.04^{a}**	1.62a	2.47^{a}
s.e.m.	***0.11***	*0.16*	*0.16*

Cattle

Table 4.9 summarises cattle OMI over the whole experimental period. Values for each intake measurement period are also included. Accordingly, variables with significant effect on overall OMI were, intake measurement period (P<0.01), species mixture (P<0.05), stocking system (P<0.01) and species mixture x stocking system interaction (P<0.01). Other interactions were not significant (Appendix 4.4b).

Over all treatments, mean OMI of cattle increased from 6.51 to 10.22 kg head^{-1} day^{-1} (P<0.01) between the two intake measurement periods. There was 13 % difference in daily OMI of CA and CS (8.89 vs 7.84 kg, respectively), which was statistically significant (P<0.05) (Table 4.9). Across species mixture, rotationally stocked cattle had 20 % higher daily OMI (9.12 vs 7.61 kg head^{-1}) than those continuously stocked (P<0.01). Within stocking system, CS cattle had only 69 % of the daily OMI of their CA counterparts under continuous stocking (P<0.01). The difference between these groups during period I was not significant (Table 4.9). In contrast, under rotational stocking there was only 0.65 kg difference between the overall daily OMI of CS cattle (9.45 kg) and CA cattle (8.80 kg); nor did they differ significantly during each intake measurement period (Table 4.9).

Digestible organic matter intake (DOMI)

The organic matter digestibility of OE samples and calculated DOMI of sheep and cattle are given in Table 4.10. For both cattle and sheep, the comparison of DOMI was similar to their respective OMI comparison presented above.

Table 4.9. Mean OMI of cattle either grazed alone or co-grazed with sheep, using continuous or rotational stocking. (Over all intake measurement periods).

Comparison		OMI (kg day-1)		
		Overall	Period I	Period II
1. Across stocking system:				
	CA	**8.89**[a]	6.79[a]	10.99[a]
	CS	**7.84**[b]	6.23[a]	9.46[b]
	s.e.m.	*0.28*	*0.40*	*0.40*
2. Across species mixture:				
	Continuous	**7.61**[b]	5.58[b]	9.64[a]
	Rotational	**9.12**[a]	7.44[a]	10.81[a]
	s.e.m.	*0.28*	*0.40*	*0.40*
3. Stocking system x species mixture:				
Continuous:	CA	**8.98**[a]	6.66[ab]	11.29[a]
	CS	**6.24**[b]	4.94[b]	8.00[b]
Rotational:	CA	**8.80**[a]	6.93[a]	10.68[a]
	CS	**9.45**[a]	7.96[a]	10.94[a]
	s.e.m.	*0.40*	*0.56*	*0.56*
	CV %	*18.9*	*24.1*	*15.5*

Table 4.10. *In vitro* digestibility of oesophageal extrusa OM and DOMI of cattle and sheep under different treatments.

			DOMI	
Species	**Treatment**	**OMD (%)**	kg hd^{-1} day^{-1}	g $(kg.LW^{0.75})^{-1}$
Sheep	CS-C	84.4	1.65	82.8
	CS-R	83.2	1.70	86.3
Cattle	CA-C	76.5[α]	6.87	100.0
	CS-C	74.7	4.66	71.6
	CA-R	79.4	6.99	100.0
	CS-R	77.8	7.35	104.4

[α]Calculated from *in vitro* OMD of botanical components weighted for their proportion in CA-C diet, because OMD of extrusa for CA-C was unrealistically low, at 69.8 % OM.

4.3.3.5. Diet composition

From the canonical variate analysis alkanes that were shown to best discriminate between botanical components were C27-C31, C33 and C35. These alkanes were taken from the first two canonical variates which accounted for 96.3 % of the between botanical component variation in alkane pattern. The canonical means showed good discrimination was possible between clover, grass leaves and grass stem. However, the use of these alkanes did not discriminate well between grass leaf and dead herbage (Fig. 4.11), as most of the dead herbage was also grass leaf.

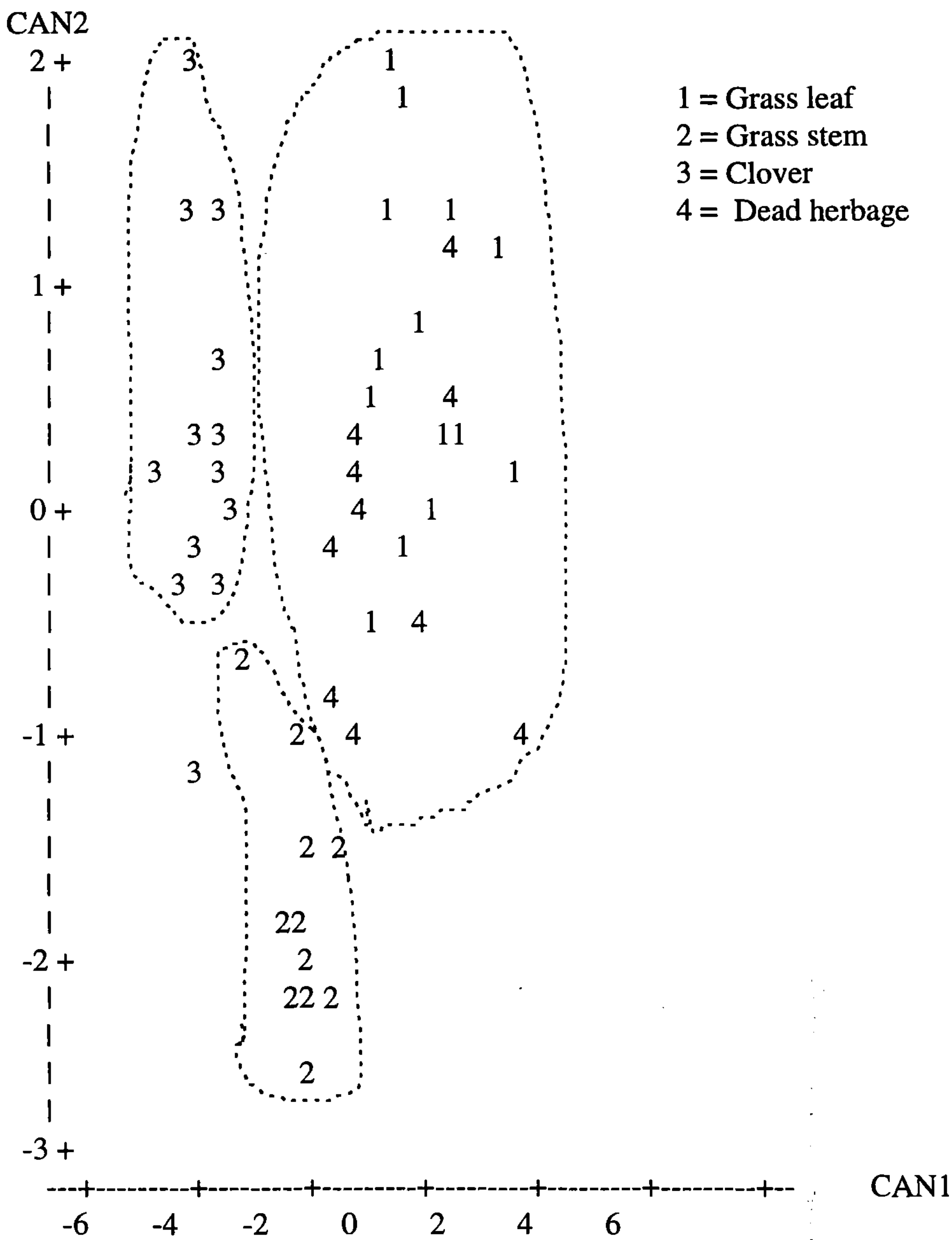

Fig. 4.11. Plot of canonical means for botanical components.

Sheep diet

The composition of sheep diet predicted using alkane patterns contained more grass leaf (60 vs 46 % OM), more dead herbage (15 vs 0.0 % OM), and less stem (0.0 vs 31 % OM) under rotational than continuous stocking (Fig. 4.12). The clover content of sheep diet was predicted to be similar under both stocking systems (Fig. 4.12).

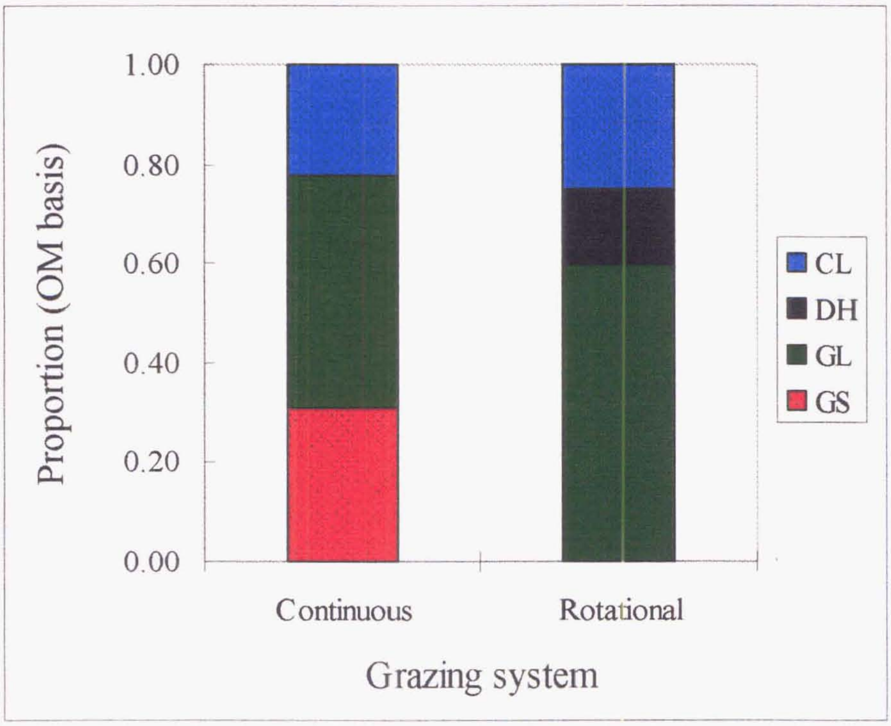

Fig. 4.12. Predicted botanical composition of sheep co-grazed with cattle using different stocking systems.

Cattle diet

Predicted clover content of cattle diet showed an interaction between stocking system and species mixture. Under continuous stocking, cattle diet contained three times more clover in total diet OM when grazed alone (30.7 %) than when stocked with sheep (10.4 %) (Fig. 4.13a). In contrast, clover in the diet of cattle was similar for CA (24 % OM) and CS (22 % OM) under rotational stocking (Fig. 4.13b). Under both stocking systems CS cattle had a greater proportion of grass leaf (GL) in their diet than CA cattle (Fig. 4.13a,b). Within species mixture, CS diet had twice as much clover under rotational (21.5 % OM) as it did under continuous stocking (10.4 % OM). Stem content in CA-R cattle was twice that of CS-R (Fig. 4.13b), but the proportion of stem in cattle diet was similar for CA-C and CS-C cattle (Fig. 4.13a). The method did not predict dead herbage as a major contributor to cattle diet, especially under continuous stocking(Fig. 4.13a,b).

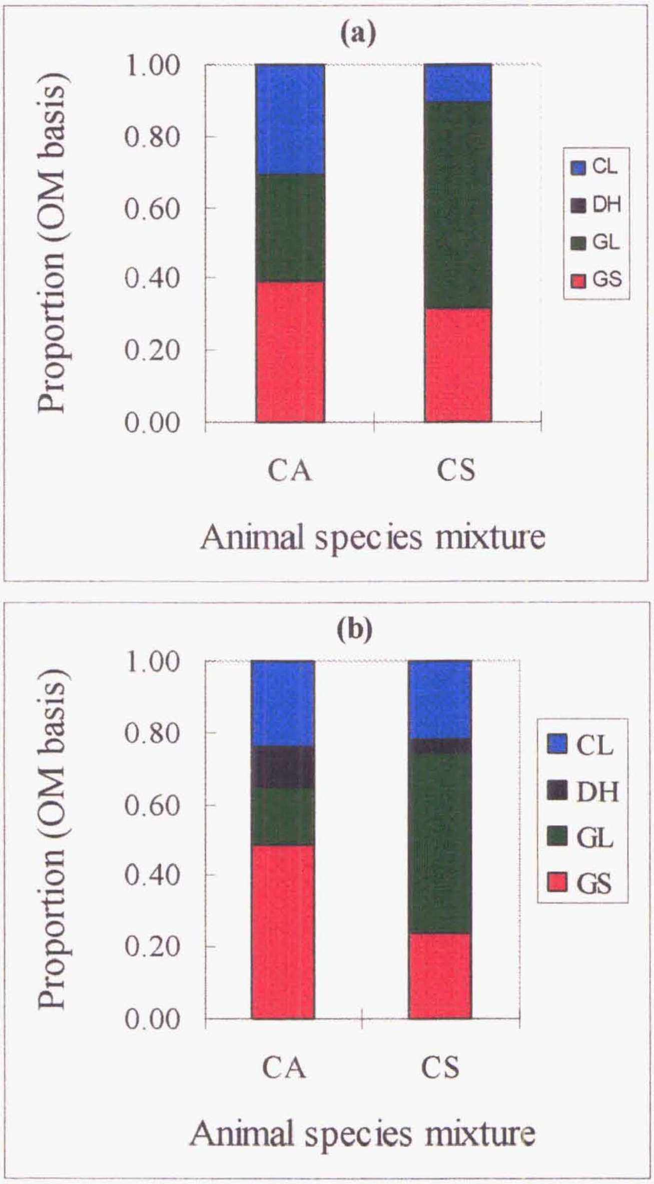

Fig. 4.13. Botanical composition of cattle diet grazed alone (CA) or co-grazed with sheep (CS) under (a) continuous stocking or (b) rotational stocking.

The clover content of cattle diet that was predicted using C29:C33 ratio (as opposed to using 7 alkanes) in herbage and faecal samples is shown in Fig. 4.14. Clearly, this ratio also showed greater difference in clover content of diet OM between CA (60 % OM) and CS cattle (2.5 % OM) under continuous stocking; but no such marked difference in CA and

CS cattle under rotational stocking (Fig. 4.14). For all diets except CS-C, the absolute clover content figures predicted using this ratio were higher than that predicted using least-squares procedure (Fig. 4.13a,b vs Fig. 4.14).

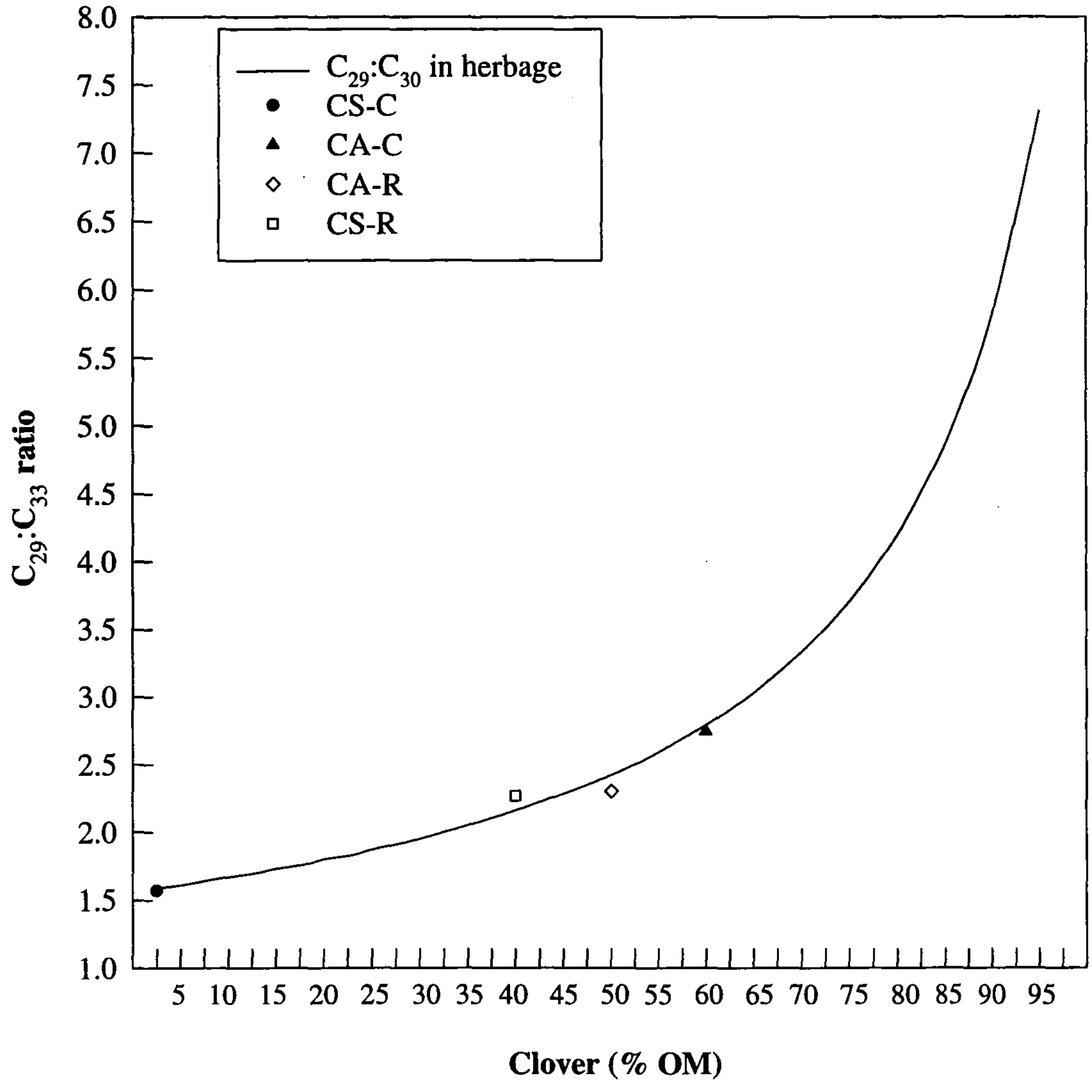

Fig. 4.14 The relationship between clover content of herbage OM and its C_{29}:C_{33} alkane ratio, used to estimate the clover content of cattle diets from this ratio in faecal samples.

Similarity coefficients

Kulcyznski's similarity coefficients between animal diet and swards were not computed, because the least-square method did not separate between grass leaf and dead herbage (Fig. 4.11). In addition, a number of 0 % solutions for botanical components in animal diets gave a low similarity coefficient for most animals irrespective of treatment groups.

4.4. DISCUSSION

The primary objective of Experiment II was to dissociate the effect of difference in mean sward height from that of stocking system which were confounded in the first experiment, to more effectively compare the influence on cattle of continuously or rotationally co-grazing with sheep. Accordingly, this discussion will primarily summarise the main findings of this experiment in relation to the above objective. Later sections of the discussion will provide separate appraisal of each of the animal variables measured in relation to both the prevailing pasture conditions, and relative to other published reports of similar experiments. Results from Experiment I and II are considered together, in a separate section under general discussion (Chapter 5) to formulate theories about how mixed grazing operates in each stocking system.

Primarily, the results from this study have confirmed the core tenet of this thesis that mixed grazing outcome is influenced by the stocking system applied. At similar sheep liveweight gain, cattle continuously stocked with sheep grew at 69 % of the daily LWG attained by their rotationally stocked counterparts (706 vs 1028 g day^{-1}). Perhaps more importantly, LWG of CS differed from that of their counterparts grazed alone under each stocking system, but in different directions. Under rotational stocking, compared to those grazed alone, cattle co-grazed with sheep had no apparent advantage or disadvantage in terms of daily LWG, final LW or total OMI and its botanical composition. In contrast, cattle continuously stocked with sheep had significantly lower daily OMI (6.24 vs 8.98 kg day^{-1}), had less clover in their total OMI (10.4 vs 30.4 %) and consequently grew at a slower rate (706 vs 916 g day^{-1}). They also achieved lower final fasted liveweight (283.2 vs 322.8 kg) than those continuously stocked on their own.

The difference in growth rate of continuously and rotationally stocked CS cattle was due to both difference in mean grazing sward height (4.26 vs 9.9 cm) plus the differential effect of the interplay of mixed grazing and stocking system on cattle performance (stocking system x mixed grazing interaction). How much of the difference between CS-C and CS-R cattle was due to mixed grazing *per se*? The answer to this question will be attempted by using the schematic presentation in Fig. 4.15, where daily LWG achieved by cattle in each treatment is shown against the contributing factors for difference between treatments (see also Fig. 4.2 in materials and methods). The difference between CS cattle LWG under rotational and continuous stocking (1028 vs 706 g day^{-1}) was greater than the difference between CA cattle under rotational and continuous stocking (1022 vs 916 g day^{-1}) by about 216 g in daily LWG (322-106=216). This amounted to 67

% of the total difference observed between CS cattle daily LWG under continuous and rotational stocking (216/322). This suggests that about two-thirds of the difference in daily LWG of CS cattle under the two stocking systems can be attributed to mixed grazing *per se*. In other words, the detriment to cattle performance of reducing mean SSH from about 10 cm under rotational stocking to 4 cm under continuous stocking becomes greater (by twofold) when sheep are introduced into the equation.

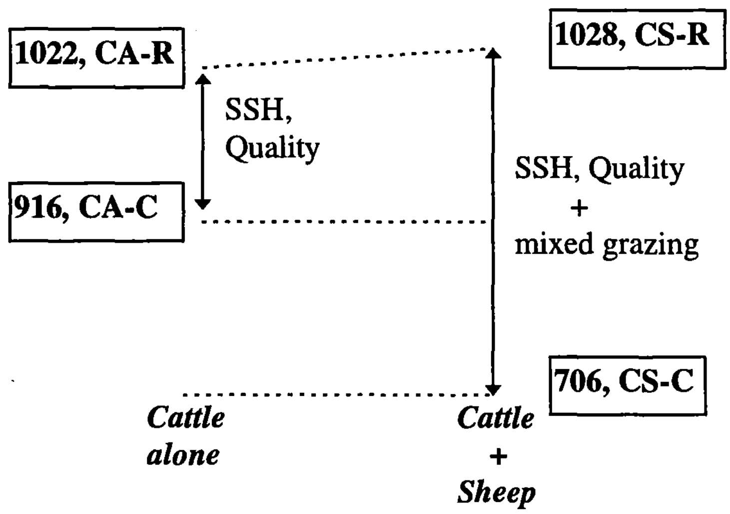

Fig. 4.15. A schematic presentation of daily LWG of cattle (g) and contributing factors under various treatments.

One of the interesting results under the continuous stocking system was the interaction between the progressive increase in clover content of the CA pasture and the reduced patchiness and therefore lower proportion of infrequently grazed heights of CS pasture (0.30 vs 0.05). These results suggest that the advantage of mixed grazing arising from sheep grazing around cattle dung patches on sown grass/clover pasture is more than offset by their selective grazing of clover, with the net result that cattle continuously stocked with sheep were at a disadvantage compared to those grazed alone. Comparison at a different sward height may lead to a different conclusion. See chapter 5.

On rotationally stocked treatments, the presence of sheep did not have any apparent effect on the botanical composition of the sward, with the net result that co-grazing with sheep had no measurable effect on intake and liveweight gain of cattle co-grazed with sheep. Further, at the residual sward height used in this study, there was no difference in patchiness of the post-grazing areas of pasture grazed by CA or CS. That is, at the post-grazing height applied here (CA: 4.87; CS: 4.82 cm), there was no greater area of pasture rejected by CA than CS to give any advantage to CS cattle when both were grazed to similar residual sward height. See chapter 5 for possible outcomes in other scenarios.

Overall, the results from this study do not lend any support to recommend co-grazing cattle and sheep over grazing cattle alone on ryegrass/clover pasture, as cattle either had similar growth rate (rotational stocking), or grew at a slower rate (continuous stocking) than their mono-grazed counterparts. Further, observations on liveweight gain per ha also showed greater output from cattle alone than CS treatments in both stocking systems. Therefore, it follows that if there is a need to use co-grazing of sheep and cattle for diversification, parasite control, or other aspects of mixed grazing, observations from this study provide some basis for using rotational stocking rather than continuous stocking. The results do not present a case for improvement in individual cattle performance due to co-grazing with sheep at least under conditions of this experiment. However, a true estimate of stocking system x mixed grazing interaction on a whole system basis will require further research which incorporates sheep grazed alone.

In the remaining section of this discussion, results from this study are compared to relevant previous mixed grazing reports in the literature. The fact that many early mixed grazing reports that compared CA vs CS were confounded by latent change in stocking rate due to erroneous species substitution rate (Refer chapter 2), will limit the ease with which useful inferences can be made by collating supporting data.

4.4.1. Liveweight gain per animal

The effect of stocking system applied on the outcome of mixed grazing was confirmed by the significant interaction between species mixture and stocking system for final fasted liveweight attained by cattle from different treatments (Table 4.6; see also Appendix 4.2b). However, there was no significant interaction between species mixture and stocking system for average daily LWG, considering daily LWG was higher for CA than CS under continuous stocking, but lower (though not by much) for CA than CS under rotational stocking (Table 4.6). This was most likely due to the high within treatment variation in daily LWG of CS cattle, which would have diluted between treatment variation in individual LWG per day. Within treatment coefficient of variation of daily LWG and final fasted LW, averaged across treatments, was 21.0 and 9.1 %, respectively. As Holecheck and colleagues (1984) observed, "Small differences are usually measured with poor precision." Next, LWG from each stocking system is separately discussed in relation to relevant previous reports in the literature.

4.4.1.1. Continuous stocking

Daily LWG of CS cattle from this experiment (706 g day^{-1}) was lower than that observed the preceding year (804 g day^{-1}). This was probably a reflection of the difference in SSH as shown in the later part of this section. Primarily, it may help to get an overview of previous findings before considering detailed comparisons. As far as this author is aware, only Merrill (1975, cited by Lambert and Guerin, 1989) has reported considerable improvement in LWG (20 %) of cattle continuously stocked with sheep as compared to those stocked alone. This was a study on rangelands of Texas on a vegetation of shrub-forbs-grass (see Lambert and Guerin's (1989) summary table), and therefore is of little relevance to this study. In any case, it was not possible to get access to that publication and get an insight into this outcome relative to the experimental protocol. Brelin (1979) reported a mere 5 % increase in LWG of CS cattle over CA on a continuously stocked *Poa-Agrostis* pasture. Most other cattle-sheep mixed grazing studies that used continuous stocking (Ebersohn, 1966; Reynolds *et. al.*, 1971; Hamilton, 1976; Hamilton and Bath, 1970; Bennett *et al.*, 1970; Dyrmundsson and Gudmundsson, 1980) reported neither a disadvantage nor improvement in cattle LWG due to grazing with sheep. Hamilton (1976) reported that over three years, out of a four-year study period, mixed grazing had no benefit to cattle daily LWG, but depressed cattle LWG in one year of drought. Considering the drought factor and that the design was based on stock number per ha, it is hard to say how much of that depression in cattle LWG was due to mixed grazing *per se*.

In contrast to the above studies, cattle co-grazed with sheep under continuous stocking in this study grew at a slower rate (706 vs 916 g day) and reached a significantly lower final liveweight (283.2 vs 322.8 kg) than those grazed on their own on a pasture maintained at similar sward state. Probably the only other experiment that found lower LWG in cattle co-grazed with sheep than those grazed on their own, was that of Culpin and colleagues (1964) where LWG of CS cattle was 90 % of CA in a treatment where the relative sheep proportion was low, and 86 % of CA where sheep proportion was relatively higher. In that study the driving variable, i.e., equivalence between CA and CS, was stocking rate rather than sward state (as in this study), and their design involved concurrent change in stocking rate as well as species mixture to confound the results. Therefore, it appears as though this study is the first mixed grazing experiment on sown ryegrass/clover pasture that has shown a substantial negative effect of continuous co-grazing with sheep on cattle LWG as compared to cattle grazed on their own at a similar sward state (SSH).

As far as mixed grazing under continuous stocking is concerned, it can be argued that lack of true species substitution rate is of little consequence in comparing individual animal performance as long as both pastures under mono- and mixed grazing are maintained at a similar sward state. Hence, in comparing data on the relative performance of CA and CS cattle from different continuous stocking experiments, it is vital that the studies considered have similar parameters to control sward state. Reynolds and colleagues' (1971) work could provide some parallel for this study, because it was also based on put-and-take to maintain sward at a certain target level; in their case herbage mass. They had CA and CS grazed on swards maintained at 500 and 1100 kg ha pasture mass. Curiously though, they presented the average animal performance across pasture mass levels, rather than per animal or per ha LWG at each pasture mass (see Table 3.12 footnote). Hence, their results will be of little use in drawing a pattern of change in the relative performance (growth rate or intake) of CA and CS cattle with change in sward state. Of necessity, results from this study are considered in relation to the relationship between cattle LWG and sward height reported from single species grazing.

Accordingly, the daily LWG of both CA and CS cattle from this experiment is included into the data presented in Fig. 3.7 and presented in Fig. 4.16 below. As stated earlier, some of the collated data includes calves suckling their mothers. From the limited range of data presented, it appears that co-grazing cattle with sheep increases the rate at which daily LWG declines with falling SSH (Fig. 4.16). As shown in Fig. 4.16, the daily LWG of CA-C fell at the junction of the linear relationship between LWG and SSH for compensating and non-compensating growing beef cattle. There are two possible interpretations. If we assume that CA-C fitted with Wright and others (see Fig. 4.16) data for compensating cattle, then the nutritional environment as modified by the presence of sheep limited the opportunity of CS cattle to exhibit compensatory growth (Fig. 4.16). If we assume the growth rate of CA-C fitted better with that of non-compensating cattle, it also follows that the presence of sheep partially prevented CS cattle from achieving the normal growth rate attainable at that SSH (Fig. 4.16). Hence, there is some basis to suggest that the response of CS-C cattle to change in sward height is different from that commonly shown for cattle grazed alone. Further study is required to substantiate this claim. This is argued further on theoretical grounds in chapter 5.

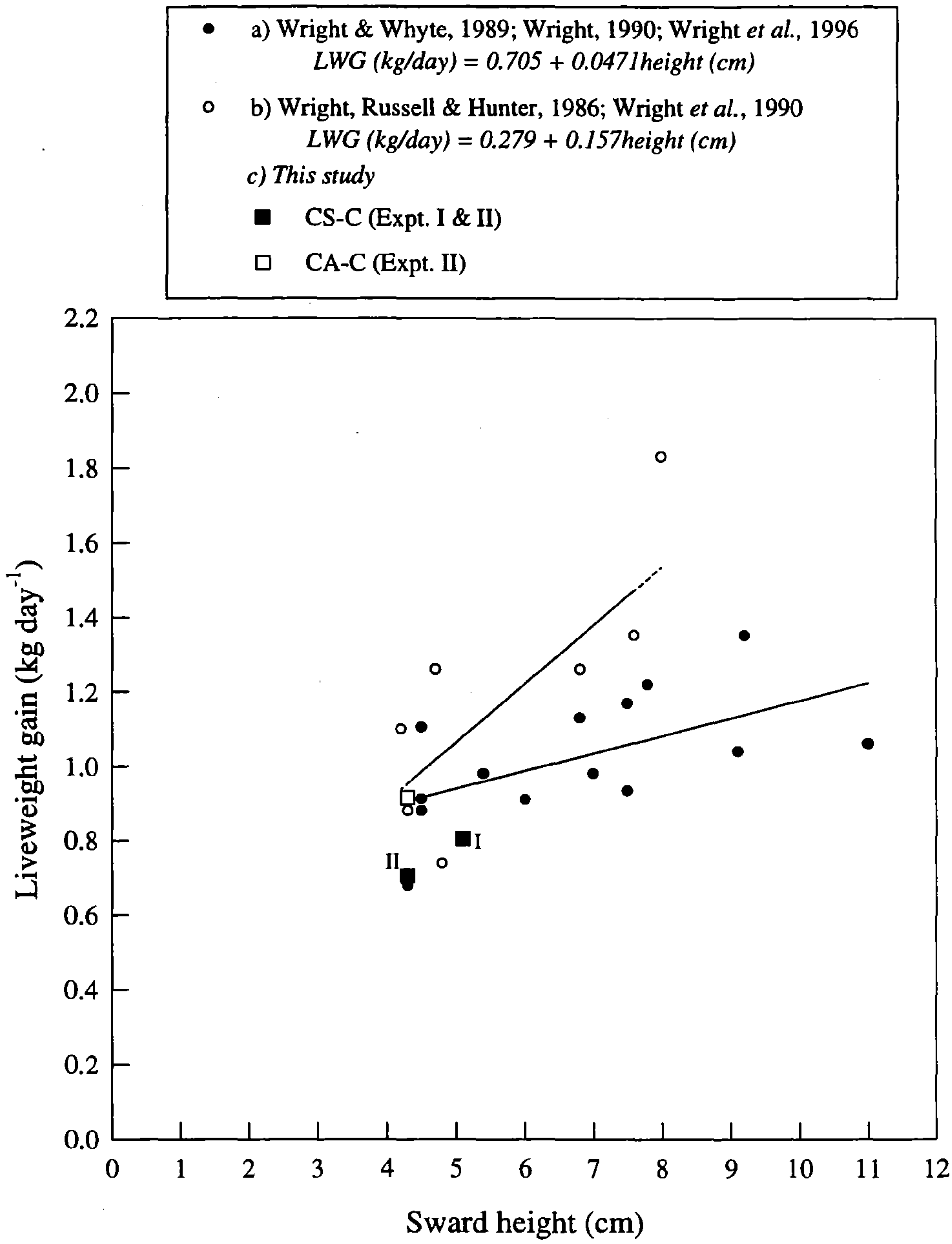

Fig. 4.16. Sward height and liveweight gain of beef calves previously under non-restricted (a), or restricted feeding (b), and cattle from this study (c) under continuous stocking.

Further comparison with work from New Zealand (Morris *et al.* 1993) on Friesian bulls (initial LW, 288) and Charolais x Angus steers (initial LW, 329) also provides some interesting points (Fig. 4.17). This figure clearly shows that cattle growth rates recorded in this study (experiments I & II) were within the range of LWG previously reported for steers at the respective sward heights. The response of LWG of CS heifers to change in SSH from the two experiments in this study matched that of mono-grazed steers (Fig. 4. 17).

Bearing in mind inter-experimental variation, one might have expected the change in daily LWG of heifers in relation to change in SSH to be lower and flatter than that of steers, because the steers were heavier than the heifers used in this study (initial LW, 329 vs 230 kg). It is well documented that smaller animals are better able to ameliorate the effect of declining SSH on their intake and LWG than larger animals (Zoby and Holmes, 1983; Nicol and Sousa, 1993). Perhaps this might lend some support to the assumption that heifers from this study were showing compensatory growth; those grazed alone having greater opportunity to express it than those grazed with sheep (Fig. 4.17).

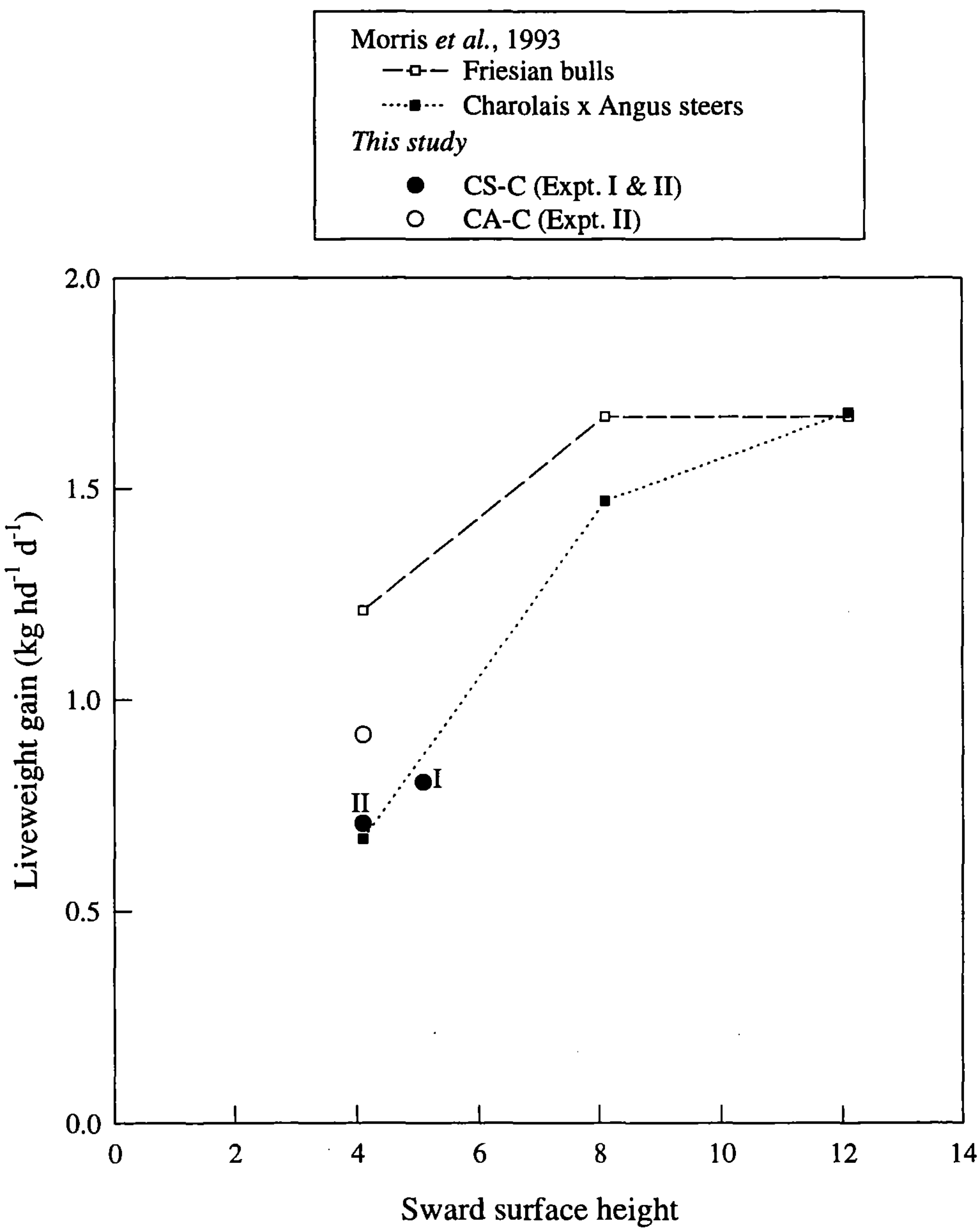

Fig. 4.17. Comparison of daily LWG of CA-C and CS-C cattle to that of bulls and steers under similar grazing management.

In summary, all the evidence presented suggests that the difference in growth rate of CA and CS cattle was a mixed grazing effect, because neither CA cattle grew exceptionally faster nor CS cattle grew exceptionally slower than previously documented by other authors for a pasture continuously stocked at 4.0 cm SSH. There is a need for further study to describe whether the response pattern of cattle LWG to change in sward state is modified by the presence of sheep. Nicol and Sousa's (1993) short-term work which investigated how young and old cattle were affected by the presence of sheep as they grazed a falling pasture mass has already shown the possibility for different response patterns to SSH of CA and CS.

4.4.1.2. Rotational stocking

Cattle daily LWG from the CS treatment from this experiment (1028 g day^{-1}) can be considered a replicate of that from the preceding experiment (1039 g day^{-1}). This was a reflection of the closeness of the pre- (15.9 vs 15.2 cm) and post-grazing (5.6 vs 4.8 cm) SSH applied in experiments I & II. This provided some confirmation of the observed cattle growth rate from experiment I.

In contrast to those based on continuous stocking, there are a number of mixed grazing studies that found increase in daily LWG of cattle rotationally stocked with sheep (Nolan, 1980; Dickson *et al.* 1981; McCall *et al.*, 1986; Nolan and Connolly, 1989). There are also others who did not find any improvement in cattle LWG due to rotationally grazing with sheep (Ebersohn, 1966; Van Keuren, 1970; Boswell and Cranshaw, 1978). It is admitted that those experiments that did not find mixed grazing benefit to cattle LWG under rotational stocking pre-date the criticism of lack of true substitution rate in many mixed grazing trials (Connolly, 1987; Nolan and Connolly, 1989).

An interesting observation was that of Boswell and Cranshaw (1978) which found no significant difference between LWG of cattle co-grazed with (concurrent) or rotated ahead of sheep (sequential) and those grazed on their own. Their results are extracted into Table 4.11. Since pasture control for cattle under both mixed and mono-grazing in that experiment was based on similar pre- and post-grazing height, sward state variables, it is unlikely that erroneous substitution rate played a role in lack of mixed grazing effect. It is more likely that at the residual sward height applied (2-3 cm) to both cattle alone and cattle-sheep treatments were equally effective in harvesting most of the herbage on offer. That is, the less patchy a sward is due to low post-grazing height, the less likelihood there is for a mixed grazing benefit to cattle (Refer to section 2.1.1.1 in literature review).

Table 4.11. Summary of cattle and sheep LWG data from mixed grazing experiments with similar pasture control.

Authors		Ratio	SSH (cm)		PM (kg/ha)		LWG (g/hd/d)		
		C:S	Pre-	Post-	Pre-	Post-	CS	CA	Sheep
This study	*I*	*1:1*	*15.9*	*5.6*	*4020*	*1980*	*1039*	-	*138*
	II	*1.1*	*15.2*	*4.82*	*3102*	*1602*	*1028*	-	*147*
		1:0	*14.9*	*4.87*	*3063*	*1751*	-	*1022*	-
Boswell &		100:0	15-20	2-3	2800	1100	-	660	-
Cranshaw,		66:33	15-20	2-3	2800	1100	580	-	128
1978		33:66	15-20	2-3	2800	1100	700	-	121

N.B. Boswell and Cranshaw's values also were not significantly different (P>0.05).
Ratio in this study, LW0.75 basis; Boswell and Cranshaw (1978), % stock units.

In another New Zealand experiment based on controlling sward state (rate of reduction in pasture mass), Collins (1989) found no benefit to cattle from grazing with sheep; rather an 18.7 % decrease in DOMI of cattle grazed with sheep as opposed to those grazed alone. Since this was a short-term experiment it can be argued that the effect would have faded as cattle adapt to the situation.

Of the studies that reported improvement in cattle LWG under mixed rotational stocking (see above) McCall *et al.* (1986) are the only ones who provided pre- and post-grazing pasture mass. Even then, they did not present cattle LWG for each post-grazing pasture mass (1200, 1700 & 2300 for easy land and 1200 & 1700 kg ha^{-1} for steep land) x species ratio (cattle:sheep- 0/100, 80/20, 60/40, 100/0) combination (see Table 2 in McCall *et al.* 1986). Therefore, it can only be assumed that those studies that recorded improved cattle LWG from mixed grazing probably used a higher residual herbage mass or sward height than applied in this study. This is based on the assumption that higher post-grazing mass will lead to greater patchiness, which in turn will lead to improvement in cattle LWG under mixed grazing through better use of dung patches by sheep.

For comparison to Experiment I, LWG of rotationally stocked cattle from this experiment was added to that in Fig. 3.8 to create Fig. 4.18. As shown, the difference in residual herbage mass between Experiment I (*ca.* 2,000 kg DM ha^{-1}) and Experiment II (*ca.* 1,650 kg DM ha^{-1}) was not high enough to elicit considerable change in LWG of rotationally stocked cattle common to both experiments (Fig. 4.18). This is probably a reflection of the less sensitivity of animal performance to pasture mass than to sward height, which was very similar between the two experiments (Fig. 3.2 vs Fig 4.5).

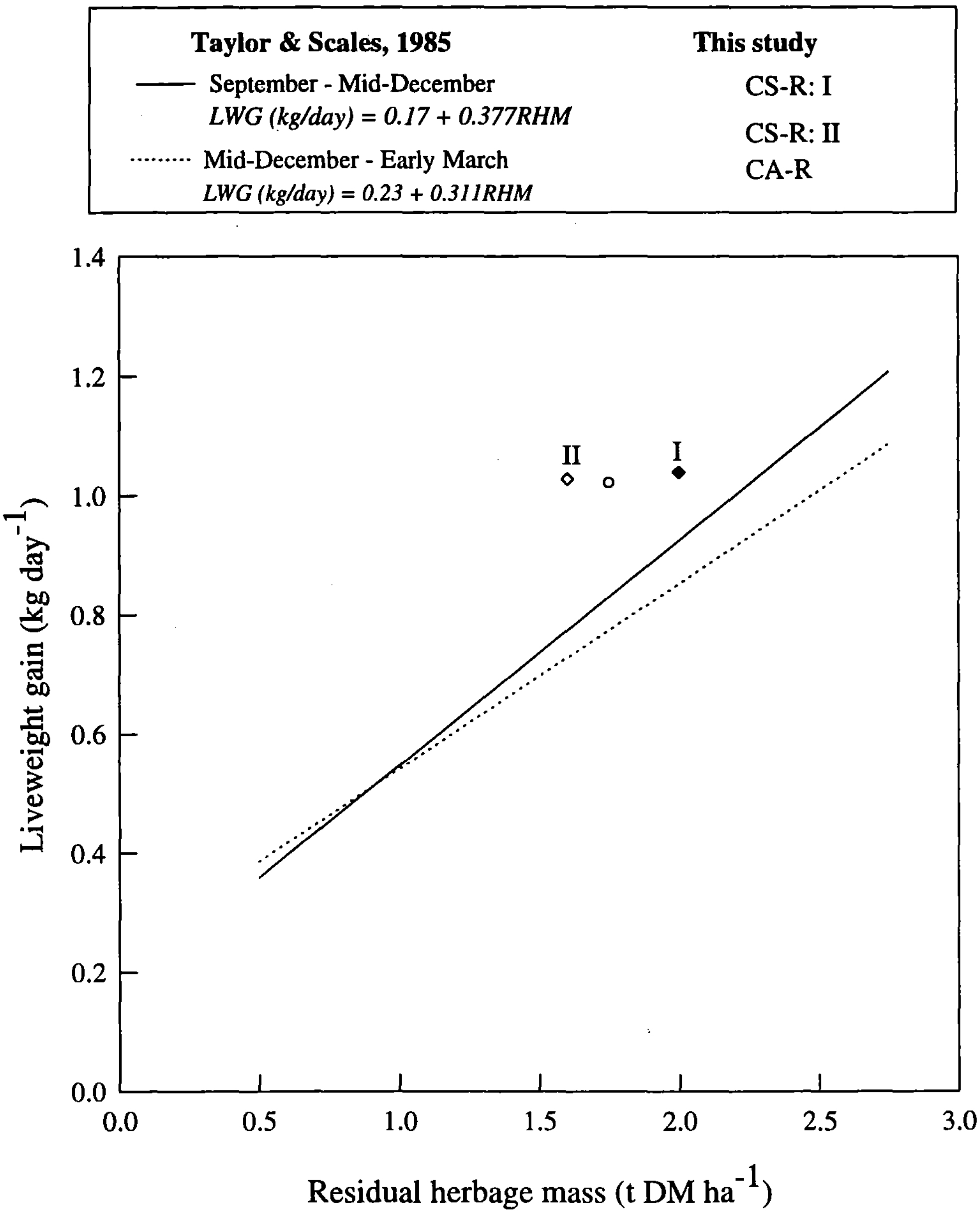

Fig. 4.18. Liveweight gain of growing beef cattle at different residual herbage mass under rotational grazing (*Adapted from Taylor & Scales, 1985*). (Includes data from experiments I & II).

4.4.2. Liveweight gain per ha

LWG per ha is more influenced by stocking rate than any other variable, and is not a strong parameter for discerning mixed grazing effect (Nolan and Connolly, 1989). It is only used here to show that total LW output from experiments in this study was within the range observed elsewhere.

It can generally be stated that LWG per ha will be greater under cattle alone than cattle plus sheep, due to the inherent difference in metabolic efficiency between a small and a large animal (Kleiber, 1965). The results from this study concur with this premise, as under both continuous and rotational stocking LWG per ha was greater on CA than CS treatments. Nolan and Connolly (1989), on the other hand, reported greater LWG per ha from cattle sheep combinations than cattle alone treatments. However, they also concede that the increased output from mixed grazing was inflated by a higher average mixed stocking rate (0.02 per ha) than mono-grazing cattle. Further, they state that despite its benefit to lamb growth rate, mixing does not necessarily lead to improved total output because lambs may not contribute as much to total liveweight output as the steers they replaced. Some LWG per ha data from various reports are extracted into Table 4.12.

The liveweight gain per ha computations in this study were done by removing areas under ewe mob grazing in calculating animals per ha per day. This may have under- or overestimated the actual LWG per ha. Since this was done for all treatments it is deemed that there was no differential effect on any treatment. Again, the observed difference in LWG per ha between continuously or rotationally stocked cattle-sheep mixture in experiment I was confirmed by results from this experiment (Table 4.12). However, there was a change in the magnitude of the difference between the two experiments: 6.3 % higher LWG per ha from CS-R in year I to 21 % higher LWG per ha from CS-R than CS-C in year II (Table 4.12). This was probably due to the substantial depression in LWG of CS-C cattle in the second experiment, since sheep LWG of CS-R cattle and sheep LWG in both systems were similar between years. Perhaps the presence of sheep has forced output per ha under continuous stocking below the level where reduced per animal gain is associated with increase in output per ha.

Table 4.12. Summary of LWG per ha data from some grazing experiments with cattle alone or cattle plus sheep.

Authors		Grazing system	Animals ha^{-1}		LWG(kg ha^{-1})
			Cattle	Sheep	Total
This study	I	*Continuous*	*3.6*	*12.3*	*630*
	II		*3.8*	*12.3*	*580*
	II		*6.3*	-	*731*
Culpin *et al.*, 1964		Continuous	2.5	-	144
			2.5	2.5	180
			2.5	3.7	202
			3.7	-	206
			3.7	2.5	228
			3.7	3.7	240
Hamilton & Bath, 1970		Continuous	1.41	5.63	359
			1.06	4.23	326
			0.54	2.82	240
			2.82	-	404
			1.41	-	225
This study	I	*Rotational*	*3.3*	*11.2*	*670*
	II		*3.7*	*12.2*	*704*
	II		*7.7*	-	*970*
Dickson *et al.*, 1981(2 ewes+twin lambs = 1 steer)		Rotational	7.5	5	1420
			5	10	1400
			7.5	10	1390
			5	15	1470
			7.5	-	1060
Nolan, 1986; & Nolan Connolly, 1989 (Liveweight gain to drafting)		Rotational	1.24	8.6	600
			1.54	7.4	600
			2.47	4.9	653
			1.65	11.1	754
			2.47	9.9	807
			3.40	6.8	789
			3.86	-	571
			4.53	-	646
			4.94	-	718

LWG per ha from continuously stocked treatments was higher than that reported elsewhere (Table 4.12), most probably due to the higher number of animals per ha than that applied by other authors for both CA and CS. LWG per ha from rotationally stocked treatments were lower than that reported by Dickson *et al.* (1981) for both CA and CS treatments. Values for CS-R were close to that reported by Nolan (1986). There are too many inter-experimental sources of variation that affect output per ha to consider for any valid inference to be made about the source of difference in output per ha shown in Table 4.12.

In summary, co-grazing with sheep has different effects on both per animal LWG of cattle and total output per ha depending on the stocking system applied. Results from this experiment concur with the preceding one, in that both in terms of cattle daily LWG and total output per ha, rotational co-grazing of cattle and sheep is preferable to continuously stocking them. Co-grazing cattle and sheep using either stocking system did not provide greater overall output per ha than grazing cattle alone. The remaining part of this discussion considers how well the measured intake, diet and pasture botanical composition support the observed difference in LWG and output per ha.

4.4.3. Pasture intake

Daily OMI predicted for both sheep and cattle in each treatment was congruent with the corresponding daily LWG per head, Table 4.5 vs 4.8 for sheep, and Table 4.6 vs 4.9 for cattle. Further, there was an increase in OMI of both sheep and cattle between periods (Table 4.8; Table 4.9) corresponding to the growth exhibited by each species. The lack of significant interaction between period, species mixture or stocking system for OMI agreed with the increase in OMI with period on all treatments (Sheep: Table 4.8; Cattle: Table 4.9). Therefore, in relative terms, the OMI data was in harmony with the liveweight data (i.e. low LWG per day - low OMI per day and vice versa). It would be interesting to see how the actual values compare with results from Experiment I and other reported data.

Primarily, OMI data together with corresponding LWG and SSH of treatments common to both Experiment I and II are presented in Table 4.13. When considered both in terms of the lower sward height in experiment II and the minor difference in daily LWG of sheep between experiments, OMI estimates from this experiment appear to be slightly high (Table 4.13). Further analysis of predicted OMI in each treatment is considered in relation to the respective LWG per metabolic body weight of cattle and sheep in experiments I & II (Fig. 4.19).

Table 4.13. Mean daily OMI and corresponding SSH and LWG of sheep and cattle for treatments common to experiments I and II.

			Sheep		Cattle	
Stocking system		SSH (cm)$^{\alpha}$	OMI, kg	LWG, g	OMI, kg	LWG, g
Continuous:	Expt. I	5.1	1.44	150	6.31	804
	II	4.3	1.96	155	6.24	706
Rotational	Expt. I	10.8	1.40	138	7.94	1039
	II	10.0	2.04	147	9.45	1028

$^{\alpha}$ SSH for rotational is the mean of pre- and post-grazing height.

There are some points to consider from Fig. 4.19. Overall, the distribution of predicted OMI (for cattle and sheep) in relation to LWG per metabolic body weight was similar for both continuous and rotational stocking treatments (Fig. 4.19). That is, there was no apparent bias in accuracy of OMI prediction using n-alkanes between continuous and rotational stocking. The same was true of cattle and sheep OMI estimates (Fig. 4.19). Values for predicted OMI per unit metabolic BW in relation to LWG per unit metabolic BW from this study were very similar to that calculated from sheep OMI data (also predicted using n-alkanes) reported by del Pozo and colleagues (1996). Computational errors, if any, are mine. Such congruence between estimates of OMI per unit metabolic BW from two different experiments lends support to the advocated accuracy of n-alkanes as faecal markers for intake measurement at grazing (Dove and Mayes, 1991). However, compared to values calculated using AFRC (1993) guidelines, OMI estimates from both studies appear to be high for the respective LWG in each study (Fig . 4. 19). This may suggest that the 5 % allowance (for activity) provided for using AFRC (1993) guidelines for outdoor grazing was insufficient. As stated earlier AFRC (1993) estimates did not have allowances for endo-parasites which may account for some of the difference. Alternatively, n-alkane based estimates of OMI may be prone to overestimating intake since the method relies on absolute recovery of herbage C_{32} and C_{33}, which may not always be achieved (see Equation 3). The former (i.e. lower estimates by AFRC) is more likely given that the OMI per unit metabolic BW from AFRC guidelines and that visually projected from the trends shown by the empirical data seem to converge at zero LWG per unit metabolic body weight (Fig. 4.19). See also Appendix 3.1b. In any event, the apparent accuracy of OMI estimates was similar under both grazing treatments and for both animal species, such that conclusions regarding treatment effects remain valid.

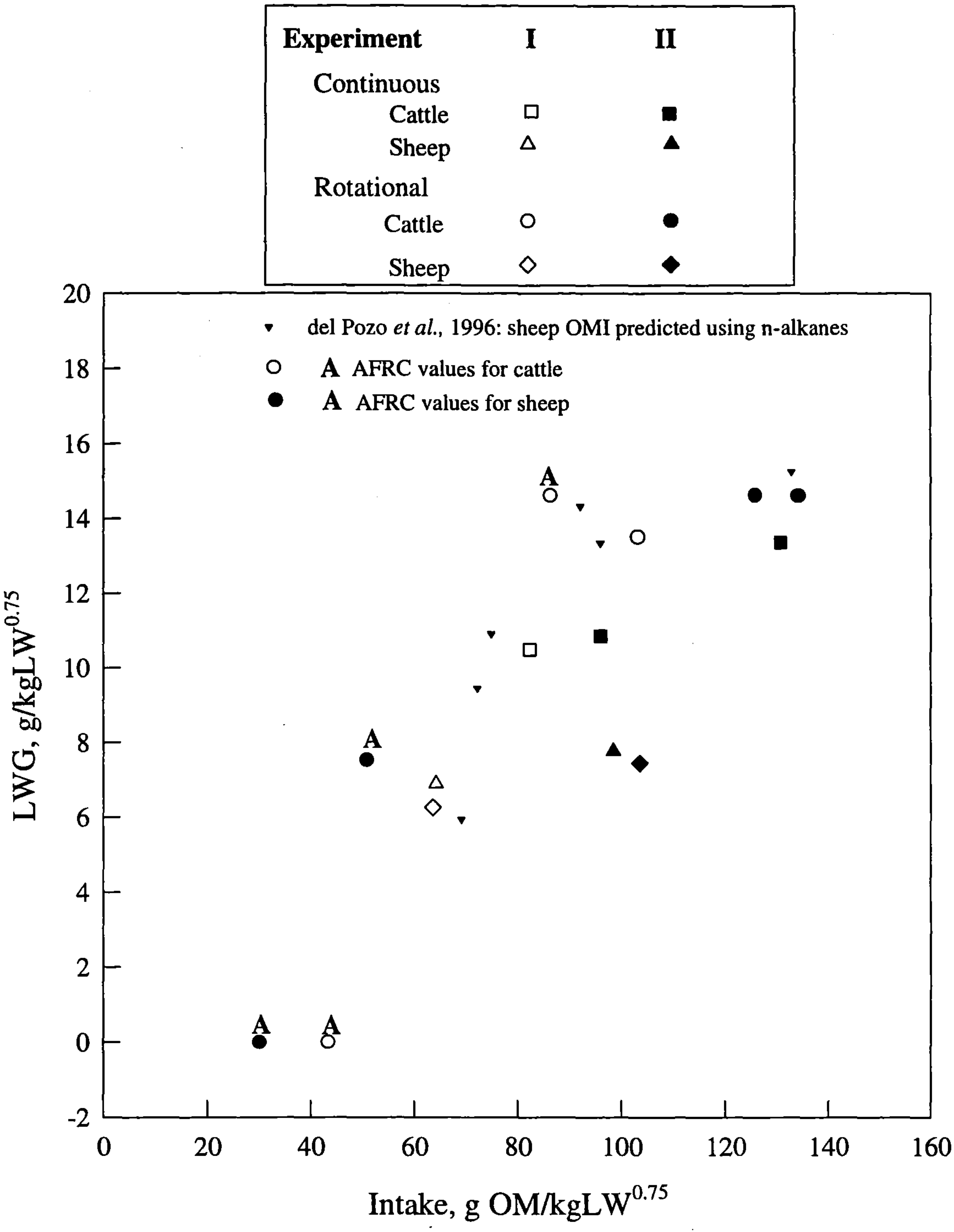

Fig. 4.19. Relationship between LWG and predicted OMI considered on metabolic body weight basis.

Now, the question why there was a large difference in intake between CA and CS cattle under continuous, but not rotational stocking? It has been established that on temperate pastures, sward height is the most important factor determining animal intake (Hodgson, 1985a,b; 1990) and has been recommended for use as a guideline for beef cattle feeding (Lowman *et al.,* 1988; Wright, 1990). Hence, the lack of difference in intake or LWG between CA and CS under rotational stocking can be accounted for by the similarity in pre- and post-grazing height as well as botanical composition of swards under CA and CS treatments. On continuously stocked treatments, CA and CS swards, though similar in overall mean sward height, had different clover content which may account for the different levels of OMI predicted.

The *in vitro* OM digestibility of OE were similar for CA and CS cattle (Table 4.9), but it has been shown that at equivalent digestibilities, clover has higher rate of degradation of OM (hence higher rate of intake) and more escape protein and greater intestinal digestion of escape protein (hence higher MP per kg OMI) (Steg *et al.*, 1994) than grass. It therefore seems very possible that due to the higher proportion of clover in CA than CS diet (30 vs 10 % OMI), CA cattle in continuously stocked swards benefited from rapid break down of clover OM in the rumen (Beever *et al.,* 1986), more escape protein and intestinal digestion of escape protein (Beever *et al.,* 1986, Steg *et al.,* 1994) than CS cattle and attained higher OMI and greater rate of growth at the same SSH. It is also estimated that *ad libitum* DM intake of cattle and sheep is at least 20 % more on clover than on grass diets (Thomson, 1984). Detailed comparison of the nutritive and feeding value of ryegrass versus white clover (Thomson, 1984) as well as the extent and site of digestion of grass vs clover OM is given elsewhere (Beever *et al.* 1986). Diet composition is considered below.

4.4.4. Diet composition

Discussion of diet composition here is limited to grass versus clover as the method used to predict diet composition was not successful in discriminating between all components (Fig. 4.11). Appraisal of using alkanes for predicting diet composition is presented in the later part of this section. Primarily, the predicted diet composition of animals will be discussed in relation to pasture composition. It has been argued that diet composition differs relatively little from pasture composition, despite large variation in preference of animals (Schwinning and Parsons, 1996). It then follows that greater clover in CA diet than CS diet on continuously stocked swards was a reflection of greater clover build up over time in CA-C swards (Fig. 4.6). Both the least-square method- which used 7 alkanes- and C_{29}:C_{33} ratio predicted higher clover proportion in diet OM of CA than that of CS cattle under continuous stocking (Fig. 4.13; 4.14). The absolute figures were higher for the ratio than the least-squares method (Fig. 4.13 vs Fig. 4.14). Similarly, the lack of difference in clover content between diets of cattle on CA-R and CS-R swards was supported by the absence of difference in clover composition of the two swards (Fig. 4.6). The lack of difference in sward composition on rotationally stocked swards, was probably because the post-grazing sward height may have limited clover density to the extent that both cattle and sheep abandoned their preference for clover to maintain total intake by grazing non-selectively (see Schwinning and Parsons, 1996 model). Considering the mean sward height applied, it would have required a strong preference for clover by sheep to create a large difference between their diet and pasture composition and have an impact on subsequent pasture clover content of rotationally stocked swards. The results do not support this preference premise. From a different perspective, the regular renewal of pasture resource under rotational stocking may not have given sheep time to express their preference and greater capacity to select for clover (refer chapter 2), and hence there was less opportunity for either species to influence the sward composition (each having 'equal bite at the cherry'). This premise lends support to lack of difference in clover proportion in the diet of CA and CS cattle under rotational stocking.

On continuously stocked swards, the difference in sward clover composition and thereby diet composition may have been enforced by the animals, as SSH was low enough for shading of clover by grass not to affect clover growth. At the 4 cm pasture, the high preference of sheep for clover and their smaller incisor arcade breadth as compared to cattle may have allowed them to select out clover and thus not allowing it to build up as it did in CA-C swards. This opportunity was given a continuous chance to take place. In addition, Schwinning and Parsons' (1996) model seems to suggest that conditions that encourage initial boost in clover growth in a clover-grass association will shift the level at which subsequent increase in grass density (benefiting from the abundance of fixed nitrogen) will curtail further clover expansion. Hence, it is in the grazers benefit not to seek out clover initially (Schwinning and Parsons, 1996). Therefore, difference in clover build up between CA and CS swards under continuous stocking may have been the result of selective grazing by sheep over the first 3-4 weeks, during which the greatest increase in clover content of CA swards happened (see Fig 4.6). See Schwinning and Parsons (1996) model for further details on grass-clover coexistence mechanisms. Now, a few comments on using alkanes for estimation of diet composition.

Prediction of diet composition using n-alkanes in this study was only useful in separating grass-clover proportions although earlier reports on the method suggested a wider application of the technique (Dove and Mayes, 1991; 1996; Dove and Moore, 1995). One of the observations in this study was that the solution obtained using least-squares for diet composition of animals exhibited large between animal variation within the same treatment and a high number of 0 % values for some components. This may be because a very small range in C_{29}:C_{33} ratio is associated with a wide range in clover content in a mixture (Fig. 4.14). That is, the difference in C_{29}:C_{33} ratio of a species mixture with 5 % clover and say 70 % clover is not as high as one would expect (Fig. 4.14). It does not appear that much of this C_{29}:C_{33} ratio effect is removed by addition of other alkanes.

Regarding separation of plant parts, it appears alkane patterns of plant parts within a species are not as dissimilar as required to successfully separate botanical composition using alkane patterns (see leaf vs dead herbage: Fig. 4.11). In fact, later findings by Dove and *et al.* (1996) indicated that the greatest similarities in the pattern of alkane concentration occurred either between plant parts within a species or between the same plant part in closely related species. It seems the scope of using alkanes in prediction of the botanical composition of diets of grazing animals may not be as high as earlier reports indicated. Perhaps an idea to consider would be to see if alkane patterns in faeces and in indigestible residues of plant components subjected to *in vitro* digestibility are similar. If that is the case, then alkane patterns of *in vitro* digestibility residues could replace the need for OE samples. Such approach would mean larger number of samples could be used to reduce the problem of high between sample variation. This needs to be investigated. For now, dissection of OE samples remains the method of choice in grazing trials where the absolute proportions of diet composition are of paramount importance.

4.4.5. Frequently and infrequently grazed areas

The greater proportion of infrequently grazed areas for CA than CS on continuously stocked swards concurs with earlier observations on mixed grazing (Nolan and Connolly, 1977; 1989), that ascribed it to sheep grazing closer to cattle dung pats than cattle themselves. However, the level of patchiness in continuously stocked swards in this experiment had an effect that was contrary to previously held views in mixed grazing studies (Nolan and Connolly, 1977; 1989). That is, cattle LWG was not greater in CS swards, although CS swards were less patchy than CA swards (Table 4.4 vs Table 4.6). The most probable explanation is that the disadvantage of having a smaller frequently grazed area on CA than CS swards was more than offset by the higher clover content of CA swards. In addition, at the low SSH applied in this experiment infrequently grazed areas may have been recycled into frequently grazed areas faster by cattle themselves than that was the case in other studies. In theory, dung pats should decompose faster on short swards where there is greater air flow than when these pats are at the bottom of tall pastures (see Williams and Haynes, 1995 for other aspects of dung decomposition).

Lack of difference in the proportion of infrequently grazed areas between CA and CS pastures on rotationally stocked swards was probably a reflection of the low post-grazing sward height applied. Boswell and Cranshaw's (1978) work is the only other mixed grazing study on sheep and cattle on temperate pastures that provided post-grazing height. Since they did not have predictions on frequently and infrequently grazed areas of CA vs CS, the above claim remains speculative. Frequency distribution of sward height on frequently and infrequently grazed areas of CA and CS swards from this study are also published elsewhere (Kitessa and Nicol, 1996: Appendix 4.5).

4.4.6. Equivalence and weekly liveweight change

As with the preceding experiment, sheep weekly liveweight change was used successfully as a way of defining equivalence between CS cattle under continuous stocking and rotational stocking. The slight slump in weekly liveweights of animals on all treatments around the first intake measurement period (Fig. 4.9; Fig. 4.10), was probably due to both less familiarity of animals to handling than period II, as well as the very high rainfall (less grazing time) shown for that period (Fig. 4.3). Overall, the use of similar liveweight change in one species to assess mixed grazing effect on its companion species has shown promise as a technique which avoids at least some of the difficulties of comparing (a) stocking systems and (b) mono- vs mixed grazing (see review section 2.2.2). For further points see section 3.4.6.

4.5. Summary and conclusion

This experiment has untangled the confounding effects of difference in mean sward height and stocking system that prevented unequivocal conclusion from results of experiment I. Under sward conditions that provided similar sheep liveweight gain, cattle continuously stocked with sheep grew at 69 % of the daily LWG attained by their rotationally stocked counterparts (706 vs 1028 g day^{-1}). Mixed grazing and stocking system interaction accounted for nearly 70 % of this difference between continuously and rotationally stocked CS cattle. The other 30 % was attributed to difference in the mean grazed sward height. These results suggest that the detriment to cattle performance of reducing mean SSH from about 10 cm under rotational stocking to 4 cm under continuous stocking becomes greater by about two-fold when sheep are involved. Put another way, almost as high cattle LWG (916 g day^{-1}) can be achieved by CA-C at 4.3 cm as can be achieved by CS-R at a mean grazing height of 9.9 cm.

Comparison of daily LWG and final fasted LW of CA and CS cattle showed different pattern under continuous and rotational stocking. Under rotational stocking, the presence of sheep had no effect either on daily LWG or final fasted LW of cattle as compared to those grazed alone. On the contrary, cattle continuously stocked with sheep had:

(1) lower daily OMI (6.24 vs 8.98 kg day^{-1}),

(2) had less clover in their total OMI (10.4 vs 30.4 %)

(3) slower rate of growth (706 vs 916 g day^{-1}) and lower final fasted LW than their CA counterparts.

Difference in effects of sheep on cattle performance under the two systems was explained in terms of difference in how each system allowed selective grazing of clover as well as the effects of SSH applied on frequently and infrequently grazed patches.

So far as per animal and per ha LWG are concerned, results from this study do not provide any basis for using mixed grazing on sown grass/clover temperate pastures rather than grazing cattle alone. However, it should be noted that the results may be peculiar to the set target performance in sheep LWG. That is, future research that evaluates cattle performance under sward conditions that provide higher or lower weekly LW change in sheep may arrive at a different conclusion. However, results from both experiments in this study do provide some basis for recommending co-grazing of cattle and sheep using rotational stocking rather than continuous stocking.

Chapter 5. GENERAL DISCUSSIONS AND CONCLUSION

5.1. Overall response of cattle LWG to co-grazing with sheep

The initial tenet of this study, that mixed grazing outcome may be influenced by the stocking system chosen has been given some basis, at least in a cattle-sheep association. A logical progression, and the most difficult task, then is to conceptualise an overall response pattern for cattle intake and LWG as influenced by their association with sheep. In order to formulate this pattern, SSH has been chosen as a parameter, because:

(1). It has been generally recognised that sheep and cattle have different critical levels of sward height to acquire maximum intake (see Table 2.7).

(2). Sward surface height is also the variable with the greatest effect on both pasture attributes (quantity, quality, composition and canopy structure) and animal intake (see Figs. 2.3; 2.4).

(3). Latest studies on diet selection by sheep (using artificial patches of pellets) also identified vertical availability (height) and horizontal availability (number of patches) and the interaction between the two as determinants of the consumption of preferred species by sheep (Edwards *et al.,* 1996).

(4). Sheep and cattle have been shown to differ in their capacity to maintain intake with falling pasture mass (Collins, 1989; Nicol and Sousa, 1993) and there is close association between SSH and pasture mass (Hodgson, 1985a).

As stated in the review of literature, complementary resource use between sheep and cattle grazed on grass/clover pastures is most likely to accrue from sheep grazing around cattle dung patches, rather than from difference between the grazing species in selection of different plant species or plant parts. This is because the greater ability of sheep to selectively graze (within a patch) grass leaf and clover (Frame and Newbould, 1984) would not be an advantage to co-grazing cattle. This assumes both sheep and cattle have preference for clover, but sheep are more able to exercise selection in fine-grained mixtures than cattle due to their smaller incisor arcade breadth (see section 2.1). Therefore, the following discussion on the response of cattle LWG to the presence of sheep is considered in the context of selection of clover by sheep (competitive effect) and grazing of sheep around cattle dung patches (complementary effect) as influenced by SSH.

It can be assumed that the prevalence of infrequently grazed areas generally increases with SSH under most conditions. Therefore, if we assume both sheep and cattle to increasingly graze around dung patches as the SSH declines, the comparative LWG of cattle when grazed alone and co-grazed with sheep can be represented by Fig. 5.1. Grounds for the three different zones (i.e. CA > CS; CS > CA and CA = CS in liveweight gain) are considered, before looking into whether this pattern might be different under continuous and rotational stocking.

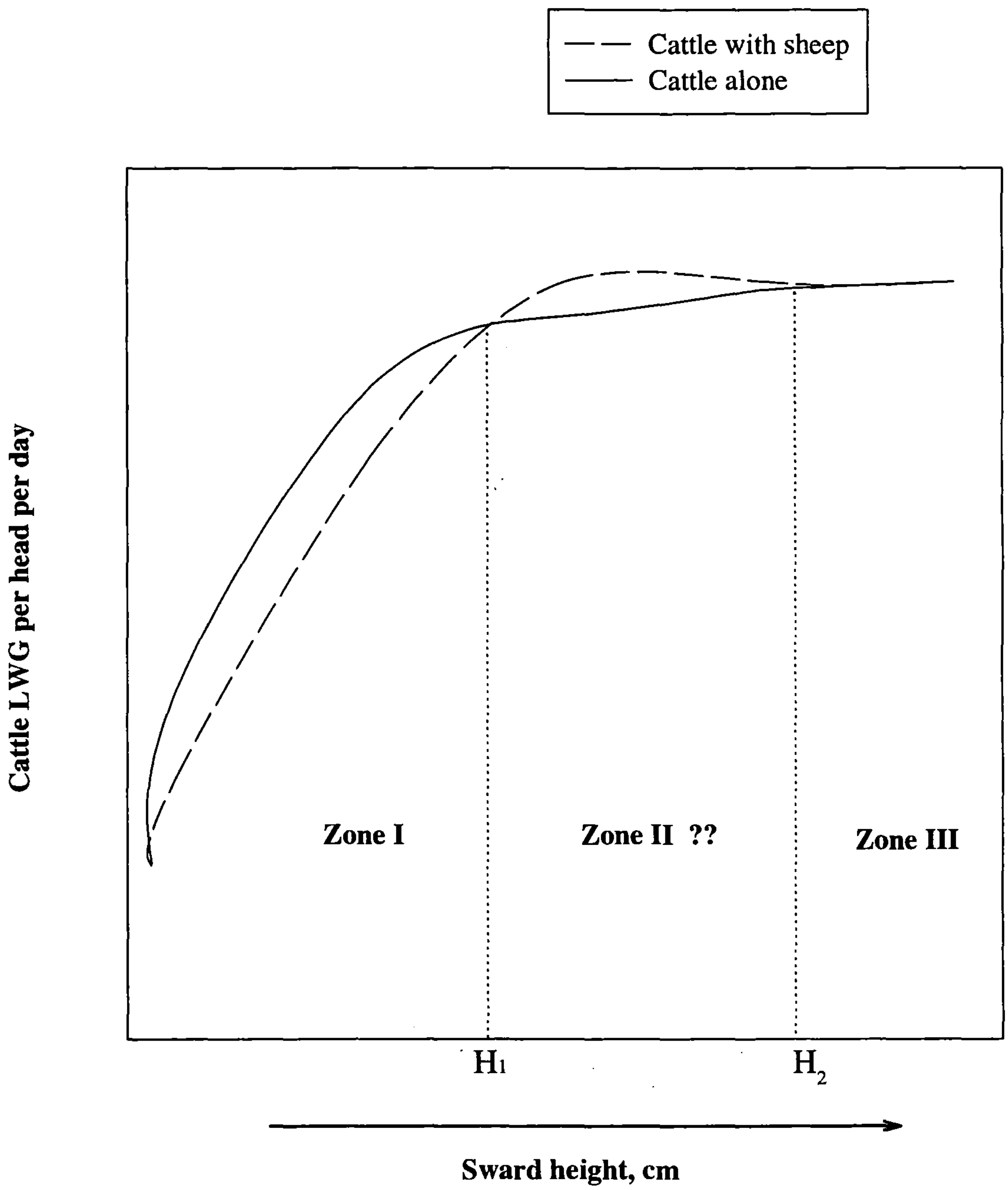

Fig. 5.1. A conceptual model for the likely response of cattle LWG to increase in SSH when grazed with sheep(dashed lines) or on their own (solid lines) on grass/clover pastures.

Zone I: CA liveweight gain > CS Liveweight gain

There are two assumptions made for Zone I.

(1). At low sward height, the significance to cattle of sheep grazing around cattle dung patches should become minimal because: (a) there would be proportionately fewer patches than at high sward height (see Greenhalgh and Reid, 1969 on effect of allowance on percent area rejected), (b) they would probably be rapidly recycled back to frequently grazed areas by cattle themselves, i.e. the presence of sheep would have no apparent benefit to cattle in maintaining a higher proportion of the area recently grazed, and (c) it has been suggested that small animals have greater capacity of subsisting on short swards and maintaining intake on declining pasture resource than large animals, which suggests that the former are likely to capture a greater proportion of the resource on offer in Zone I (competitive exclusion: see Illius and Gordon, 1987; Gordon, 1989). Point (b) is supported by the suggestion that less preferred food items (in this case dung patches) are accepted to a greater degree as the availability of the preferred items (frequently grazed areas) decreases (Dumont *et al.*, 1995). See also Edwards *et al.*'s (1996) work with sheep where they tested the effect of total, vertical and horizontal availability of preferred (cereal pellets) and non-preferred (lucerne pellets) on diet selection and intake of sheep. They showed that when both vertical (height) and horizontal (number of patches) availability of the preferred pellets were low, sheep rejected only 10 % of the less-preferred lucerne patches.

(2). Although Milne *et al.* (1982) reported that most of (up to 80 %) of the variation in clover content of sheep diet can be explained by the composition of the pasture on offer, it is generally understood that on mixed swards sheep have greater capacity to selectively graze than cattle (Gordon and Illius, 1988). Other authors have noted reduction in clover content of swards due to grazing by sheep (Briseno de la Hoz and Wilman, 1981; Frame and Newbould, 1984). No difference was found in clover content of cut and cattle-grazed grass/clover swards (Briseno de la Hoz and Wilman, 1981), which suggests cattle graze clover in proportion to its ratio in the sward. Reduction of sward height and sheep grazing appear to have an additive effect of reducing clover content of grass/clover swards (Briseno de la Hoz and Wilman, 1981). This is perhaps due to greater accessibility of clover on short than tall swards. Since Edwards and colleagues' (1995) mechanistic model predicted greater intake rate for sheep on pure clover than on pure grass across all sward heights, it seems logical for sheep to seek out clover. Hence, in Zone I, in Fig. 5.1, cattle co-grazed with sheep would be subjected to the disadvantages of selective grazing by sheep (qualitative disadvantage) as well as competitive exclusion (quantitative disadvantage) with little or no advantage in overall utilisation of dung patches as compared to those grazed alone. This zone can be interpreted as the range over which competition between co-grazing species exceeds complementarity, with a net negative outcome from co-grazing (e.g. CS-C vs CA-C cattle in chapter 4). This is assuming that CS sheep did not show benefit in LWG, in comparison to sheep alone (if there had been such a treatment), in excess of the disadvantage to cattle.

One of the possible counter arguments to these premises for Zone I, is the claim that tiller density on cattle grazed swards is lower than sheep grazed swards at the same sward height (Arosteguy, 1982; Arosteguy *et al.*, 1983). The authors explained this in terms of higher rate of tiller loss under cattle grazing. Some of Arosteguy's (1982) data are extracted into Table 5.1. However, the observed differences in CA and CS swards in both tiller number and net disappearance of tillers did not result in significant difference in OM intake of CA and CS cattle: 3580 vs 3640 g OM day^{-1} at 1600 OM ha^{-1} and 4460 and 4490 g OM day^{-1} at 1900 kg OM ha^{-1} (Arosteguy, 1982). The lack of disadvantage to CS cattle of grazing with sheep in that experiment, as opposed to that observed in this study, may be explained in terms of the difference in the clover composition of the two swards. In Arosteguy's (1982) study, the proportion of clover in the sward was so small that it constituted less than 1 % of total diet for both CA and CS cattle. Even if the absence of sheep had a doubling effect on the clover content of the sward, it may not have been possible to cause a detectable difference in the clover content of either the CA and CS swards or the diet of CA and CS cattle. It may follow that sheep and cattle mixtures in that study had a slight advantage in pasture production (though not demonstrated in different animal output) from increased overall utilisation of infrequently grazed areas without the opportunity for clover expansion on CA swards to counter that benefit. Therefore, their observation need not be contradictory to theme presented in Fig. 5.1.

Table 5.1. Mean herbage mass, mean sward height and tiller density of swards grazed by cattle, sheep or cattle plus sheep (*from Arosteguy, 1982*).

Species	Herbage mass kg OM/ha	Sward surface height (cm)	Tiller density, units/m^2	
			September	October
Cattle	1600	3.0	21600	32700
Sheep	1600	3.0	38000	34900
Cattle + sheep	1600	3.0	25400	26700
Cattle	1900	4.5	23600	19600
Sheep	1900	4.5	27200	21600
Cattle + sheep	1900	4.5	29800	20000

Nolan and colleagues (1988) presented some additional supporting data for this concept which also suggested lower tiller density in swards grazed by high cattle:sheep ratios as a possible explanation for mixed grazing advantage. Since they presented no corresponding data on total herbage production, and because tiller number and tiller weight are inversely related (Parsons *et al.,* 1983), increase in tiller density may not be a good argument for mixed grazing over cattle only. Actually, lower tiller density on CA than CS swards may enhance greater clover expansion as can be inferred from the CA-C and CS-C swards in this experiment (see Fig. 4.6). Schwinning and Parsons' (1996) model on co-existence of clover and grass supports this premise. Perhaps this is one of the reasons why sheep usually benefit from their association with cattle, i.e. reduction of tiller density by cattle coupled with their less selectivity leading to clover expansion, which in turn enhances sheep growth rate. See also Parsons' (1988) review for further details on tiller dynamics and grass growth under different grazing management options.

There are not many mixed grazing reports (i.e. other than co-grazing using continuous stocking in this study) that support Zone I as a possible outcome of co-grazing of sheep and cattle. Nicol and Sousa (1993) observed that with decline in pasture mass, digestible dry matter intake (DDMI) of adult cattle grazed with sheep decreased from being 20 % higher than CA at about 5,000 kg DM ha^{-1} to being about 20 % lower than that of CA at 1,000 kg DM ha^{-1}. The point the two DDMI crossed over was at a pasture mass of about 3,500 kg DM ha^{-1} (Nicol and Sousa, 1993). The study lends support to the existence of both zones I and II as possible outcomes of co-grazing cattle and sheep.

Zone II: CS liveweight gain > CA liveweight gain

Does Zone II exist, and how might it arise? Zone II is the outcome of mixed grazing advocated by most reports in the literature (Nolan and Connolly, 1977, 1989; Dickson *et al.*, 1981; Nolan, 1986; Wright and Connolly, 1995). The logic and experimental evidence provided is that sheep, by grazing around cattle dung patches (high grass), improve overall production and utilisation of pasture (Nolan and Connolly, 1977, 1989; Nolan *et al.*, 1988). Nolan and colleagues (1988) reported a 33 % increase in average daily LWG of steers due to addition of sheep to an already high steer stocking rate. Given the high cattle LWG recorded, it is likely that in Nolan *et al.*'s work the high stocking rate was not associated with a very low sward height probably through good pasture growth, otherwise their results might have been in Zone I. Therefore, there is a scope and some evidence for CS liveweight gain to be greater than CA liveweight gain over some range of SSH.

This outcome can also be argued for in terms of the effect of sward state (i.e. sward height) on dung patches and clover content of grass/clover swards. The author suggests that Zone II occurs over a range of SSH which is high enough for both prevalence of dung patches (increase usefulness of sheep to cattle) and for minimising excessive exposure of clover to sheep grazing (decrease adverse effect of sheep). Studies that found significant benefit to cattle LWG due to co-grazing with sheep (Nolan and Connolly, 1989) may have operated in this range. If one has to speculate on the value of H_1 in Fig. 5.1, it should be higher than the 5-6 cm deemed to suit sheep grazing (see Table 2.7). This zone can be interpreted as the range over which the net effect of competitive and complimentary interaction between sheep and cattle is a positive response in cattle LWG to co-grazing with sheep. What about the upper limit to complementarity? That brings about Zone III.

Zone III: CA liveweight gain = CS liveweight gain

Zone III has not been suggested by anyone before (to this author's knowledge). The author concedes that this is outside the range of data from this study and probably that of other studies in the literature. The arguments for Zone III are two-fold. First, as overall mean SSH increases, there would also be an increase in the mean height of the frequently grazed areas, which would in theory minimise the value (in increasing overall area under frequent grazing) of utilisation of dung patches by sheep to CS cattle. Put another way, since overall utilisation is low on tall swards, the significance of co-grazing with sheep should be minimal. Secondly, in very tall swards, the SSH and canopy structure may have far greater depressing effect on clover content of the sward than the presence or absence of sheep. It is also possible that over a very high range of SSH the interaction between cattle and sheep would be minimal (because there would be less of them per unit area), and any level of competition and complementarity would cancel each other out. In addition, the level of pasture allowance per animal to maintain such a SSH would be so high and the growth rate of both groups close to their potential, that it would be unlikely to detect a difference in LWG of CA and CS cattle. Hence, there would be little, if any, grounds to anticipate advantage or disadvantage to cattle LWG from co-grazing with sheep over such SSH range. This is the range over which the net effect of competitive and complimentary interaction between sheep and cattle is deemed to be insignificant. There is insufficient information to speculate on the value of H_2 in Fig. 5.1. Further study is required to substantiate these claims.

This conceptual model helps in comprehending Nolan and Connolly's (1989) observation that response to mixed grazing increases as stocking rate increases. Assuming increase in stocking rate entails decrease in SSH, response of cattle LWG to co-grazing with sheep may show no effect (Zone III), may increase (Zone III to II), or may decrease (Zone II to I) as stocking rate increases (Fig. 5.1), This may show why there are so many equivocal mixed grazing reports.

5.2. Response under different stocking systems

5.2.1. Continuous stocking

As stated earlier, at a set target SSH, swards under continuous stocking characteristically maintain a fairly steady state condition (see section 2.2.2.3.2). Therefore, it can be assumed that competitive or complementary effects would be constant and cumulative over time. That is, if the sward condition is such that sheep are out competing cattle for clover with little beneficial effect through grazing around dung patches, overall output per unit area should become progressively lower than for single species grazing. This assumes progressive depression of clover content will also negatively influence overall pasture production (Schwinning and Parsons, 1996). Therefore, at least theoretically, depression in cattle LWG in Zone I in Fig. 5.1 should be augmented by continuous stocking. The modified version of Fig. 5.1. for continuous stocking is given in

Fig. 5.2 with the addition of data from this study. The need for more data from further research to substantiate this scheme (or proof otherwise) cannot be overstated.

Regarding Zone II for Fig. 5.2 there are no published data (to this author's knowledge) that have shown higher cattle growth rate under mixed than mono-grazing using concurrent, continuous stocking system on temperate swards (section 4.4.1.1). Results from this study only corroborate the proposed model in Zone I. Mixed grazing studies that used continuous stocking usually found no effect on cattle LWG (Ebersohn, 1966; Hamilton and Bath, 1970; Reynolds *et al.*, 1971). However, those studies did not use sward height as a parameter. Nicol *et al.* (1993) found no difference in LWG of cattle continuously stocked on their own and those co-grazed with goats at a SSH of 12 cm, which may suggest their experiment was operating in Zone III. Until further evidence emerges, it is not possible to state whether Zone II exists under concurrent, continuous stocking. One would have thought that where the net result of interaction between sheep and cattle is complementarity, the use of continuous stocking is intrinsically suited for maintaining that level of interaction to effect sustained advantage for cattle. It may be that patchiness of continuously stocked pastures (usually higher than under rotational) provides greater potential for sheep performance to be higher under mixing and the range over which this potential can be captured without disadvantage to cattle may be small. The point at which this occurs is likely to depend on species ratio. There are no data to back up these notions.

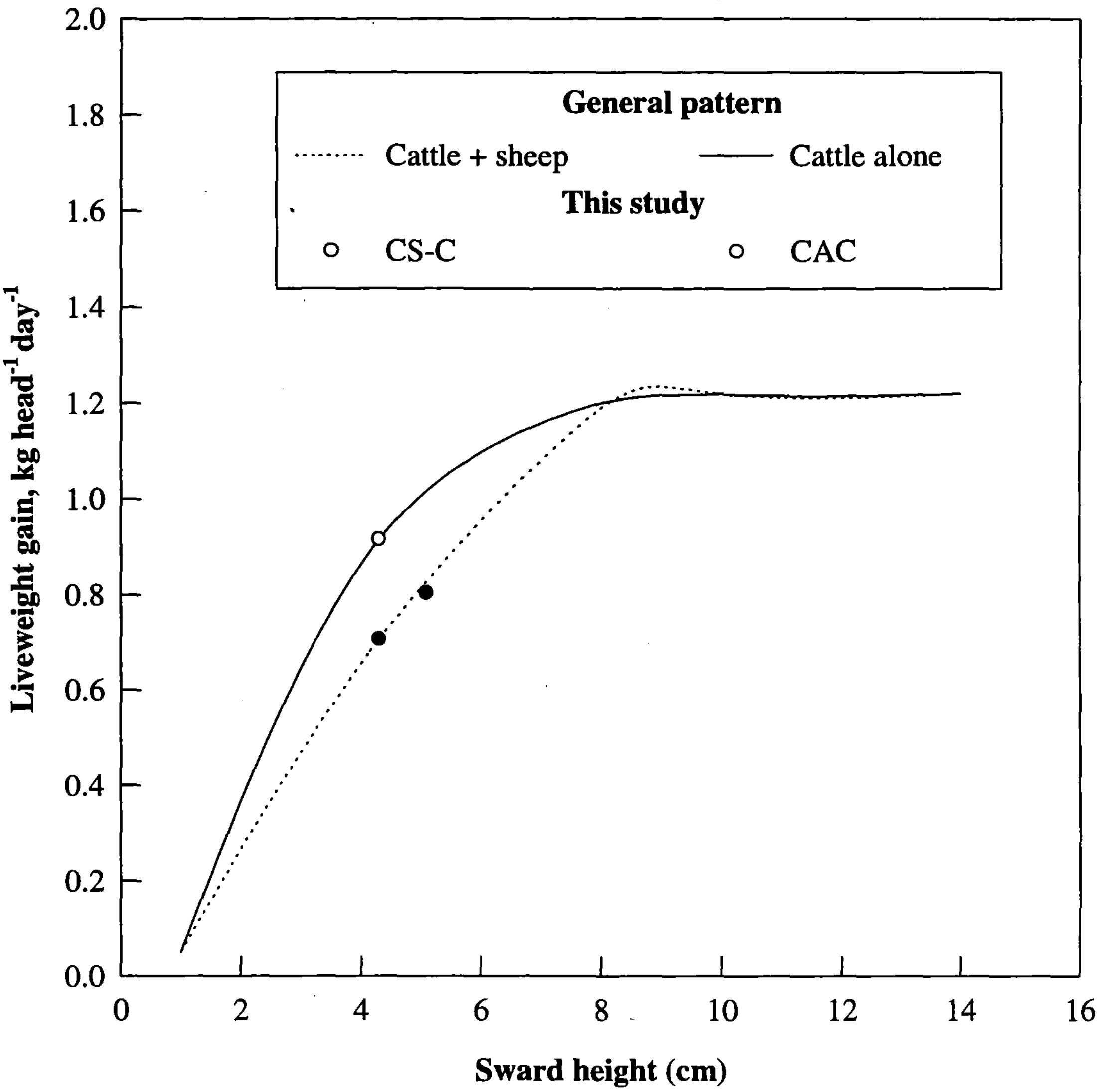

Fig. 5.2. Likely response of cattle LWG to changes in sward height in the presence or absence of sheep under continuous stocking.

Due to logistic limitations, this study did not include a sheep-only treatment. Therefore, it is not possible to categorically state if co-grazing cattle and sheep using continuous stocking could be recommended in comparison to a sheep and cattle only system. However, it is possible to speculate on the different scenarios of sheep-only vs CS sheep. The first assumption is that a cattle only system will produce greater output per unit area than a sheep only system, (because maintenance requirement increases at a decreasing rate (Kleiber, 1965)). Hence, complementarity is a more likely outcome where LWG of CA and CS cattle are similar, or the disadvantage to CS cattle LWG is negligible. Many studies have shown this (Bennett *et al.*, 1970; Hamilton and Bath, 1970; Brelin, 1979; Dyrmundsson and Gudmundsson, 1980). Regarding this study, if we assume CS sheep in this study were growing at a rate less than or equal to what they would have achieved when grazed on their own, then there is no ground for recommending co-grazing of sheep and cattle using continuous stocking. This is because the disadvantage in cattle LWG remains unaccounted for. If CS sheep were at an advantage over sheep grazed alone, this advantage in sheep LWG has to be high enough to offset all the disadvantage in cattle LWG. In a 1:1 $LW^{0.75}$ cattle:sheep mixture and considering the 210 g depression in daily LWG of CS cattle (compared to CA) in this study, this will be a very rare occurrence. It should be noted that in 1:1 $LW^{0.75}$ in this study 3 sheep were equivalent to one heifer, which means each CS sheep would have had to grow 70 g daily better than sheep grazed on their own, at a similar sward height.

In summary, evidence from this study and other reports suggests that when cattle are co-grazed with sheep using continuous stocking, there seems to be limited opportunity to pick up complementary effects on cattle LWG (i.e. cattle LWG greater under mixed than mono-grazing). Late introduction of sheep (after clover build up) and use of young rather than adult cattle (Nicol and Sousa (1993) is recommended to minimise the effect of sheep on cattle LWG when co-grazed using continuous stocking.

5.2.2. Rotational stocking

Co-grazing of cattle and sheep using rotational stocking showed either no effect on cattle LWG (Boswell and Cranshaw, 1978; this study) or greater LWG of CS than CA (Dickson *et al.,* 1981; McCall *et al.,* 1986; Nolan, 1986; Nolan and Connolly, 1989). This suggests that the rapid, cyclic changes in pasture conditions under rotational stocking limits the opportunity of either species to modify the pasture to its own characteristic sward in terms of clover composition or patchiness, or any other way. On the other hand, there would be some opportunity for complementary resource use through utilisation of dung patches for CS cattle to have an advantage over CA cattle. The significance of the latter will increase or decrease depending on change in post-grazing sward height. Therefore, the hypothetical response of cattle LWG to co-grazing with sheep over different post-grazing heights may appear like Fig. 5.3. The arguments for differences between Fig. 5.1 and 5.3 in Zone I are as follows.

Many authors have suggested that the time spell between defoliations provided by rotational stocking enhances clover survival in a clover/grass mixture (Brougham *et al.*, 1978; Frame and Newbould, 1984). It seems the system inherently minimises the adverse effect of clover selection by sheep either through the spell from grazing, or due to the rapid changes during defoliation which limit selective grazing by either species. For instance, Boswell and Cranshaw (1978) found no significant difference in LWG of CA and CS even at a low post-grazing height of 3.0 cm. In simulated rotational stocking, Collins (1989) also showed that when pasture mass was low (*ca.* 1,000 kg DM ha^{-1})) there was no advantage or disadvantage to CS over CA. The author is not aware of any published reports that show a negative effect on cattle LWG when rotationally stocked with sheep. There is no evidence to suggest Zone I in the proposed model in Fig. 5.1 operates under rotational stocking. In summary, using rotational stocking appears to minimise the opportunity for competitive resource use than continuous stocking. Evidence from this study and the literature has not shown adverse effects on cattle LWG when co-grazed using rotational stocking. How would a sheep-only treatment have affected this conclusion?

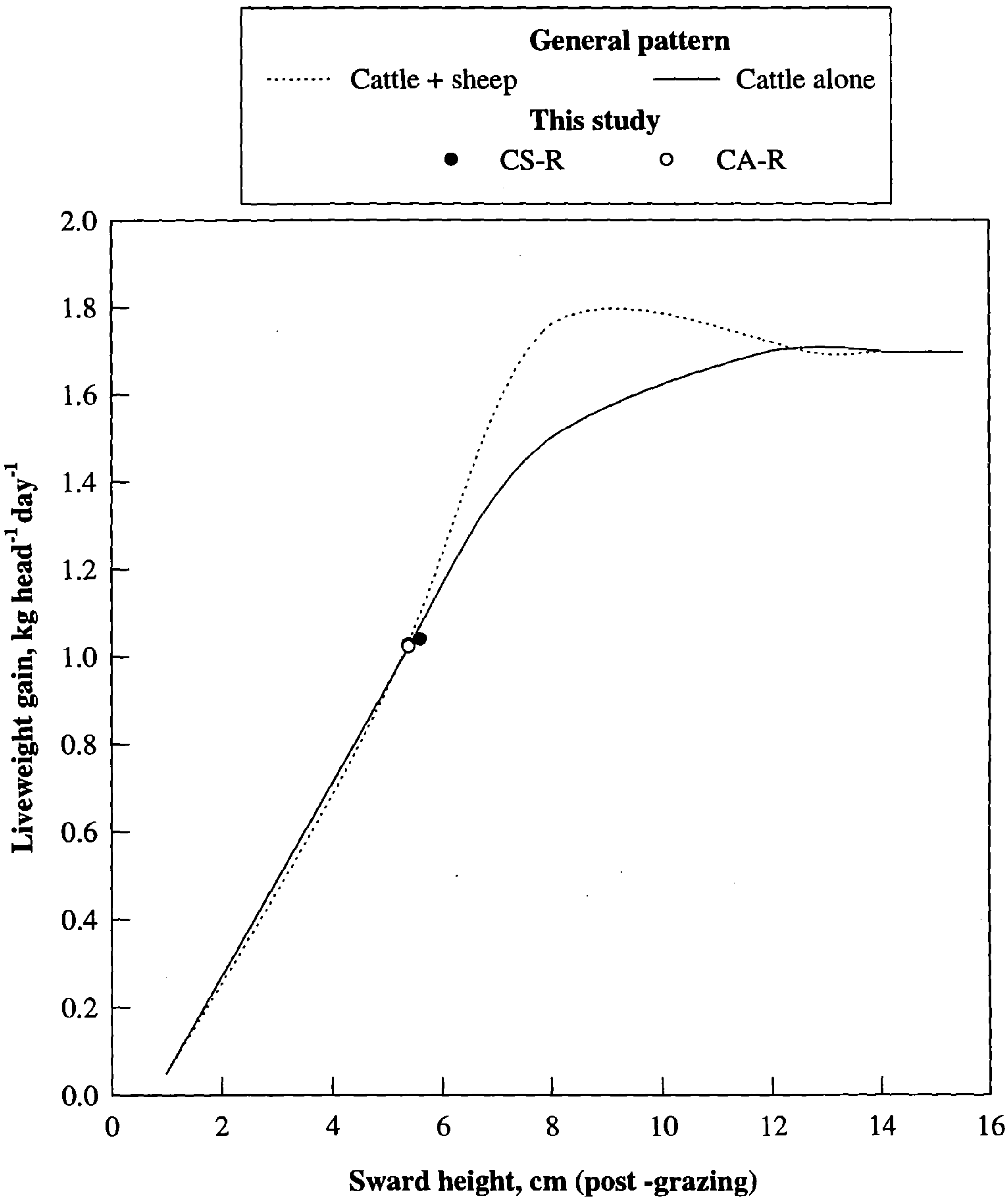

Fig. 5.3. Likely response of cattle LWG to changes in post-grazing sward height in the presence or absence of sheep under rotational stocking.

An inference can be drawn by looking at the growth rate of CA and CS cattle under rotational stocking. Since there was no apparent advantage to CS cattle, it is hard to argue that CS sheep were disadvantaged by their association with CS cattle. Therefore, it is most likely that the growth rate of CS sheep was either similar to or better than what they would have achieved if they had grazed on their own, the latter being more likely due to their access to cattle dung patches, which offer greater quantity of pasture (Williams and Haynes, 1995) that is of probably higher nutrient content. This further substantiates the notion that rotational stocking of sheep and cattle is preferable to continuously stocking them. It appears that although patchiness of swards is generally lower under rotational than continuous stocking, rapid changes in pasture resource under rotational grazing limit opportunity for competition and minimise the qualitative (selectivity) and quantitative (competitive exclusion at low allowance) advantage of sheep over cattle in using pasture resource suggested by other authors (Illius and Gordon, 1987).

Before concluding this discussion, the author concedes that species ratio in mixed grazing would affect many of the statements made about mixed grazing outcome. However, since this study was carried out at a 1:1 ratio and because there are insufficient data in the literature (that are not confounded by simultaneous change in ratio and stocking rate), it has not been possible to forward a conceptual framework for discussion. It is hoped that further research will fill this void.

5.3. GENERAL CONCLUSION

This study has clearly shown that the outcome of mixed grazing is affected by the stocking system chosen. All the evidence from this study suggests that at equivalent sheep weekly liveweight change, the LWG of cattle would be depressed by about 30 % when they are co-grazed using continuous rather than rotational stocking. Results of this study and data from the literature indicate that there is greater chance of limiting competitive interaction between sheep and cattle by using rotational rather than continuous stocking. Such recognition of the impact of stocking system on mixed grazing outcome should help in the interpretation of existing mixed grazing data and assist in the discussion of any subsequent mixed grazing work.

It should be noted that this study compared stocking systems in relation to the effect of sheep on cattle LWG. Evaluation of stocking systems for mixed grazing as a whole would require allowing both cattle and sheep LWG to vary. The operational difficulty of comparing stocking system and mixed grazing where both cattle and sheep performance is allowed to vary should not be underestimated. Perhaps the reverse of the protocol in this study where cattle LW change is equivalent in both continuous and rotational stocking and sheep LWG is measured for treatment effects may provide additional information from which a more solid recommendation can be made.

It is hoped that the use of equivalent LW change in one species as a parameter for evaluating mixed grazing effects as successfully applied here would help future research to overcome some of the design difficulties to generate more data for modelling response to mixed grazing.

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APPENDICES

Appendix 2.1

Collated data for Fig. 2.2.

Stocking Rate	Ratio (S:C)	%change[α] in ADG[β] Sheep	Cattle	Source
Low	7	8.0	-1.6	Nolan & Coonnoly, 1989
Low	4	13.7	14.9	(ADG to weaning)
Low	2	15.1	16.6	
High	7	7.7	-8.5	
High	4	5.1	4.3	
High	2	6.7	11.8	
Low	7	9.8	10.8	Nolan & Coonnoly, 1989
Low	4	13.8	19.3	(ADG to drafting)
Low	2	16.3	19.3	
High	7	7.0	18.7	
High	4	7.4	5.0	
High	2	11.3	-1.2	
Low	7	5.4	4.8	Nolan, 1986
Low	4	11.3	14.3	(ADG to drafting)
Low	2	10.4	17.0	
High	7	0.0	11.6	
High	4	0.5	1.1	
High	2	-3.6	-6.3	

$^{\alpha}$ % Change = (ADG mixed - ADG mono)/(ADG mono-grazing)

$^{\beta}$ ADG= average daily gain.

Some further modifications to alkane extraction procedures

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Various reviews and publications have now shown that plant wax components, used as internal markers, provide the most accurate and precise estimate of both pasture intake and diet composition. The technique enables estimation of intake without having to predict faecal output (i.e. estimate is not affected by faecal recovery of markers) and the estimation of diet composition without using fistulated animals. Despite such obvious benefits, the adoption of the technique has been slow, probably due to the costs of new equipment involved affecting its cost-competitiveness with other established methods. We propose the following cost saving modifications to the extraction procedure outlined by Mayes *et al.* (*1986: J. Agric. Sci., Cambridge,* **107**: 161-170).

Internal standard, 0.5 mg of C_{34} (Tetratriacontane) in 0.2 g of C11 (Undecane), was added to pasture but not faecal samples. In the original method, C_{34} was added to samples to provide an alkane with known peak area and quantity against which the peak areas of other alkanes are compared and their concentration per sample calculated. We have eliminated this because intake can be estimated using the ratios of the peak areas of C_{32} and C_{33} without using a standard to calculate their concentrations in faecal samples (Appendix 1). The cost of C_{34} and its solvent C_{11} is currently about US $35 per g and $115.50 per 500 ml respectively (Sigma Catalogue, 1995). In cases where digestibility needs to be estimated, the internal standard should be added to both faecal and herbage samples.

Samples were then digested in an ordinary oven (at 90 ^{0}C for 3.5 hours) rather than using heating blocks. The cost of multi-block heating base and heating blocks is in excess of $1,200 US dollars (Cole-Parmer Catalogue, 1995/96). The liquid-liquid extraction phase as well as the elution of the extracts through a silica gel column were done using industrial hexane (US $1.58/litre) rather than n-heptane (US $22.6/litre) or n-hexane (US $53.9/litre). In addition, the silica gel column was also prepared using industrial hexane. We found no traceable alkane peaks in industrial hexane. The final extract before chromatography was dissolved in 0.7 ml of n-heptane. This was as a precaution against impurities accumulating on the GC column.

The comparative estimated cost of extracting alkanes using the original and modified (Lincoln) method show a total saving of $ 0.59 or $1.01 per faeces sample analysed depending on the type of solvent used in the original method (Table 1). It should be noted that these are not estimates of total cost of extraction as costs common to both methods were excluded. These are significant savings.

Table 1. Cost per sample for faeces samples analysed using the original or modified method of extracting N-alkanes.

Item	**Original Method**		**Modified (Lincoln)**
	N-heptane	*N-hexane*	**method**
Internal standard	0.06	0.06	0.00
Solvents	0.57	1.35	0.04
'Total' cost	**0.63**	**1.41**	**0.04**

considering that there are significantly greater number of faeces samples than herbage samples to be analysed in each experiment.

Table 2 summarises the comparison of estimates of intake from a single herbage and single faecal sample analysed in different laboratories which followed the original (CSIRO and DRC) or modified (Lincoln) extraction procedures. The results clearly indicate that there was very little, if any, difference in estimated intake regardless of where the alkane extraction was done..

Table 2. Comparison of predicted intake from herbage and faecal samples analysed for N-alkanes in three different laboratories.

Extraction lab.	**Chromatography lab.**	**Intake (kg)**
Lincoln	Lincoln	12.9
Lincoln	CSIRO$^{\alpha}$	*12.3*
CSIRO	CSIRO	*12.2*
Lincoln	DRC$^{\Phi}$	**11.7**
DRC	DRC	**11.1**

$^{\alpha}$ Division of Plant Industry, Canberra, A.C.T., Australia
$^{\Phi}$ Dairy Research Corporation, Hamilton, New Zealand.

Validation of the modified extraction procedure in an indoor trial

Animals: Eight mature non-pregnant ewes with mean LW of 66.5 (±3.4) kg.

Herbage: Autumn 4-week regrowth of a ryegrass/white clover pasture.

Feeding: One week acclimatisation to metabolism crate feeding, followed by 10-day dosing period (faecal collection during last 5 days).

Meals: 3.0 kg of fresh herbage each at 0900 and 1600 hours.

Dosing: 130 mg of C_{32} once a day at 0900 hours.

Faeces samples: grab samples and total faeces collected at 0900 and 1600 hours.

Herbage and faeces samples were handled and processed as in chapter 3, section 3.2.5.2.

Intake data:

Animal ID	FO kg day^{-1}	*In vivo* OMD	Actual OMI	D-based OMI[1]	D-based OMI[2]	Alkane-based OMI[3]
602	0.224	0.78	0.91	0.95	0.94	.90
693	0.318	0.75	1.15	1.35	1.18	1.06
718	0.338	0.72	1.06	1.44	1.09	1.05
902	0.225	0.81	1.04	0.96	1.07	0.93
278	0.266	0.78	1.10	1.13	1.13	0.98
279	0.405	0.69	1.16	1.72	1.19	1.04
280	0.308	0.74	1.05	1.31	1.09	1.07
281	0.293	0.76	1.08	1.24	1.12	1.02
Mean			**1.07**	**1.26**	**1.10**	**1.01**
s.e.m			0.027	0.091	0.028	0.022
CV %			7.1	20.3	7.1	6.2

D = Digestibility of herbage OM.
FO = faecal output.

[1] OMI = faecal output/(1-*in vitro* OMD). Single *in vitro* OMD value of 0.75 for all animals.

[2] OMI = faecal output (1-*in vivo* OMD); *in vivo* OMD = (Actual intake - faecal output)/actual intake. This was done for each animal.

[3] Using C_{32}:C_{33} ratio (Chapter 3).

Appendix 3.1c. Recovery values (proportion) for alkanes and Cr_2O_3

	Markers							
	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{33}	C_{35}	Cr_2O_3
Sheep[α]	0.63	0.76	0.73	0.79	0.84	0.86	0.93	0.94
Cattle[β]	0.63	0.76	0.73	0.79	0.83	0.85	0.88	-

[α] Values obtained from indoor validation trial.

[β] C_{27}-C_{30} from sheep indoor trial (no published values for cattle), C_{31}-C_{35} from Dillon & Stakelum, 1988.

Appendix 3.2. Height-mass regressions for Experiment I.

Parameters for the regression of pasture mass (Y, kg ha^{-1}) and sward surface height (X, cm) for pastures grazed by sheep and cattle using continuous or rotational stocking. (P refers to whether the slope is significantly different from 0).

Equation : **Pasture mass (kg ha^{-1}) = (B_0) + (B_1)SSH (cm)**

Stocking system	Period	Intercept (B_0)	Slope (B_1)	R^2	P
Continuous	I	302	316	0.90	0.00
	II	72	372	0.70	0.00
	III	-404	425	0.93	0.04
	Whole period	*-296*	*448*	*0.81*	*0.00*
Rotational: Pre-grazing	I	-89	255	0.92	0.00
	II	1559	162	0.57	0.00
	III	-81	213	0.96	0.00
	Whole period	*615*	*214*	*0.79*	*0.00*
Post-grazing	I	-751	464	0.82	0.0
	II	226	359	0.54	0.01
	III	85	297	0.83	0.08
	Whole period	*-204*	*391*	*0.69*	*0.00*

Appendix 3.3a

ANOVA: Regression slopes of LW on days for sheep: Experiment I

Source	d.f.	SS	MS	F	P
Between slopes	1	66.92	66.92	1.97	ns
Error	1072	36494	34.04		
Total	1073				

Appendix 3.3b

ANOVA: Regression slopes of LW on days for cattle, Experiment I.

Source	**d.f.**	**SS**	**MS**	**F**	**P**
Between slopes	1	8092.17	8092.17	14.34	**
Error	338	193566	572.68		
Total	339	201658			

Appendix 3.3c

ANCOVA: final fasted LW for cattle, Experiment I.

Source	DF	ADJ SS	MS	F	P
Covariate	1	7237.7	7237.7	18.96	0.001
Stocking system	1	3913.6	3913.6	10.25	0.006
Error	15	5726.8	381.8		
Total	17	14476.9			

Covariate	Coeff	Stdev	t-value	P
Initial LW	1.143	0.263	4.354	0.001

Appendix 3.4a

ANOVA: sheep OMI: Experiment I

Source	df	SS	MS	F	P
Period	2	0.9884	0.4942	10.64	0.00
Stocking system	1	0.0154	0.0154	0.33	0.57
Period x system	2	0.2397	0.1198	2.58	0.09
Error	42	1.9503	0.0464		
Total	47	3.1939			

Appendix 3.4b

ANOVA: cattle OMI, Experiment I.

Source	df	SS	MS	F	P
Period	2	6.77	3.386	1.37	0.266
Stocking system	1	29.84	29.84	12.05	0.001
Period x system	2	69.59	34.80	14.05	0.000
Error	42	104.04	2.477		
Total	47	210.25			

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The co-grazing of cattle and sheep under rotational and continuous grazing

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In their review of mixed grazing, Nolan and Connolly (1977, Herbage Abstracts, 47, 367-374) showed considerable variation in the response of cattle and sheep to mixed grazing. They identified a number of factors as potential sources of this variation but did not consider grazing system. This experiment reports the growth rate of cattle and sheep co-grazed under rotational or continuous grazing.

Nine yearling heifers (188 kg liveweight) and 27 ewe hoggets (45 kg liveweight) were continuously co-grazed for 19 weeks on an irrigated perennial ryegrass - white clover pasture (2.95 ha) maintained at a sward surface height (SSH) of 5 cm by adding or removing additional animals in a fixed ratio (1 : 1 $W^{0.75}$ cattle : sheep). Similar groups of animals were rotationally co-grazed on perennial ryegrass-white clover pasture (15.9 cm pre-grazing SSH) where they received a new area of pasture daily and also had access to the area grazed over the previous 2 days. The size of the new area provided daily was such that the weekly liveweight change of the rotationally grazed sheep was equal to that of the continuously grazed group. The mean post-grazing SSH on the rotational grazing treatment was 5.6 cm. SSH was recorded daily (60 observations / treatment).

The daily liveweight gain (DLWG, regression of liveweight (kg) on time (d)) of the treatment groups is shown in the table below. As determined by the protocol of the experiment, there was no significant difference in the daily liveweight gain of sheep under continuous and rotational grazing . In contrast, cattle rotationally co-grazed with sheep grew 33 % faster (1.027 kg/day) than continuously co-grazed cattle (0.767 kg/d). Consequently, the ratio of cattle : sheep DLWG/ha increased from 1.8 : 1 under continuous grazing to 2.4 : 1 with rotational grazing.

The lower DLWG of continuously co-grazed cattle may have been a response to the lower mean SSH under continuous (5.0 cm) than rotational (10.7 cm) grazing, or the inability of cattle to compete well with sheep where there is a small, continual renewal of the pasture resource (continuous grazing) in contrast to a large, periodic renewal under rotational grazing.

This experiment shows that the results of mixed grazing experiments do depend on the grazing system applied. When high cattle liveweight gain/head is required from mixed grazing, rotational co-grazing should be adopted in preference to continuous co-grazing.

	Grazing System		
Daily liveweight gain	Continuous	Rotational	Significance
Sheep (g/d)	147 ± 7	139 ± 7	NS
Cattle (kg/d)	0.767 ± 0.063	1.027 ± 0.063	P<0.01

Appendix 3.6a

Individual liveweight of sheep: Experiment I.

Animal ID	Day	Stocking system C	Stocking system R	Animal ID	Day	Stocking system C	Stocking system R
1	0	54.5	*	1	14	48.8	55.5
2	0	56.5	*	2	14	57.5	49.2
3	0	51.0	59.5	3	14	54.5	58.0
4	0	54.0	59.0	4	14	57.5	59.0
5	0	52.5	57.5	5	14	54.0	59.0
6	0	54.0	53.5	6	14	57.5	52.0
7	0	59.0	54.0	7	14	60.0	54.0
8	0	57.0	46.6	8	14	58.0	45.4
9	0	52.0	53.0	9	14	52.0	51.0
10	0	55.5	61.5	10	14	56.5	61.0
11	0	57.5	49.0	11	14	63.5	49.8
12	0	48.8	61.0	12	14	52.0	61.0
13	0	59.0	49.6	13	14	61.0	49.4
14	0	64.0	51.5	14	14	67.0	51.0
15	0	54.0	65.5	15	14	56.5	64.5
16	0	54.0	48.4	16	14	56.0	47.6
17	0	50.0	57.5	17	14	52.5	58.0
18	0	54.0	44.6	18	14	56.5	45.2
19	0	53.0	50.5	19	14	57.5	51.5
20	0	46.2	51.5	20	14	48.4	52.0
21	0	45.4	55.5	21	14	47.2	57.5
22	0	57.0	61.5	22	14	61.0	61.0
23	0	52.0	59.5	23	14	57.5	57.0
24	0	46.0	55.5	24	14	48.8	54.0
25	0	*	57.0	25	14	56.0	57.5
26	0	50.5	47.2	26	14	51.0	48.6
27	0	42.4	60.5	27	14	44.6	58.5
1	7	56.0	53.5	1	21	58.0	55.0
2	7	56.5	47.0	2	21	59.0	48.2
3	7	52.5	57.0	3	21	55.0	60.5
4	7	55.5	56.5	4	21	57.0	61.0
5	7	54.0	55.5	5	21	56.0	59.5
6	7	54.5	51.0	6	21	56.0	52.0
7	7	58.0	52.0	7	21	62.5	55.0
8	7	57.5	44.4	8	21	60.0	48.2
9	7	52.5	49.8	9	21	54.0	54.5
10	7	56.5	60.0	10	21	58.5	64.5
11	7	59.5	47.2	11	21	62.5	52.0
12	7	51.5	59.5	12	21	54.0	62.5
13	7	59.0	48.8	13	21	61.5	52.0
14	7	65.0	49.6	14	21	68.5	51.5
15	7	56.0	64.0	15	21	56.0	66.5
16	7	55.5	45.6	16	21	58.5	49.6
17	7	52.5	56.5	17	21	55.0	60.0
18	7	54.0	42.8	18	21	57.0	47.6
19	7	54.5	50.0	19	21	57.5	53.5
20	7	47.8	49.6	20	21	50.0	54.5
21	7	46.4	55.0	21	21	47.8	60.0
22	7	60.0	61.5	22	21	62.0	64.0
23	7	55.0	56.0	23	21	59.0	58.5
24	7	47.4	53.0	24	21	49.2	55.5
25	7	56.0	55.0	25	21	57.5	59.0
26	7	52.0	45.2	26	21	51.5	49.4
27	7	44.2	58.0	27	21	46.2	61.5

1	28	57.5	57.5	1	42	62.5	59.0
2	28	59.0	51.0	2	42	62.5	53.0
3	28	53.5	60.5	3	42	57.0	65.0
4	28	60.0	60.5	4	42	58.5	65.5
5	28	56.0	60.5	5	42	59.5	63.5
6	28	58.5	52.0	6	42	59.0	56.0
7	28	65.0	54.5	7	42	69.5	57.0
8	28	62.0	47.6	8	42	64.5	50.0
9	28	55.5	51.0	9	42	59.0	57.5
10	28	58.5	63.0	10	42	62.5	68.5
11	28	64.5	51.0	11	42	68.5	55.0
12	28	55.0	61.0	12	42	61.0	65.0
13	28	62.5	51.0	13	42	66.0	54.0
14	28	70.0	51.5	14	42	74.5	54.5
15	28	57.5	63.0	15	42	62.0	67.0
16	28	61.0	49.0	16	42	64.5	50.5
17	28	53.0	59.5	17	42	58.5	62.5
18	28	57.5	47.0	18	42	62.0	50.0
19	28	60.0	53.5	19	42	63.0	56.0
20	28	51.0	54.0	20	42	52.5	56.0
21	28	46.4	58.5	21	42	54.0	61.0
22	28	63.5	64.0	22	42	68.5	68.5
23	28	53.0	59.0	23	42	53.5	62.0
24	28	46.6	56.5	24	42	56.0	58.5
25	28	58.5	59.0	25	42	62.0	63.0
26	28	53.5	48.8	26	42	57.0	53.5
27	28	47.8	61.0	27	42	50.0	65.5
1	35	59.5	59.5	1	49	60.0	59.0
2	35	59.5	51.0	2	49	63.0	54.0
3	35	56.0	64.0	3	49	59.0	66.5
4	35	59.5	62.5	4	49	61.5	66.0
5	35	58.0	61.5	5	49	59.5	62.5
6	35	58.0	55.0	6	49	60.5	54.0
7	35	64.5	56.0	7	49	69.5	57.5
8	35	62.5	50.0	8	49	65.5	51.5
9	35	56.5	57.0	9	49	58.5	58.0
10	35	60.0	66.0	10	49	63.0	68.0
11	35	65.0	55.0	11	49	67.5	57.5
12	35	56.5	64.0	12	49	60.0	67.0
13	35	63.0	54.5	13	49	65.5	55.0
14	35	70.5	54.0	14	49	74.0	57.0
15	35	59.0	69.5	15	49	62.5	67.5
16	35	60.0	49.8	16	49	63.0	52.0
17	35	57.0	63.0	17	49	56.5	64.0
18	35	59.5	49.8	18	49	61.5	50.5
19	35	60.0	54.5	19	49	62.5	53.5
20	35	52.5	55.5	20	49	53.9	56.0
21	35	52.0	61.5	21	49	54.0	64.0
22	35	65.5	68.0	22	49	69.5	69.5
23	35	53.5	61.0	23	49	53.0	62.0
24	35	52.5	58.5	24	49	55.5	58.5
25	35	59.5	61.0	25	49	60.0	62.5
26	35	52.5	52.0	26	49	57.0	53.5
27	35	47.8	64.5	27	49	50.0	67.5
1	63	64.0	61.0	1	77	65.0	60.6
2	63	65.5	54.5	2	77	67.5	58.0
3	63	60.5	59.5	3	77	61.5	75.5
4	63	65.0	65.5	4	77	66.5	69.0
5	63	63.5	63.5	5	77	63.5	66.5

6	63	63.0	56.0	6	77	62.5	61.0
7	63	71.0	57.0	7	77	73.0	60.0
8	63	67.5	52.5	8	77	70.5	53.5
9	63	61.0	59.0	9	77	62.5	61.5
10	63	65.5	67.0	10	77	67.0	72.5
11	63	70.5	58.0	11	77	70.5	61.0
12	63	62.5	64.0	12	77	69.0	69.0
13	63	69.0	55.0	13	77	68.5	58.0
14	63	78.5	56.5	14	77	78.0	59.0
15	63	66.5	72.5	15	77	65.5	75.0
16	63	65.0	52.0	16	77	66.5	56.0
17	63	60.5	65.0	17	77	61.5	62.5
18	63	64.0	51.0	18	77	64.5	55.0
19	63	66.0	54.5	19	77	68.5	54.5
20	63	55.0	56.5	20	77	57.5	60.5
21	63	56.5	63.0	21	77	57.5	67.5
22	63	70.0	69.5	22	77	72.5	74.0
23	63	52.5	62.0	23	77	67.0	65.5
24	63	58.5	59.5	24	77	59.5	63.5
25	63	63.5	63.5	25	77	64.0	66.5
26	63	60.0	54.0	26	77	60.0	56.5
27	63	52.0	66.0	27	77	53.5	70.5
1	70	66.0	63.0	1	84	66.5	62.0
2	70	68.0	57.5	2	84	69.5	59.5
3	70	63.0	75.5	3	84	63.0	78.0
4	70	66.5	70.0	4	84	67.0	70.5
5	70	64.0	67.0	5	84	64.0	68.5
6	70	63.5	58.0	6	84	63.5	60.5
7	70	73.0	60.0	7	84	74.0	60.0
8	70	69.0	53.5	8	84	70.0	56.5
9	70	61.5	62.5	9	84	62.5	63.5
10	70	63.5	73.0	10	84	67.5	75.0
11	70	70.0	59.5	11	84	72.0	63.0
12	70	64.0	68.5	12	84	65.5	70.0
13	70	69.5	57.5	13	84	70.0	60.0
14	70	79.0	58.0	14	84	79.0	61.0
15	70	65.5	72.5	15	84	67.0	75.5
16	70	68.0	54.5	16	84	68.0	57.0
17	70	62.5	68.5	17	84	62.5	62.5
18	70	65.0	52.5	18	84	66.0	56.0
19	70	66.5	58.0	19	84	66.0	52.0
20	70	54.5	60.0	20	84	56.5	62.5
21	70	57.0	66.5	21	84	58.5	69.0
22	70	72.5	73.5	22	84	74.0	74.5
23	70	51.0	64.5	23	84	69.0	67.0
24	70	59.5	62.5	24	84	60.5	65.0
25	70	65.0	66.5	25	84	65.5	67.5
26	70	60.5	55.5	26	84	61.5	57.5
27	70	53.5	70.0	27	84	55.0	72.0
1	91	69.5	64.5	1	105	71.0	63.5
2	91	72.0	59.0	2	105	70.5	62.0
3	91	64.0	78.5	3	105	63.0	80.5
4	91	69.0	72.0	4	105	71.0	70.0
5	91	67.0	68.0	5	105	69.0	65.5
6	91	66.0	63.5	6	105	67.0	61.0
7	91	72.5	63.0	7	105	79.0	58.0
8	91	70.5	57.0	8	105	71.5	59.5
9	91	66.5	63.5	9	105	68.4	62.5
10	91	70.5	75.5	10	105	67.5	80.0

11	91	74.0	65.5	11	105	76.0	68.0
12	91	66.5	71.0	12	105	68.5	70.5
13	91	72.0	60.5	13	105	75.0	63.0
14	91	81.0	61.5	14	105	84.0	62.5
15	91	69.5	77.5	15	105	71.0	73.5
16	91	70.5	57.0	16	105	70.0	60.0
17	91	65.5	65.5	17	105	69.0	65.5
18	91	67.5	57.5	18	105	69.0	61.5
19	91	69.0	56.0	19	105	71.0	59.5
20	91	59.0	63.5	20	105	60.5	65.5
21	91	61.0	70.0	21	105	62.5	75.5
22	91	76.0	76.0	22	105	77.0	77.0
23	91	65.5	67.5	23	105	72.5	66.0
24	91	62.0	65.5	24	105	65.0	69.0
25	91	68.0	68.5	25	105	68.0	67.0
26	91	66.0	58.5	26	105	60.0	58.5
27	91	57.5	73.5	27	105	59.0	77.5
1	98	71.0	65.5	1	112	71.5	67.5
2	98	73.0	60.5	2	112	74.0	59.0
3	98	67.0	78.5	3	112	67.0	80.0
4	98	71.0	73.5	4	112	71.5	74.0
5	98	69.0	69.5	5	112	70.0	71.0
6	98	67.0	64.5	6	112	67.0	66.0
7	98	78.5	63.0	7	112	79.0	64.5
8	98	73.0	57.5	8	112	73.5	58.5
9	98	67.0	65.0	9	112	68.0	65.5
10	98	71.5	78.0	10	112	73.0	82.0
11	98	77.0	66.5	11	112	77.5	67.5
12	98	69.5	72.5	12	112	68.0	74.0
13	98	74.0	62.5	13	112	75.0	63.0
14	98	83.5	61.5	14	112	84.5	62.0
15	98	71.0	77.5	15	112	71.0	78.5
16	98	72.5	59.5	16	112	72.0	59.0
17	98	66.0	68.0	17	112	68.0	70.0
18	98	69.5	59.0	18	112	69.0	60.5
19	98	70.5	57.0	19	112	69.0	60.0
20	98	59.5	64.0	20	112	60.5	66.0
21	98	62.5	70.5	21	112	63.5	73.5
22	98	78.5	76.0	22	112	77.0	78.5
23	98	72.5	68.5	23	112	72.0	70.0
24	98	65.0	67.5	24	112	66.0	68.0
25	98	70.0	70.0	25	112	70.5	71.0
26	98	66.0	60.5	26	112	66.0	62.0
27	98	58.0	74.0	27	112	58.5	76.5
1	119	70.5	66.5	1	134	73.5	69.0
2	119	74.0	64.0	2	134	75.5	64.5
3	119	66.5	81.0	3	134	67.0	82.0
4	119	70.5	73.5	4	134	74.5	75.5
5	119	68.5	70.5	5	134	72.0	72.0
6	119	66.0	68.5	6	134	68.0	69.0
7	119	78.0	63.0	7	134	80.5	66.0
8	119	75.5	61.0	8	134	76.5	61.5
9	119	68.0	67.5	9	134	70.5	67.5
10	119	70.5	81.0	10	134	74.0	84.5
11	119	77.0	69.5	11	134	78.5	71.5
12	119	71.0	76.0	12	134	72.0	78.5
13	119	75.0	64.0	13	134	78.5	64.0
14	119	84.0	65.5	14	134	85.5	64.5
15	119	72.0	80.0	15	134	75.0	80.0

16	119	72.5	61.0	16	134	75.0	63.5
17	119	68.5	72.0	17	134	69.0	73.0
18	119	69.0	60.5	18	134	70.5	61.5
19	119	67.5	62.5	19	134	72.5	64.0
20	119	58.0	67.5	20	134	61.5	68.0
21	119	64.5	75.5	21	134	67.5	75.5
22	119	77.0	78.0	22	134	79.0	79.0
23	119	74.5	72.0	23	134	74.5	71.0
24	119	64.5	71.0	24	134	67.5	72.0
25	119	70.5	72.0	25	134	72.0	71.0
26	119	65.5	59.5	26	134	67.5	63.0
27	119	58.5	77.5	27	134	61.5	80.0
1	126	73.0	67.0				
2	126	73.5	63.0				
3	126	66.5	80.0				
4	126	71.5	75.5				
5	126	70.0	70.0				
6	126	68.0	67.5				
7	126	80.0	64.5				
8	126	75.0	60.0				
9	126	69.0	66.5				
10	126	73.5	80.5				
11	126	77.5	69.5				
12	126	70.5	77.5				
13	126	76.5	62.5				
14	126	84.5	*				
15	126	72.5	80.0				
16	126	71.5	60.5				
17	126	67.0	72.5				
18	126	69.5	60.0				
19	126	70.5	62.5				
20	126	60.5	66.5				
21	126	65.0	74.0				
22	126	78.0	78.5				
23	126	74.0	71.0				
24	126	67.0	69.5				
25	126	70.0	72.0				
26	126	66.5	62.0				
27	126	60.0	78.0				

Individaul liveweight of cattle: Experiment I.

Stocking system	Day	Animal ID	LW (kg)	Stocking system	Days	Animal ID	LW (kg)
R	0	1	245.0	C	0	1	273.0
R	0	2	243.0	C	0	2	265.0
R	0	3	263.0	C	0	3	298.0
R	0	4	252.0	C	0	4	290.0
R	0	5	239.0	C	0	5	284.0
R	0	6	250.0	C	0	6	285.0
R	0	7	275.0	C	0	7	254.0
R	0	8	288.0	C	0	8	263.0
R	0	9	290.0	C	0	9	240.0
R	7	1	263.0	C	7	1	279.0
R	7	2	234.0	C	7	2	269.0
R	7	3	254.0	C	7	3	302.0
R	7	4	251.0	C	7	4	294.0
R	7	5	231.0	C	7	5	280.0
R	7	6	243.0	C	7	6	291.0
R	7	7	264.0	C	7	7	257.0
R	7	8	281.0	C	7	8	268.0
R	7	9	292.0	C	7	9	245.0
R	14	1	285.0	C	14	1	297.0
R	14	2	232.0	C	14	2	278.0
R	14	3	271.0	C	14	3	305.0
R	14	4	262.0	C	14	4	298.0
R	14	5	246.5	C	14	5	283.0
R	14	6	268.0	C	14	6	297.0
R	14	7	290.0	C	14	7	261.0
R	14	8	290.5	C	14	8	274.0
R	14	9	305.5	C	14	9	248.0
R	21	1	302.0	C	21	1	289.0
R	21	2	246.0	C	21	2	276.0
R	21	3	284.0	C	21	3	311.0
R	21	4	275.5	C	21	4	303.0
R	21	5	257.5	C	21	5	288.0
R	21	6	274.5	C	21	6	305.0
R	21	7	299.0	C	21	7	266.0
R	21	8	310.0	C	21	8	281.0
R	21	9	317.5	C	21	9	251.0
R	28	1	293.0	C	28	1	303.0
R	28	2	244.0	C	28	2	281.0
R	28	3	287.0	C	28	3	318.0
R	28	4	279.0	C	28	4	306.0
R	28	5	245.0	C	28	5	292.0
R	28	6	273.0	C	28	6	311.0
R	28	7	290.0	C	28	7	269.0
R	28	8	298.0	C	28	8	286.0
R	28	9	307.0	C	28	9	258.0
R	35	1	308.0	C	35	1	308.0
R	35	2	258.0	C	35	2	281.0
R	35	3	294.0	C	35	3	321.0
R	35	4	287.0	C	35	4	312.0
R	35	5	262.0	C	35	5	299.0
R	35	6	283.0	C	35	6	320.0

R	35	7	306.0	C	35	7	273.0
R	35	8	328.0	C	35	8	291.0
R	35	9	324.0	C	35	9	263.0
R	42	1	320.0	C	42	1	314.0
R	42	2	274.0	C	42	2	289.0
R	42	3	311.0	C	42	3	326.0
R	42	4	301.0	C	42	4	316.0
R	42	5	274.0	C	42	5	312.0
R	42	6	294.0	C	42	6	327.0
R	42	7	320.0	C	42	7	278.0
R	42	8	338.0	C	42	8	295.0
R	42	9	339.0	C	42	9	270.0
R	49	1	314.0	C	49	1	316.0
R	49	2	263.0	C	49	2	300.0
R	49	3	302.0	C	49	3	340.0
R	49	4	297.0	C	49	4	324.0
R	49	5	268.0	C	49	5	316.0
R	49	6	294.0	C	49	6	341.0
R	49	7	317.0	C	49	7	286.0
R	49	8	331.0	C	49	8	309.0
R	49	9	324.0	C	49	9	372.0
R	63	1	327.0	C	63	1	334.0
R	63	2	280.0	C	63	2	316.0
R	63	3	323.0	C	63	3	345.0
R	63	4	317.0	C	63	4	330.0
R	63	5	274.0	C	63	5	331.0
R	63	6	307.0	C	63	6	349.0
R	63	7	339.0	C	63	7	291.0
R	63	8	351.0	C	63	8	316.0
R	63	9	341.0	C	63	9	282.0
R	70	1	352.0	C	70	1	341.0
R	70	2	293.0	C	70	2	323.0
R	70	3	340.0	C	70	3	348.0
R	70	4	327.0	C	70	4	334.0
R	70	5	304.0	C	70	5	337.0
R	70	6	327.0	C	70	6	355.0
R	70	7	351.0	C	70	7	296.0
R	70	8	368.0	C	70	8	322.0
R	70	9	354.0	C	70	9	290.0
R	77	1	356.0	C	77	1	347.0
R	77	2	292.0	C	77	2	327.0
R	77	3	335.0	C	77	3	351.0
R	77	4	328.0	C	77	4	339.0
R	77	5	303.0	C	77	5	345.0
R	77	6	326.0	C	77	6	364.0
R	77	7	380.0	C	77	7	301.0
R	77	8	373.0	C	77	8	328.0
R	77	9	365.0	C	77	9	294.0
R	84	1	366.0	C	84	1	361.0
R	84	2	305.0	C	84	2	337.0
R	84	3	352.0	C	84	3	357.0
R	84	4	339.0	C	84	4	344.0
R	84	5	310.0	C	84	5	351.0

R	84	6	337.0	C	84	6	371.0
R	84	7	363.0	C	84	7	305.0
R	84	8	384.0	C	84	8	335.0
R	84	9	368.0	C	84	9	302.0
R	91	1	372.0	C	91	1	367.0
R	91	2	310.0	C	91	2	348.0
R	91	3	364.0	C	91	3	364.0
R	91	4	348.0	C	91	4	349.0
R	91	5	323.0	C	91	5	358.0
R	91	6	340.0	C	91	6	379.0
R	91	7	368.0	C	91	7	311.0
R	91	8	395.0	C	91	8	340.0
R	91	9	370.0	C	91	9	305.0
R	98	1	378.0	C	98	1	376.0
R	98	2	315.0	C	98	2	355.0
R	98	3	371.0	C	98	3	369.0
R	98	4	357.0	C	98	4	354.0
R	98	5	326.0	C	98	5	364.0
R	98	6	353.0	C	98	6	385.0
R	98	7	376.0	C	98	7	315.0
R	98	8	403.0	C	98	8	345.0
R	98	9	383.0	C	98	9	309.0
R	105	1	383.0	C	105	1	374.0
R	105	2	325.0	C	105	2	359.0
R	105	3	381.0	C	105	3	373.0
R	105	4	363.0	C	105	4	358.0
R	105	5	337.0	C	105	5	371.0
R	105	6	356.0	C	105	6	391.0
R	105	7	379.0	C	105	7	321.0
R	105	8	414.0	C	105	8	349.0
R	105	9	390.0	C	105	9	315.0
R	112	1	386.0	C	112	1	372.0
R	112	2	322.0	C	112	2	360.0
R	112	3	384.0	C	112	3	377.0
R	112	4	367.0	C	112	4	361.0
R	112	5	339.0	C	112	5	378.0
R	112	6	363.0	C	112	6	397.0
R	112	7	389.0	C	112	7	324.0
R	112	8	417.0	C	112	8	355.0
R	112	9	390.0	C	112	9	321.0
R	119	1	401.0	C	119	1	382.0
R	119	2	316.0	C	119	2	373.0
R	119	3	392.0	C	119	3	383.0
R	119	4	371.0	C	119	4	366.0
R	119	5	350.0	C	119	5	383.0
R	119	6	369.0	C	119	6	404.0
R	119	7	398.0	C	119	7	329.0
R	119	8	419.0	C	119	8	361.0
R	119	9	403.0	C	119	9	323.0
R	126	1	399.0	C	126	1	389.0
R	126	2	322.0	C	126	2	368.0
R	126	3	392.0	C	126	3	390.0
R	126	4	375.0	C	126	4	370.0

R	126	5	346.0	C	126	5	391.0
R	126	6	371.0	C	126	6	412.0
R	126	7	394.0	C	126	7	333.0
R	126	8	425.0	C	126	8	366.0
R	126	9	396.0	C	126	9	328.0
R	134	1	414.0	C	134	1	387.0
R	134	2	338.0	C	134	2	369.0
R	134	3	407.0	C	134	3	392.0
R	134	4	395.0	C	134	4	374.0
R	134	5	359.0	C	134	5	398.0
R	134	6	384.0	C	134	6	418.0
R	134	7	410.0	C	134	7	337.0
R	134	8	447.0	C	134	8	370.0
R	134	9	418.0	C	134	9	332.0

Appendix 4.1. Height-mass regression for Experiment II.

Parameters for the regression of pasture mass (Y, kg ha^{-1}) and sward surface height (X, cm) for pastures grazed by CA or CS using continuous (C) or rotational (R) stocking. (P refers to whether the slope is significantly different from 0).

Equation : **Pasture mass (kg ha^{-1}) = (B_0) + (B_1)SSH (cm)**

Sward	Intercept (B_0)	Slope (B_1)	R^2	P
CA-C	-2	383	0.79	0.00
CS-C	8	339	0.85	0.00
CA-R + CS-R: Pre-	182	197	0.94	0.00
CA-R post grazing	-310	423	0.94	0.00
CS-R post-grazing	-287	392	0.84	0.00

Appendix 4.2a.

ANOVA: Slopes of sheep LW on number of days, Experiment II.

Source	d.f.	SS	MS	F	P
Between slopes	1	21.241	21.24	0.73	ns
Error	955	27926	29.24		
Total	956	27947			

Appendix 4.2b

ANOVA: Average daily liveweight gain and final mean fasted liveweight of cattle.

Source	d.f.	SS	MS	F	P
1. Liveweight gain					
Species mixture	1	93.60	93.60	1.97	0.170
Stocking system	1	411.02	411.02	8.65	0.006**
Mixture*system	1	104.66	104.66	2.20	0.148
Error	32	1520.52	47.52		
Total	35	2129.80			
2. Final mean fasted liveweight					
Species mixture	1	3249.0	3249.0	3.86	0.058
Stocking system	1	6944.4	6944.4	8.25	0.007**
Mixture*system	1	3802.8	3802.8	4.52	0.041*
Error	32	26951.3	842.2		
Total	35	40947.6			

Appendix 4.3.

ANOVA: Regression slopes of liveweight on number of days for CA and CS.

Source	d.f.	SS	MS	F	P
Continuous:					
Between slopes	1	5068.62	5068.62	6.68	0.011*
Error	318	241400	759.12		
Total	319	246469			
Rotational:					
Between slopes	1	2.05	2.05	0.003	ns
Error	319	224900	705.02		
Total	320	224902			

n = 9 animals x 19 weeks (including week 0). Missing values: continuous 21; rotational 20.

Appendix 4.4a

ANOVA: Daily OMI of sheep, Experiment II.

Source	**df**	**SS**	**MS**	**F**	**P**
Period	1	2.582	2.582	12.45	0.001**
Stocking system	1	0.049	0.049	0.24	0.631
Period x system	1	0.647	0.647	3.12	0.088
Error	28	5.807	0.207		
Total	31	9.085			

Appendix 4.4b

ANOVA: Daily OMI of cattle, Experiment II.

Source	DF	SS	MS	F	P
Period	1	220.67	220.67	88.18	0.000**
Species mixture	1	17.47	17.47	6.98	0.011**
Stocking system	1	36.66	36.66	14.65	0.000**
Period x mixture	1	3.64	3.639	1.45	0.233
Period x system	1	1.95	1.953	0.78	0.381
Mixture x system	1	45.73	45.73	18.27	0.000**
Period x mixture x system	1	0.126	0.126	0.05	0.823
Error	56	140.14	2.502		
Total	63	466.39			

Frequency distribution of sward height on pastures grazed by cattle alone or co-grazed with sheep

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ABSTRACT

Pasture height is increasingly employed in feed planning as a measure of pasture availability. The frequency distribution of pasture height on a ryegrass/white clover pasture grazed by steers has been shown to be a double normal distribution representing "frequently" and "infrequently" grazed areas. It is not known to what extent a similar double normal distribution of pasture height exists under mixed grazing.

In a 17 week grazing experiment, sward surface height (SSH) was measured daily on a ryegrass/white clover sward, continuously grazed at a mean pasture height of 4.0 cm by nine yearling heifers (CA) or by nine heifers plus 27 ewe hoggets (C + S) on a ratio 1:1 $W^{0.75}$. A companion rotational grazing treatment was involved.

The mean SSH was similar for CA and C+S in both grazing systems (Continuous: 4.27 vs. 4.26 cm; Rotational: 4.87 vs. 4.82 cm). The effect of species mix on sward height distribution was only significant under continuous grazing, where the proportion of the infrequently grazed heights was six times higher in CA than C+S pastures (0.30 vs. 0.05). The mean height of the "frequently" and "infrequently" grazed area was 0.5 cm (12 %) and 1.5 cm (24 %) higher in C+S than on CA pastures, respectively. Although the trends were similar in rotationally grazed treatments, neither the difference in the proportion frequently and infrequently grazed height, nor the mean sward height of these areas significantly diffrered between C+S and CA swards.

We suggest that this increase in 'grazing height' at the same mean SSH in continuously grazed pastures may explain some of the increase in animal performance under mixed grazing. This effect of mixed grazing was less obvious under rotational grazing.

Keywords: Cattle; co-grazing; continuous grazing; double normal distribution; dung patches; frequently grazed; infrequently grazed; pasture height; rotational grazing; and sheep.

INTRODUCTION

Pasture height is considered the best single predictor of both pasture availability and animal performance, especially on intensively managed temperate pastures. It has been increasingly used, as sward surface height to describe the vertical height of the pasture as presented to the grazing animal, or as a sward plate height to provide a height-mass regression (Gibb and Ridout, 1986). The two main reasons for the popular use of sward surface height in describing pasture condition and animal performance are: (1) that grazing animals show more consistent patterns of response to pasture height than other sward parameters under different conditions (Hodgson, 1990), and (2) that it is easy to measure.

Traditionally, pasture height has been described by a sample mean and standard deviation with the assumption of a symmetrical distribution. However, in practice the grazing of pasture by domestic ruminants is patchy and exhibits "frequently" and "infrequently" grazed areas giving a skewed frequency distribution of height measurements. Gibb and Ridout (1986) argue that the assumption of a symmetrical frequency distribution can be potentially misleading, as the frequently and infrequently grazed areas can differ in the vertical distribution of plant parts (Gibb, 1991). They proposed the use of a double normal distribution which they successfully applied to the frequency distribution of pasture height on a ryegrass/white clover pasture grazed by steers. Their later work (Gibb and Ridout, 1988) on swards under five different systems of management, all grazed by steers, further showed that the fitting of a double normal distribution gives a true reflection of the distribution of heights on grazed swards, because it estimates the relative proportion as well as the mean height, of the 'frequently' and 'infrequently' grazed areas.

Mixed grazing studies with sheep and cattle have shown that pasture grazed by sheep and cattle is less patchy, because sheep more readily graze around cattle dung pats than do cattle (Forbes & Hodgson, 1985). The question as to whether this phenomenon would lead to different frequency distribution of height measurements and proportion of frequently and infrequently grazed areas on pastures grazed by cattle and sheep to that grazed by cattle alone has not been formally tested. This paper addresses this question.

MATERIALS AND METHODS

Treatments. Nine heifers (cattle alone:CA) and nine heifers plus 27 ewe hoggets (cattle and sheep: C+S) were continuously grazed on an irrigated ryegrass/white clover pasture during late spring-summer of 1993/94 (15 Nov. to 5 March). Respective companion groups were grazed rotationally on a similar pasture, completing the planned four treatments: two grazing systems (rotational vs. continuous) and two species mix (cattle alone vs. cattle and sheep). The heifers were a mixture of Hereford and Hereford-Angus yearlings (initial liveweight 190 kg), while the sheep were all two-tooth Corriedale ewe hoggets (initial liveweight 45 kg). The co-grazed cattle and sheep were mixed on a 1:1 $LW^{0.75}$ basis.

A total area of 4.42 ha was allocated to each treatment under continuous grazing. 2.95 ha (2/3) was assigned to C+S and 1.47 (1/3) to CA, and sward height was kept at 4.0 cm by adding or removing extra animals. In the rotationally grazing group, C+S and CA were grazed side by side separated by an electric fence. They were given fresh area daily, CA received one-third of the new area (i.e. half the area given to C+S) though the size was adjusted regularly to achieve the same post-grazing height with C+S. Both CA and C+S animals had access to areas given on the previous two days. The size of the new area provided daily was such that the weekly liveweight change of the rotationally grazed sheep was equal to that of the continuously grazed group (details and liveweight data are reported elsewhere (Kitessa and Nicol, 1995)).

Measurements. Sixty measurements of sward surface height (SSH) were made daily over the 17 week period on the continuously grazed pastures using the HFRO sward stick (Hill Farming Research Organisation, 1986). On eight different occasions, the site of each height measurement was classified as being frequently grazed or infrequently grazed area based on the presence or absence of dung fouling and/or evidence of recent severance of leaves through grazing. On the rotational treatment, 40 measurements of pre- and post-grazing SSH were taken daily.

Data analysis. The test for a double normal frequency distribution of the SSH and the post-grazing height data from continuously and rotationally grazed swards respectively, was made using the computer programme MLP, maximum likelihood programme (Ross, 1987). For each treatment, height data on only every second day was used in fitting the models because the programme had a data limit maximum of 5, 000. The programme provided the fit of a sequence of models to the data in the following order of increasing number of parameters:

(1) single normal distribution ,
(2) double normal distribution with equal proportion and equal variance,
(3) double normal distribution with different proportions but equal variance, and
(4) double normal distribution with different proportions and unequal variance.

With each treatment, the model which first showed a non-significant chi-square test of predicted values with observed values was accepted. The mean, standard deviation, and the proportion of the frequently and infrequently grazed areas were obtained from the MLP output. Using these parameters, predicted values within each distribution of heights were determined by using the statistical NORMDIST function of Microsoft Excel 5.0 (Microsoft Corporation, 1993).

RESULTS

Over the 17 week grazing period, the mean sward height of CA and C+S treatments were 4.27 and 4.26, and 4.87 and 4.82 on continuous and rotational grazing systems, respectively. There was no significant difference between the mean sward heights of the two species mix under either grazing system. As shown in Table 1, there was agreement between the proportion of the sward subjectively classified as being infrequently grazed and that predicted using the maximum likelihood programme. Parameters from the fitted double normal distributions, including the overall mean heights, for each treatment are summarised in Table 2. In each treatment, a double normal distribution better fitted the data than a single normal distribution. All treatments showed equal variances for the mean sward heights of the frequently and infrequently grazed areas, except CA on continuous grazing, which showed unequal variance. In both grazing systems, the mean height of the frequently grazed areas was higher and the proportion of the infrequently grazed areas was lower on the swards grazed by cattle plus sheep than on those grazed by cattle alone (Table 2). However, both contrasts were less marked in rotationally grazed swards.

The frequency distribution of observed and fitted sward heights of continuous grazing treatments are illustrated in Fig. 1. The observed data show a skewed distribution irrespective of the animal species mix. C+S, the less skewed of the two treatments (Fig. 1), still showed a significant lack of fit to a single normal distribution ($P>0.001$).

TABLE 1: The proportion of swards subjectively classified as infrequently grazed and that predicted using MLP(Maximum Likelihood Programme).

	Subjectively Classified	MLP Predicted	Difference ($P<0.05$)
CA	0.20	0.17	ns
C+S	0.08	0.05	ns

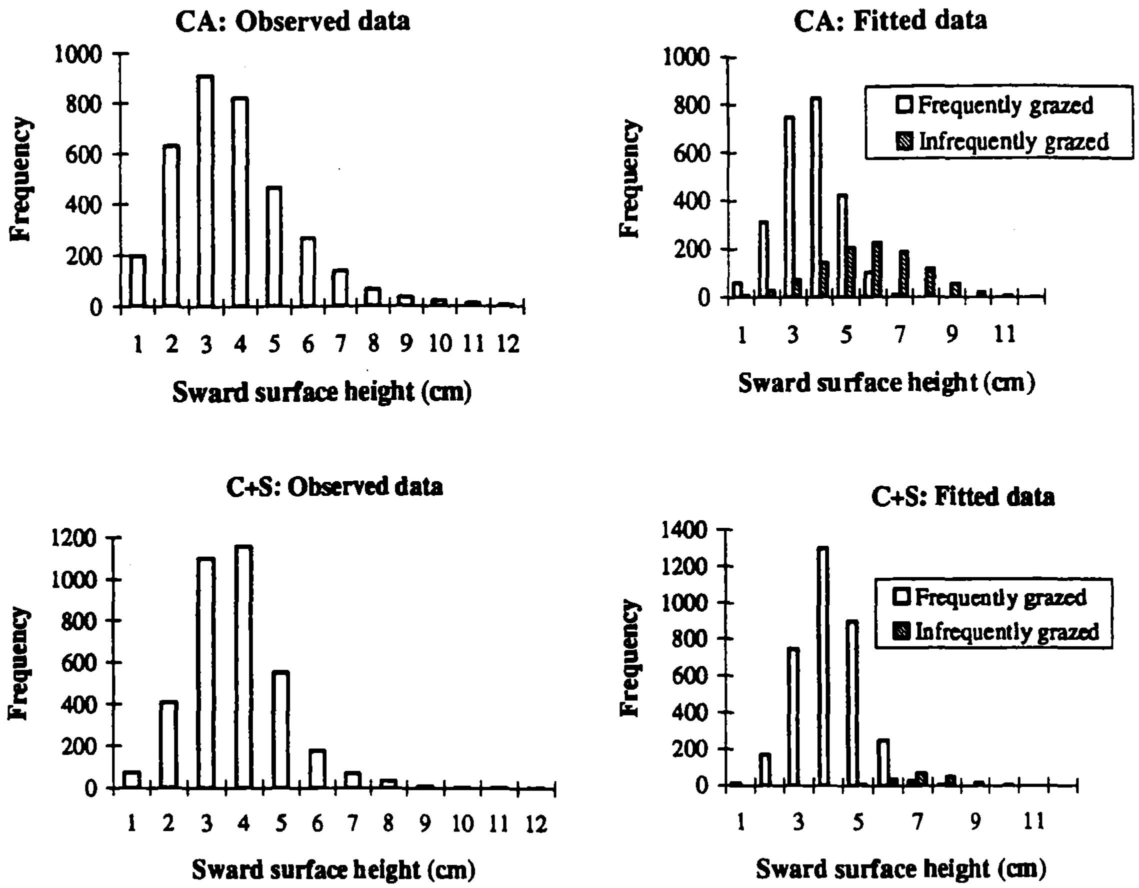
TABLE 2: Parameters of the frequency distribution of sward height on pastures grazed by cattle alone (CA) or cattle plus sheep (C+S) using continuous or rotational grazing.

	CONTINUOUS		ROTATIONAL	
Parameter	**CA**	**C+S**	**CA**	**C+S**
Overall mean (cm)	4.27	4.26	4.87	4.82
s.d.	1.80	1.32	1.96	2.03
Mean height of frequently grazed area (cm)	3.63	4.10	4.09	4.20
s.d.	1.14	1.04	1.08	1.26
Mean height of frequently grazed area (cm)	5.83	7.23	7.46	7.73
s.d.	1.19	1.04	1.08	1.26
Proportion of area infrequently grazed (p)	0.30	0.05	0.22	0.17

DISCUSSION AND CONCLUSIONS

The less "patchiness" of swards continuously co-grazed by cattle and sheep observed by other authors (Nolan and Connolly, 1992) appears to be a consequence of a large reduction in the proportion of areas infrequently grazed (in this case about 80 % reduction: from 30 to 5 % of total area). This would support the supposition of the willingness of sheep to graze around cattle dung pats (Forbes and Hodgson, 1985) with a consequent increase in the percent area utilised which leads to improvement in animal performance (Bennett *et. al.*, 1970, Hamilton, 1976,

FIGURE 1: The frequency distribution of observed and fitted (double normal) pasture heights on swards continuously grazed by cattle alone or cattle plus sheep.



Bowns, 1989). Our results suggest that in addition to improvement in percent utilisation, co-grazing cattle and sheep also increases the mean sward surface height on both the frequently and infrequently grazed areas of the sward. That is, under continuous grazing, at the same overall mean height, cattle grazing with sheep are grazing on a higher sward height than cattle grazed alone, independently of whether they are grazing frequently or infrequently grazed areas. Therefore, the improvement in animal performance reported by various authors on mixed grazing experiments could be partly an outcome of co-grazed cattle and sheep grazing at a higher height.

There are two sets of published work on the frequency distribution of sward height on continuously grazed pastures: Gibb and colleagues work with steers grazed on ryegrass/white clover pastures under different managements (Gibb and Ridout, 1986, 1988; Gibb, 1991), and Wright and Whyte's (1989) report on multiparous cows and calves also grazed on a similar pasture species. Wright and Whyte (1989) subjectively classified the sites of each height measurement as frequently and infrequently grazed area while Gibb and Ridout's and our results were based on estimates obtained from a double normal distribution. However, our observations on data gathered on some occasions during the current experiment show little difference between the proportion of areas subjectively classified as being infrequently grazed and that determined using the MLP programme.

The following sections compare our results to regression lines fitted to data from the reports of other authors (see above). The proportion of the area infrequently grazed by CA lies close to the regression line for this proportion and the mean height of swards grazed by steers, whereas the proportion infrequently grazed by C+S agree more with data from grazing by cows plus calves (Fig. 2). Similarly, although not so conclusively, both the mean height of frequently and infrequently grazed areas of swards grazed by cattle alone appear closer to the respective regression lines of the steer data (Fig. 3) than those heights from swards grazed by cattle plus sheep which lie closer to the regression line of data on cows plus calves (Fig. 4).

Interestingly, the steer data suggest that for a unit increase in the mean height of pasture, the mean height of the infrequently grazed areas increases about three times as much as the increase in the mean height of the frequently grazed areas (Fig. 3). On the other hand, on swards grazed by cows and calves, sward height on both frequently and infrequently grazed areas seemed to increase with the same magnitude, with increasing overall mean height of the sward (Fig. 4).

FIGURE 2: The proportion infrequently grazed on CA and C+S treatments compared to that on swards grazed by cows and calves (Wright & Whyte, 1989), or steers (Gibb & Ridout, 1986, 1988; Gibb, 1991).

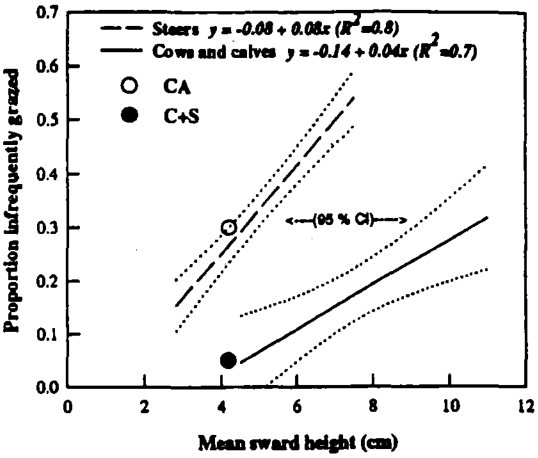
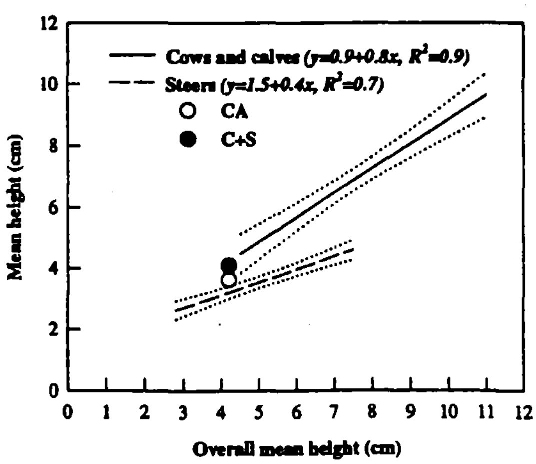


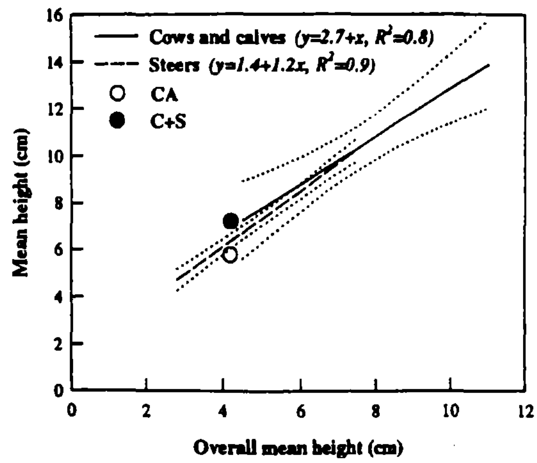
FIGURE 3: The mean height of frequently grazed areas on CA and C+S swards compared to the regression of this height on the mean height of swards grazed by cows and calves Wright & Whyte, 1989), and steers (Gibb & Ridout, 1986, 1988)



This suggests that patchiness of grazed swards can also be reduced by combining different classes of animals of the same species as well as by different species combination. However, whether swards grazed by cows and calves are less patchy than swards grazed by cows alone, as well as the implicit suggestion that swards grazed by cows and calves are of similar patchiness as swards grazed by cattle plus sheep requires validation under the same management. Similarly, further investigation is needed to test if the change in the height of the frequently and infrequently grazed areas with increasing sward height is dependent on animal type or species combination

To summarise, in continuously grazed swards, at the same overall mean height, the mean height of the frequently grazed areas was higher and the proportion of the total area infrequently grazed was lower on swards grazed by cattle plus sheep than those grazed by cattle alone. This may be one

FIGURE 4: The mean height of infrequently grazed areas on CA and C+S swards compared to the regression of this height on the mean height of swards grazed by cows and calves (Wright & Whyte, 1989) and steers (Gibb & Ridout, 1986, 1988).



of the reasons that higher animal performance has been reported from mixed grazing experiments involving sheep and cattle. Other combinations, like cows and calves also seem to produce swards of less patchiness than swards grazed by cattle alone under continuous grazing.

In rotationally grazed swards the frequency distribution of sward height was not affected by species combination. There is no other published report on the frequency distribution of sward height on rotationally grazed pastures. From our results, it appears that there is little difference in patchiness between swards rotationally grazed by cattle alone and cattle plus sheep. It is most likely that patchiness of rotationally grazed swards depends more on the post-grazing height imposed than it does on the species mix.

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Individual liveweight of sheep: Experiment II.

Animal ID	Day	Stocking system C	Stocking system R	Animal ID	Day	Stocking system C	Stocking system R
1	0	42.4	59.0	1	14	43.4	63.0
2	0	53.5	46.0	2	14	56.0	49.4
3	0	46.6	47.4	3	14	48.8	51.5
4	0	45.6	39.4	4	14	41.4	43.6
5	0	48.0	44.8	5	14	44.8	48.6
6	0	35.4	50.0	6	14	38.6	49.8
7	0	47.0	37.2	7	14	45.4	43.2
8	0	53.0	49.2	8	14	46.2	*
9	0	57.5	47.6	9	14	47.4	52.0
10	0	53.5	42.4	10	14	51.5	46.8
11	0	50.5	40.6	11	14	49.2	43.4
12	0	49.0	58.5	12	14	46.2	55.5
13	0	54.0	44.6	13	14	47.6	46.0
14	0	50.5	44.8	14	14	*	48.6
15	0	50.0	47.4	15	14	48.0	50.5
16	0	40.4	51.0	16	14	38.6	53.5
17	0	51.0	46.2	17	14	48.6	43.0
18	0	42.4	46.4	18	14	48.2	45.0
19	0	46.4	49.4	19	14	49.2	50.5
20	0	49.0	42.5	20	14	42.0	45.0
21	0	38.6	39.0	21	14	41.0	43.0
22	0	47.8	45.6	22	14	38.8	45.2
23	0	48.6	43.0	23	14	45.0	45.8
24	0	45.5	48.4	24	14	54.5	44.4
25	0	36.6	48.0	25	14	36.2	44.0
26	0	46.8	44.8	26	14	44.2	50.5
27	0	42.6	35.8	27	14	42.2	40.8
1	7	44.2	65.0	1	21	45.4	*
2	7	57.5	50.0	2	21	57.0	*
3	7	49.6	52.0	3	21	49.6	50.5
4	7	46.4	43.0	4	21	44.4	42.6
5	7	45.4	49.8	5	21	45.0	47.2
6	7	38.8	50.0	6	21	40.0	47.8
7	7	44.8	41.6	7	21	45.4	42.6
8	7	52.0	47.2	8	21	52.5	*
9	7	54.0	52.0	9	21	54.0	52.5
10	7	50.5	46.2	10	21	51.0	44.4
11	7	51.5	44.2	11	21	48.6	43.6
12	7	45.8	56.5	12	21	46.0	53.0
13	7	51.5	47.4	13	21	*	46.0
14	7	47.8	50.0	14	21	49.2	49.2
15	7	48.4	50.5	15	21	49.2	50.5
16	7	38.8	54.0	16	21	38.6	53.0
17	7	49.4	44.8	17	21	49.2	41.6
18	7	47.6	45.8	18	21	49.0	43.8
19	7	47.2	54.0	19	21	50.5	50.5
20	7	48.0	44.8	20	21	48.4	43.6
21	7	41.4	45.0	21	21	41.0	43.0
22	7	44.2	45.8	22	21	44.6	43.6
23	7	45.6	46.8	23	21	46.8	44.8
24	7	53.5	47.8	24	21	54.5	44.2
25	7	35.6	47.8	25	21	38.0	44.2
26	7	42.0	49.0	26	21	44.6	48.2
27	7	44.4	40.2	27	21	42.4	40.4

1	28	43.4	*
2	28	57.0	51.0
3	28	47.8	52.5
4	28	47.2	44.0
5	28	43.2	47.6
6	28	41.6	48.0
7	28	43.8	42.0
8	28	55.0	48.2
9	28	54.0	*
10	28	50.5	43.4
11	28	45.0	44.0
12	28	46.1	55.5
13	28	47.0	45.6
14	28	45.2	49.4
15	28	50.5	50.5
16	28	38.0	55.0
17	28	50.0	42.8
18	28	51.5	43.2
19	28	50.5	51.5
20	28	49.9	44.4
21	28	43.2	*
22	28	45.0	43.4
23	28	51.5	45.8
24	28	54.0	44.5
25	28	38.0	42.6
26	28	46.8	49.6
27	28	42.8	40.4
1	35	45.4	62.5
2	35	58.0	49.2
3	35	52.5	48.4
4	35	48.8	40.4
5	35	47.0	45.0
6	35	43.0	50.0
7	35	45.8	36.8
8	35	56.0	*
9	35	56.5	53.0
10	35	54.0	44.6
11	35	50.0	41.6
12	35	48.8	57.5
13	35	50.5	42.0
14	35	48.4	45.5
15	35	52.5	47.2
16	35	40.2	55.0
17	35	51.5	44.2
18	35	53.0	44.2
19	35	53.0	52.5
20	35	52.0	46.2
21	35	44.4	45.2
22	35	47.6	40.6
23	35	49.4	47.2
24	35	55.0	46.0
25	35	36.4	45.0
26	35	48.4	49.2
27	35	44.8	35.4
1	56	49.2	66.0
2	56	60.0	53.0
3	56	56.5	55.5
4	56	53.0	47.6
5	56	50.0	50.0

1	42	46.0	65.5
2	42	60.0	52.5
3	42	53.0	53.5
4	42	51.0	46.8
5	42	47.8	51.0
6	42	43.8	52.5
7	42	46.4	44.2
8	42	52.0	51.0
9	42	57.0	52.4
10	42	54.5	41.2
11	42	53.5	46.4
12	42	49.6	60.5
13	42	48.8	48.2
14	42	50.5	*
15	42	52.5	54.5
16	42	41.6	56.5
17	42	52.0	50.5
18	42	54.0	46.2
19	42	53.5	55.5
20	42	53.0	48.2
21	42	44.8	46.8
22	42	49.0	41.6
23	42	48.0	49.6
24	42	55.5	48.6
25	42	31.0	46.8
26	42	49.4	52.5
27	42	46.0	41.8
1	49	47.8	63.5
2	49	59.0	50.0
3	49	54.0	52.5
4	49	51.7	44.5
5	49	49.0	50.0
6	49	45.4	51.5
7	49	43.0	41.3
8	49	58.5	49.3
9	49	58.5	52.7
10	49	59.0	44.8
11	49	55.0	45.5
12	49	51.5	58.0
13	49	52.5	46.7
14	49	49.8	48.8
15	49	53.8	52.5
16	49	42.0	54.5
17	49	52.5	43.2
18	49	56.5	44.4
19	49	53.0	52.5
20	49	54.0	46.2
21	49	41.8	45.8
22	49	49.8	45.5
23	49	51.0	46.5
24	49	52.0	46.4
25	49	38.7	*
26	49	45.2	50.5
27	49	48.3	41.0
1	70	52.5	66.8
2	70	63.0	56.0
3	70	60.5	58.5
4	70	58.0	46.4
5	70	53.0	55.5

7	56	47.6	42.4	7	70	50.0	44.8
8	56	59.5	52.5	8	70	63.0	54.5
9	56	63.0	56.0	9	70	64.0	58.5
10	56	60.0	48.6	10	70	62.0	51.5
11	56	58.0	48.2	11	70	61.0	49.2
12	56	53.0	62.5	12	70	55.5	64.0
13	56	54.5	49.6	13	70	56.5	52.0
14	56	55.0	51.0	14	70	57.5	53.0
15	56	55.5	54.0	15	70	59.0	56.5
16	56	43.6	59.0	16	70	46.4	60.5
17	56	55.0	47.2	17	70	56.0	50.5
18	56	55.5	50.0	18	70	59.5	50.0
19	56	55.0	57.0	19	70	59.0	57.5
20	56	54.5	49.0	20	70	59.0	51.0
21	56	47.6	49.8	21	70	50.0	47.4
22	56	53.0	48.6	22	70	56.0	49.2
23	56	53.0	49.0	23	70	55.5	51.5
24	56	55.5	48.2	24	70	60.0	53.5
25	56	41.8	*	25	70	44.0	52.5
26	56	52.5	56.5	26	70	54.0	55.0
27	56	50.6	42.4	27	70	53.0	43.4
1	63	51.0	66.5	1	77	54.0	68.5
2	63	61.5	55.0	2	77	67.0	58.0
3	63	57.5	58.0	3	77	59.6	60.0
4	63	56.0	48.4	4	77	61.5	50.0
5	63	52.0	54.5	5	77	54.4	56.5
6	63	48.4	57.0	6	77	51.5	59.0
7	63	50.0	44.2	7	77	51.0	46.8
8	63	61.5	53.5	8	77	65.5	54.5
9	63	62.5	58.0	9	77	65.5	59.5
10	63	61.0	49.8	10	77	63.6	52.0
11	63	60.5	50.0	11	77	63.5	52.5
12	63	54.5	63.5	12	77	57.0	66.0
13	63	56.5	51.5	13	77	58.5	54.0
14	63	55.8	53.5	14	77	59.5	51.0
15	63	57.5	56.5	15	77	58.5	57.5
16	63	45.0	60.5	16	77	47.8	65.0
17	63	56.0	49.6	17	77	58.0	52.0
18	63	57.5	49.6	18	77	63.5	51.5
19	63	57.0	57.5	19	77	61.0	61.0
20	63	57.5	50.5	20	77	60.5	53.0
21	63	49.0	49.6	21	77	52.0	50.5
22	63	53.5	48.8	22	77	58.5	46.8
23	63	54.5	49.6	23	77	57.5	54.0
24	63	58.5	50.5	24	77	60.5	53.0
25	63	42.4	50.5	25	77	47.8	56.5
26	63	52.5	55.5	26	77	57.0	58.5
27	63	52.0	44.2	27	77	54.2	45.4
1	84	56.0	70.0	1	98	57.0	72.0
2	84	66.0	59.5	2	98	68.0	63.0
3	84	59.0	60.5	3	98	61.0	64.5
4	84	61.5	52.5	4	98	61.5	53.5
5	84	55.5	57.0	5	98	57.0	62.0
6	84	52.5	58.5	6	98	53.0	62.5
7	84	52.5	48.6	7	98	54.5	51.0
8	84	65.0	58.0	8	98	67.0	61.5
9	84	66.5	62.0	9	98	69.0	65.0
10	84	65.0	53.5	10	98	66.0	56.5
11	84	65.0	52.5	11	98	65.0	56.0

13	84	61.0	57.0	13	98	61.0	59.0
14	84	61.0	57.5	14	98	61.5	60.0
15	84	60.5	61.0	15	98	62.0	63.0
16	84	48.0	64.5	16	98	51.0	69.5
17	84	61.0	53.0	17	98	61.5	56.5
18	84	63.0	52.0	18	98	64.5	56.0
19	84	62.0	65.0	19	98	63.0	64.5
20	84	61.5	54.0	20	98	63.5	58.5
21	84	52.0	52.5	21	98	52.5	55.0
22	84	58.5	52.0	22	98	59.0	54.0
23	84	59.0	53.5	23	98	61.0	57.5
24	84	62.0	56.0	24	98	63.0	58.0
25	84	47.4	56.5	25	98	46.6	59.5
26	84	57.5	58.0	26	98	58.5	62.5
27	84	55.5	47.8	27	98	57.0	50.0
1	91	56.5	71.5	1	105	58.5	73.5
2	91	67.0	61.5	2	105	68.5	63.0
3	91	61.0	61.5	3	105	61.5	64.5
4	91	60.5	52.5	4	105	62.5	53.5
5	91	55.5	59.5	5	105	57.0	61.5
6	91	51.0	62.0	6	105	54.0	63.5
7	91	53.5	48.8	7	105	55.5	51.5
8	91	64.0	59.5	8	105	66.0	61.0
9	91	68.0	63.0	9	105	69.5	62.5
10	91	67.5	53.5	10	105	67.0	56.0
11	91	64.0	54.5	11	105	66.5	55.5
12	91	59.0	68.5	12	105	59.5	72.0
13	91	59.0	57.5	13	105	61.5	58.5
14	91	61.0	58.5	14	105	62.5	60.5
15	91	60.5	62.0	15	105	62.5	63.5
16	91	48.6	67.5	16	105	50.5	67.5
17	91	60.5	51.5	17	105	63.5	55.5
18	91	63.5	53.0	18	105	64.0	56.0
19	91	60.0	63.5	19	105	64.5	64.5
20	91	62.0	54.0	20	105	63.5	58.0
21	91	52.0	53.0	21	105	53.0	54.5
22	91	58.0	52.0	22	105	60.0	55.0
23	91	59.5	56.0	23	105	62.0	57.0
24	91	61.5	56.0	24	105	64.5	58.5
25	91	48.2	57.5	25	105	48.2	59.5
26	91	57.0	60.0	26	105	59.0	61.5
27	91	56.5	49.2	27	105	60.5	50.0
1	119	60.0	74.5	1	126	61.0	76.5
2	119	69.0	66.0	2	126	71.0	68.5
3	119	63.5	66.0	3	126	66.0	67.5
4	119	65.0	56.0	4	126	65.5	58.5
5	119	57.5	63.5	5	126	60.5	66.0
6	119	55.0	66.0	6	126	55.0	67.0
7	119	56.0	51.5	7	126	58.5	54.0
8	119	66.5	63.0	8	126	68.0	66.0
9	119	74.0	66.0	9	126	72.5	67.0
10	119	69.0	59.5	10	126	71.0	60.0
11	119	67.5	57.5	11	126	70.0	59.5
12	119	59.0	73.0	12	126	62.5	77.0
13	119	63.5	60.5	13	126	64.0	63.0
14	119	63.0	62.5	14	126	65.5	65.0
15	119	65.0	65.0	15	126	66.5	68.5
16	119	47.4	70.0	16	126	52.0	73.0
17	119	65.5	56.5	17	126	68.5	59.5

18	119	67.5	56.0	18	126	68.5	57.0
19	119	64.5	67.0	19	126	67.0	70.0
20	119	65.0	59.5	20	126	66.0	62.5
21	119	57.5	55.5	21	126	55.5	58.0
22	119	60.0	55.5	22	126	63.0	57.5
23	119	61.5	59.0	23	126	64.5	61.0
24	119	65.0	61.0	24	126	67.0	62.5
25	119	48.0	60.5	25	126	50.5	65.5
26	119	61.0	64.0	26	126	62.5	64.5
27	119	60.5	52.5	27	126	61.0	53.5

Appendix 4.6b

Individual liveweight of cattle: Experiment II.

Animal ID	Day	Liveweight (kg) CA-C	CA-R	CS-C	CS-R
1	0	232.0	257.0	288.0	223.0
2	0	271.0	225.0	226.0	256.0
3	0	211.0	239.0	211.0	207.0
4	0	213.0	283.0	199.5	211.0
5	0	229.0	218.0	252.0	199.0
6	0	218.0	230.0	238.0	233.0
7	0	203.0	211.0	234.0	201.0
8	0	259.0	209.0	208.0	254.0
9	0	249.0	223.0	231.0	296.0
1	7	243.0	256.0	282.0	240.0
2	7	278.0	233.0	245.0	273.0
3	7	221.0	255.0	209.0	217.0
4	7	230.0	312.0	204.0	226.0
5	7	242.0	238.0	264.0	210.0
6	7	229.0	238.0	243.0	252.0
7	7	200.0	223.0	233.0	212.0
8	7	266.0	221.0	218.0	273.0
9	7	256.0	238.0	232.0	318.0
1	14	251.0	254.0	293.0	239.0
2	14	283.0	233.0	246.0	260.0
3	14	221.0	240.0	210.0	219.0
4	14	237.0	285.0	197.0	227.0
5	14	255.0	232.0	245.0	211.0
6	14	238.0	236.0	229.0	249.0
7	14	208.0	211.0	234.0	213.0
8	14	269.0	*	213.0	263.0
9	14	263.0	231.0	240.0	313.0
1	21	257.0	262.0	294.0	239.0
2	21	284.0	244.0	203.0	266.0
3	21	232.0	253.0	201.0	212.0
4	21	239.0	298.0	249.0	254.0
5	21	260.0	245.0	192.0	211.0
6	21	239.0	242.0	229.0	268.0
7	21	210.0	220.0	213.0	308.0
8	21	280.0	224.0	236.0	251.0
9	21	264.0	242.0	227.0	236.0
1	28	257.0	268.0	290.0	258.0
2	28	274.0	254.0	201.0	272.0
3	28	227.0	253.0	199.5	228.0
4	28	240.0	286.0	254.0	262.0
5	28	255.0	240.0	199.0	216.0
6	28	233.0	259.0	230.0	267.0
7	28	210.0	222.0	201.0	308.0
8	28	274.0	231.0	235.0	259.0
9	28	251.0	233.0	226.0	245.0
1	35	249.0	265.0	290.0	232.0
2	35	275.0	251.0	201.0	259.0
3	35	228.0	246.0	204.0	223.0
4	35	229.0	286.0	247.0	261.0
5	35	247.0	237.0	198.0	215.0
6	35	241.0	253.0	235.0	272.0
7	35	214.0	224.0	204.0	306.0
8	35	273.0	217.0	231.0	253.0
9	35	248.0	232.0	226.0	240.0
1	42	264.0	295.0	305.0	247.0

2	42	297.0	275.0	210.0	283.0
3	42	238.0	271.0	216.0	241.0
4	42	253.0	313.0	257.0	277.0
5	42	263.0	259.0	212.0	233.0
6	42	250.0	274.0	236.0	291.0
7	42	217.0	240.0	216.0	331.0
8	42	287.0	237.0	250.0	272.0
9	42	275.0	254.0	238.0	259.0
1	49	271.0	284.0	310.0	257.0
2	49	297.0	271.0	213.0	280.0
3	49	247.0	263.0	229.0	238.0
4	49	259.0	305.0	268.0	272.0
5	49	264.0	251.0	229.0	233.0
6	49	259.0	275.0	253.0	292.0
7	49	222.0	237.0	229.0	320.0
8	49	298.0	239.0	257.0	270.0
9	49	281.0	252.0	249.0	256.0
1	56	274.0	301.0	327.0	274.0
2	56	310.0	289.0	225.0	294.0
3	56	252.0	278.0	242.0	248.0
4	56	*	323.0	286.0	287.0
5	56	267.0	266.0	238.0	249.0
6	56	267.0	291.0	263.0	303.0
7	56	223.0	252.0	251.0	336.0
8	56	297.0	253.0	268.0	284.0
9	56	280.0	267.0	263.0	270.0
1	63	280.0	315.0	318.0	290.0
2	63	317.0	300.0	231.0	306.0
3	63	264.0	294.0	246.0	266.0
4	63	275.0	340.0	277.0	299.0
5	63	267.0	273.0	240.0	257.0
6	63	277.0	310.0	273.0	317.0
7	63	227.0	261.0	253.0	351.0
8	63	306.0	267.0	271.0	298.0
9	63	286.0	279.0	264.0	282.0
1	70	286.0	324.0	333.0	296.0
2	70	320.0	301.0	231.0	310.0
3	70	276.0	295.0	253.0	264.0
4	70	278.0	336.0	297.0	295.0
5	70	276.0	275.0	247.0	263.0
6	70	288.0	311.0	277.0	317.0
7	70	235.0	266.0	262.0	352.0
8	70	318.0	270.0	282.0	300.0
9	70	295.0	277.0	273.0	283.0
1	77	294.0	341.0	343.0	312.0
2	77	334.0	321.0	235.0	327.0
3	77	282.0	315.0	260.0	281.0
4	77	294.0	360.0	305.0	312.0
5	77	283.0	294.0	252.0	285.0
6	77	296.0	330.0	284.0	336.0
7	77	235.0	281.0	268.0	377.0
8	77	324.0	291.0	286.0	319.0
9	77	301.0	295.0	279.0	301.0
1	84	308.0	341.0	344.0	314.0
2	84	327.0	322.0	244.0	329.0
3	84	300.0	314.0	263.0	288.0
4	84	300.0	357.0	303.0	319.0
5	84	291.0	293.0	258.0	289.0
6	84	302.0	333.0	287.0	339.0

7	84	250.0	282.0	274.0	377.0
8	84	339.0	290.0	288.0	322.0
9	84	305.0	299.0	283.0	306.0
1	91	315.0	354.0	348.0	320.0
2	91	340.0	332.0	246.0	336.0
3	91	306.0	322.0	266.0	295.0
4	91	311.0	367.0	304.0	321.0
5	91	307.0	301.0	260.0	293.0
6	91	308.0	343.0	291.0	344.0
7	91	256.0	279.0	278.0	380.0
8	91	344.0	291.0	290.0	327.0
9	91	330.0	309.0	285.0	311.0
1	98	321.0	365.0	352.0	332.0
2	98	352.0	344.0	247.0	341.0
3	98	311.0	340.0	269.0	302.0
4	98	319.0	385.0	309.0	331.0
5	98	315.0	312.0	262.0	302.0
6	98	316.0	354.0	297.0	354.0
7	98	268.0	291.0	283.0	392.0
8	98	351.0	305.0	293.0	336.0
9	98	338.0	315.0	289.0	319.0
1	105	327.0	372.0	359.0	331.0
2	105	357.0	336.0	260.0	341.0
3	105	314.0	331.0	276.0	304.0
4	105	322.0	377.0	317.0	333.0
5	105	312.0	307.0	271.0	307.0
6	105	319.0	344.0	289.0	349.0
7	105	270.0	286.0	287.0	385.0
8	105	355.0	305.0	296.0	336.0
9	105	345.0	316.0	294.0	321.0
1	119	337.0	384.0	377.0	351.0
2	119	372.0	358.0	263.0	352.0
3	119	328.0	341.0	285.0	318.0
4	119	338.0	393.0	332.0	343.0
5	119	325.0	320.0	279.0	321.0
6	119	334.0	369.0	287.0	361.0
7	119	279.0	300.0	298.0	403.0
8	119	365.0	326.0	313.0	350.0
9	119	366.0	333.0	304.0	334.0
1	126	346.0	385.0	379.0	358.0
2	126	378.0	366.0	276.0	359.0
3	126	*	352.0	290.0	325.0
4	126	342.0	397.0	336.0	354.0
5	126	333.0	329.0	279.0	331.0
6	126	340.0	377.0	296.0	366.0
7	126	288.0	312.0	299.0	407.0
8	126	377.0	333.0	322.0	360.0
9	126	372.0	332.0	286.0	355.0