THE APPLICATION OF MIXED GRAZING

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ABSTRACT
The grazing of more than one domestic species or class of livestock on the same grazing area, mixed grazing, is common. The outcome of mixed grazing in terms of productivity per animal and per hectare, is the net effect of competition between the various classes of animals for the available herbage and/or complementarity resulting in a greater utilisation of the herbage resource. The degree of competition and complementarity depends quantitatively on the heterogeneity of the herbage, the similarity between the grazing species in their dietary preferences and the interaction of the two. The grazing system adopted influences the outcome of mixed grazing. The choice of system will be influenced by whether competition or complementarity is the desired outcome. The application of mixed grazing in mixed livestock systems involves identifying appropriate animal production outcomes and choosing the most appropriate mixed grazing system to achieve these outcomes. Research in specific areas of animal/herbage interaction would improve the ability to predict the outcome of mixed grazing.

KEYWORDS
mixed grazing, diet selection, cattle, sheep, goats, grazing system.

INTRODUCTION

Mixed grazing is defined as the grazing of a given pasture resource by more than one species or class of livestock. As Wright and Connolly (1995) noted, single species grazing is the exception not the norm if the complete ecology (including invertebrate) of the sward is considered. However, this review restricts discussion of mixed grazing to that controlled by the resource manager through grazing domestic livestock on sown temperate pastures.

In considering the application of mixed grazing to livestock systems, it is difficult to separate some of the potential advantages of mixed livestock farming, namely, better integration of the seasonal energy requirements of animals with herbage production and diversification of animal production to reduce risk (Lambert and Guerin, 1989), from those due to mixed grazing *per se*. This review is limited to a consideration of the interaction between the grazing behaviour of species and the opportunities and alternatives for harnessing these differences in mixed livestock systems. Others potential benefits, such as reduced gastro-intestinal parasite challenge and improved ecological sustainability (Nolan and Connolly, 1992) are not considered here.

There is no question that mixed livestock farming and thus the potential for mixed grazing, is strongly established in many livestock economies. For example (Table 1) only 23.0, 33.6 and 56.4% of all New Zealand beef cattle, sheep and deer respectively are located on farms in which they generate more than 75% of gross income from livestock. Conversely, at least 30% of all sheep, beef cattle and deer are on farms where they contribute less than 50% of livestock gross farm income.

That mixed grazing is not a recent grazing management strategy is illustrated by the biblical quotation “as a shepherd divideth his sheep from the goats” (Matthew 25:32). Most “common” grazed areas in the early stages of agrarian development in the UK were open to grazing by sheep, cattle and horses. In contrast many of the community-owned grazing areas in North America restrict grazing to only cattle, although this policy is based more on social history and the risk of predation than on grazing compatibility (Bowns, 1989).

Mixed grazing has the potential to utilise differences between animals in their reaction to a herbage resource. The scientific literature on mixed grazing has been well reviewed over the last 20 years (Nolan and Connolly, 1977; Lambert and Guerin, 1989; Wright and Connolly, 1995). The literature has focused on mixed grazing of sheep and cattle, to a lesser extent sheep and goats and more recently sheep and deer. There seems to have been little recognition that the grazing behaviour of different classes of the same species (Zoby and Holmes, 1983) might be sufficiently different as to constitute mixed grazing.

Although sequential mixed grazing (as “leaders” and “followers”) has received some consideration, the majority of mixed grazing studies have been made using concurrent grazing of species (Table 2). More studies have utilised continuous grazing than rotational grazing but no work has systematically compared mixed grazing responses under these two grazing management systems. The design of most mixed grazing experiments has required moderate to high levels of animal production. Fewer have been made around maintenance feeding levels.

The research literature on mixed grazing has done much to expand our understanding of the grazing ecology of common domestic livestock but ultimately, the impact of mixed grazing will depend on its application in animal production systems. The aim of this review is to identify features of animals and mixed grazing which influence the outcome of mixed grazing and to consider the ways in which mixed grazing can be applied to capture its potential benefits.

A synopsis of the mixed grazing literature is that the outcome of interactions between grazing animals on the herbage resource can result in:

(i) complementarity between their grazing behaviour leading to increased utilisation of the herbage resource,
(ii) competition between the groups animals leading to a qualitative and/or quantitative redistribution of the grazing resource from one group to the other
(iii) a change in the composition, quality and/or productivity of the herbage resource as a result of (i) and (ii).

The opportunity for competition and complementarity between classes of livestock during mixed grazing depends on diversity of both the dietary preferences of the animals involved and of the available herbage. This diversity may reflect variation in physical distribution of the herbage and grazing (eg, shady versus sunny aspects), called here “spatial” variation or to variation in the vegetation available and selected during grazing (eg green leaf or seedhead), called here “botanical” variation.

In a schematic model of the interaction between the above terms (Figure 1), superimposition of dietary overlap (or similarity), between mixed grazing species on the diversity of the available herbage identifies zones of competition (from A) which reach a maximum (line B-C). Further increases in herbage diversity leads to potential zones of complementary and ultimately complete complementarity and thus no competition (line D-E) where total separation of dietary preferences is possible.

The relative importance of zones of complementarity and competition will be altered by the range of dietary overlap and available herbage. For example, decreasing the spatial herbage diversity reduces the opportunity for spatial complementary and the relative importance of spatial competition to total competition. Other factors such as the species ratio, grazing pressure and grazing system (see later sections) also affect the size of the zones. The outcome of any mixed grazing situation will be determined by its position in the model. Because there is considerable, but not complete, overlap in dietary preferences of the domestic species commonly used in mixed grazing, the outcome of mixed grazing will be the net effect of complementarity and competition, a position which occupies both zones of competition and complementarity. For simplicity in the next section of this paper, complementarity and competition will be discussed separately.

COMPLEMENTARITY - INCREASED UTILISATION OF EXISTING HERBAGE RESOURCES

Perhaps the most important application for mixed grazing is to utilise a range of dietary components greater than that possible with a single grazing species. A number of reviewers (Lambert and Guerin, 1989, Wright and Connolly, 1995) have hypothesised that the opportunity for complementary in resource use with mixed grazing should be greatest where there is greater heterogeneity of the vegetation resource and least overlap in the dietary preferences of the animal species in the mixture. Complementarity may be based on varying preference for plant communities, individual plants or even plant parts (Wright and Connolly, 1995). There is also scope to utilise spatial preferences (sunny, shady aspects, higher or lower horizons) for the grazing resource.

An excellent illustration of utilising a very heterogeneous plant resource and large differences in dietary preferences is the work of Radcliffe (1985) with her study of goat and sheep mixtures in a gorse (*Ulex europaeus* L) and pasture environment. Over a period of three years, areas which initially contained 80% open grazing and 20% gorse cover increased to close to 100% open grazing under mixed sheep and goat rotational grazing and decreased to 50% under sheep only rotational grazing. Other examples also involve goat and sheep (Grant et al., 1984; Merchant, 1993) in rush (*Juncus effusus*) invested pasture, sheep and deer on hill grazing plant communities (Hester et al., unpublished) and cattle and sheep (Grant, et al., 1985; McCall et al., 1986) on extensive hill country pastures. Such mixtures utilise heterogeneity in herbage supply generated by variation in soil fertility, drainage and aspect.

The frequent observation (Ronnel et al., 1980; Forbes and Hodgson, 1985) that sheep graze closer to cattle dung pats than cattle, thus utilising vegetation which would decrease in quality as “infrequently” grazed areas under cattle-only grazing, is perhaps the best recognised example of an complementary effect which results in increased overall utilisation of the herbage resource and increased total animal output per ha (Nolan et al., 1989).

More recently, the propensity for goats to graze in the upper vertical sward horizons resulting in higher clover content for subsequent grazing by sheep which are willing to penetrate lower horizons of the sward for preferred components (L’Huillier et al., 1986) has been successfully utilised in systems where lambs sequentially graze after goats. Lambs grazed on pastures prepared by goats have shown substantially higher clover intake (+15 percentage units) and liveweight gain (+20%) than if they follow sheep grazing (Townsend and Radcliffe, 1990; del Pozo, et al., 1996).

There seems to be general acceptance in the literature that complementarity between species in their utilisation of the available herbage resource is the most significant reason for any increase in the combined animal production per unit area under mixed grazing (compared with the sum of the productivity of the individually grazed species).

GRAZING SYSTEM AND COMPLEMENTARITY

Mixed grazing can be applied through a number of grazing systems (Table 3) covering concurrent or sequential use of the species under continuous or rotational grazing.

Simplistically, if there is no dietary overlap between species, complementarity in terms of diet selection and intake, might be considered to be independent of the grazing system used. However, where dietary overlap exists there may be good reasons why choice of grazing system is likely to influence the outcome of complementarity. For example, where:

(a) complementarity is temporal. For example the complementarity of cattle in consuming grass seedhead when grazed with sheep, or the use of goats to control annual weeds requires their presence, (at a high grazing pressure) only at the appropriate time. Under such circumstances, concurrent-intermittent or sequential-alternate grazing systems are likely to be preferable.

(b) complementarity depends on a low preference ranking for sward components. For example, Grant et al. (1995) only showed significant complementarity, defined as a high level of *Nardus* (a low digestibility species) in the diet of cattle co-grazed with sheep, when the live herbage mass fell below 2500 kg DM/ha. Complementarity in such circumstances is likely to require simultaneous continuous grazing at high stocking density to “force” cattle to be complementary.

(c) complementarity depends on herbage quality. Concurrent grazing may be needed if a pronounced decline in nutritive value was to occur between sequential grazings. For example, herbage surrounding areas contaminated by cattle faeces has been shown to have higher DM digestibility and be grazed by sheep for six weeks under concurrent-continuous mixed grazing (Nolan and Connolly, 1987). This material may decline sufficiently in quality between sequential grazing to be rejected by sheep. Concurrent-continuous grazing may be necessary to fully utilise complementarity under such conditions.

(d) complementarity depends on the concentration of specific herbage components. The concentration of individual sward components is likely to accumulate to a greater degree in the absence of a species which consumes that component ie under (sequential-alternate grazing), than with concurrent-continuous grazing. For example, under similar environmental conditions, del Pozo et al. (1996) were able to develop a much higher proportion (0.38) of clover in the pasture for lambs, sequentially grazing after goats than Nicol et al. (1993), were able to achieve with concurrent-continuous grazing of goats and sheep (0.03 clover).

Choice of grazing system can therefore affect both the relative importance of the zones of complementarity (refer Figure 1) and how effectively they are utilised. Grazing system can increase the opportunity for complementarity by withdrawal and introduction of the alternate species from the mix ((d) above) and through the choice of co-grazing stock classes. Capture of potential complementarity can be increased by choosing a grazing system and grazing pressure which will ensure appropriate timing of mixed grazing ((a), (b) and (c) above).

COMPETITION - REDISTRIBUTION BETWEEN SPECIES OF THE SAME RESOURCE

Under mixed grazing there is potential for quantitative and qualitative redistribution between the species of the herbage available through competition for the available herbage.

Connolly (1986) used the “giants and dwarfs” analogy to illustrate that if two animals with different intakes are mixed, the one with the larger intake capacity will capture a greater proportion of the feed resource in a given time than the smaller. Although this might appear to be the result of active competition he interprets this as simply a passive effect of mixed grazing. Active competition involves qualitative redistribution of the grazing resource, and/or a quantitative change in intake. One grazing species wins by harvesting a higher proportion of the available grazing resource than the other. The degree of competition is likely to depend on:

(a) heterogeneity of the herbage available; more complex swards (greater range in components and nutritive value) give greater potential for qualitative redistribution than simple swards

(b) anatomical features of the grazing species. The association between the relative size and shape of mouths and dental arcades which give smaller animals (sheep) and those with narrow mouths (goats) greater potential to discriminate between components of available herbage compared with large broad mouthed species (cattle) has been well established (Gordon and Illius, 1988) and will ultimately control the degree of competition between species.

(c) the relative ability of species to exploit dietary preferences by selective grazing. There is considerable overlap in the dietary profiles of cattle and sheep (Grant et al., 1985), sheep and goats (Clark et al., 1982) and goats and cattle (Squires, 1982), the three species most commonly used to date in mixed grazing experiments. Sheep consistently extract a higher quality diet from a sward than do cattle (Dudzinsky and Arnold, 1973; Jamieson and Hodgson, 1979). In general there have been larger responses in terms of increased liveweight gain to mixed grazing by sheep than by cattle (Nolan and Connolly, 1977) reflecting the ability of sheep to out compete cattle for preferred sward components. It is interesting that although goats have the potential to be as selective if not more selective than sheep, their more catholic dietary preferences can result in their selected diet being of lower quality than sheep grazed on similar swards (Collins, 1989).

The possibility that diet selection can be influenced by ‘bonding’ of one species to another (Anderson et al., 1990) raises interesting questions about the outcome of this form of mixed grazing. The implication is that if “bonding” increases the dietary overlap between grazing species then the opportunity for competition between them increases, and the scope for complementarity may decrease.

A consequence of competition between sheep and cattle is that cattle can be forced to relocate their grazing in vertical horizons of the sward which contain more stem and seedhead (Grant et al.,1985) and less green leaf. Estimates of the horizons grazed by single - and mixed - grazing cattle (Nicol and Collins, 1990) show that cattle select a greater proportion of their diet from the upper sward horizons when grazing with sheep than when on their own (Figure 2). Sheep benefited from the mixed grazing by increasing the proportion of their diet apparently selected from those horizons containing green leaf (20-40 and 40-60 mm). Co-grazing with goats had less effect on the proportionate use of horizons by cattle suggesting less competition than between sheep and cattle.

The zone of competition between grazing species also depends on the relative proportion of each species in the mix and the stocking pressure. For example, the data of Nolan and Connolly (1989) demonstrates that as the proportion of sheep in a cattle/sheep mixture increases above that appropriate for complementarity (~ 25% by number), competition between sheep and cattle significantly reduces cattle performance (Figure 3). Thus to utilise zones of complementarity while minimising zones of competition, species ratio and grazing pressure must be appropriate to give close synchrony of the differences in dietary preference with the variation in the available herbage.

The dynamic effect of grazing pressure on complementarity/competition between species is illustrated by a study by Nicol and Souza (1993) which compared to the digestible dry matter intake of adult and young cattle grazed with sheep (Figure 4). The digestible dry matter intake of both young and adult cattle was greater under mixed grazing with sheep than with single grazing when pasture mass was high. However, any advantage to cattle from mixed grazing was rapidly lost as competition from sheep increased as pasture mass declined. The rate at which intake declined and the level of pasture mass (for adult and young cattle respectively) at which the intake of mixed-grazed cattle fell below that of the single-grazed groups, was greater for adult than for young cattle. The younger (smaller) cattle were apparently able to compete more effectively with sheep than the older cattle. The intake and liveweight gain of young cattle were also more resistant to an increase in stocking rate than that of older cattle when the two classes were grazed together (Zoby and Holmes, 1983).

In a longer term study, Hamilton (1975) measured an increase in liveweight gain of cattle mixed grazed with sheep in summer when pasture availability was high but reduced performance in winter when grazing pressure was higher.

GRAZING SYSTEM AND COMPETITION

Competition between grazing species is also likely to be influenced by choice of grazing system although this hypothesis has not been rigorously tested. A hypothetical ranking of grazing systems in terms of the opportunity provided for one species to capture common dietary resources is given in Table 4.

With leader-follower grazing, the species grazing first is given a greater opportunity to exploit its dietary preferences and benefit from the greater herbage availability. Competition is “enforced” by giving one species access to the herbage resource before the other. On the other hand, sequential-alternate grazing separates the species to the greatest extent in time and space, and is likely to minimise competition. The pasture resource is given time to re-establish between grazings by the two species and thus presents a more equal opportunity for both species.

Of the two forms of concurrent grazing, continuous grazing may be seen as more intense competition than rotational grazing in which a proportion of the resource is made available at regular intervals. Recently, Kitessa and Nicol (1995), have shown that, under concurrent rotational grazing conditions designed to promote similar sheep liveweight gain to that of continuously grazed sheep, the liveweight gain of co-grazed cattle was 30% higher (1.02 kg LWG/day) than under concurrent-continuous (0.7 kg LWG/day) mixed-grazing. The hypothesis is that the frequent renewal of the pasture resource under concurrent rotational grazing gave cattle a greater opportunity to compete with sheep under conditions of greater pasture availability than with continuous grazing.

There are practical situations where competition is a desirable outcome. This is the case when one grazing species or class of stock has a higher priority ranking in the farming system for the herbage available than the other and has been exploited in "leader-follower" systems. It is interesting that most of the examples, calves followed in-calf heifers (Leaver, 1974), lambs followed by non-lactating ewes (McCall and Sheath, 1993) and high producing dairy cows followed by their lower producing herd mates (Mayne et al., 1988) are all examples of within-species mixed grazing. There are fewer mixed species leader-follower data (Boswell and Cranshaw, 1977; Radcliffe and Francis, 1987; del Pozo et al., 1996) but in all leader-follower work the emphasis has been on increasing the productivity of the leaders rather than the system as an entity. There seems to be no experimental evidence for leader-follower mixed grazing of mobs of stock with similar production potential. For example, a mob of cattle with equal potential for growth could be split and grazed as leaders and followers with the aim of increasing the length of time over which cattle reached target slaughter weight or a lighter group as leaders to reduce the variability within the complete group.

In much of the mixed grazing literature, however, the (often unstated) objective appears to be to take advantage of complementarity with the minimum of competition. It is perhaps surprising then, that much of the mixed grazing work has been done under concurrent-continuous grazing (see Table 2) rather than one of the less competitive grazing systems.

There are also likely to be interactions between grazing system and other variables on the outcome of mixed grazing. For example, where grazing pressure (stocking rate) is low, there is likely to be less advantage of sequential-alternate over concurrent continuous grazing in reducing competition. Certainly, other factors, such as species ratio has less impact on the outcome of mixed grazing where stocking rate is low (Nolan and Connolly, 1987).

It has been argued in the previous two sections that grazing system has either been shown to affect, or might be suggested to affect the interaction between complementarity and competition and therefore influence the net outcome of mixed grazing. The choice of grazing system will therefore depend on the specific objectives of the resource manager. The next section gives an example of the rationale that can be used in selecting appropriate grazing systems in mixed livestock enterprises.

MIXED GRAZING IN LIVESTOCK SYSTEMS

The potential for complementarity between grazing species and their relative priority ranking for use of available resources (competition) changes seasonally in most livestock production systems. Therefore, the choice of grazing system on mixed livestock farms will also change over time. To illustrate this dynamic utilisation of mixed grazing, the example of an extensive (limited subdivision), hill country (varied aspect and limited area for conservation), sheep and beef (mixed livestock to diversify financial risk and integrate seasonal feed demand) farm can be used. It is assumed this property carries both a breeding ewe flock and a beef cow herd and finishes lambs and young cattle after weaning.

In early spring, following high winter grazing pressure and low pasture growth rate, pastures are short (1000 kg DM/ha) and relatively homogeneous (green grass leaf) giving little opportunity for complementarity but considerable scope for competition. Sheath et al. (1993) warn of the risk to cattle productivity of concurrent mixed grazing with sheep at this time of year. Sequential - rotational - alternate grazing is likely to be more appropriate.

By late spring - early summer, when pasture growth rate exceeds animal intake, pasture mass rises (2500 kg DM/ha), grazing pressure is lower and there is evidence for complementarity between sheep and cattle concurrently grazed over this period (McCall et al., 1986), presumably due to improved utilisation of herbage around cattle dung patches by sheep and emerging seed heads by cattle. As pasture growth rate further exceeds animal demand areas can be set aside from grazing and cattle, which maintain their feed intake at a higher level than sheep on declining pasture availability (Collins and Nicol, 1986), are subsequently used to "clean-up" these areas (McCall et al., 1988).

Following weaning in early summer, finishing lambs become the highest priority class of stock. They therefore should have access to the most clover-dominant, leafy pasture (e.g. sequential grazing after preferably, goats (Radcliffe and Francis, 1988, del Pozo et al., 1996), but more likely cattle at a low grazing pressure (leaders) with another class of stock with lower priority such as non-lactating ewes or cows plus calves as the followers.

By late autumn, early winter, pastures have become more heterogeneous, and contain green autumn grass and clover growth, accumulated dead material and seed heads which escaped grazing during the lower grazing pressures of late spring and summer and less preferred grass species in shady aspects. These pastures give considerable opportunity for selectivity but also competition because they will be intensively grazed (post-grazing pasture mass, 500-800 kg DM/ha) during this period to ration the available grazing over this period. Choice of mixed grazing system will again depend on priorities set by the farm manager. If the non-lactating, pregnant ewes are ranked ahead (lower condition score) of the non-lactating, pregnant cows, then ewes may precede cows in the winter rotation. Under this scenario, sheep select out the preferred green material and the sunny aspects, leaving the less preferred species and shady aspects for the cattle. Where the priorities are similar, concurrent-rotational grazing of the two stock classes is prescribed.

Most mixed livestock systems are likely to have their own most appropriate selection of mixed grazing systems and these need to be individually established. To devise these systems effectively, a good understanding of the outcome of mixed grazing systems is needed. Not all experimental data on mixed grazing can be readily interpreted to assist in designing systems.

INCREASED HERBAGE PRODUCTION UNDER MIXED GRAZING

Few good measurements have been made of the effect of mixed grazing on net herbage production. Those measurements which have been made on net herbage production or tiller dynamics are equivocal and show relatively small effects (Boswell and Cranshaw, 1977; Dickson et al., 1981; Hodgson et al., 1985; Nolan et al., 1988) other than where complementarity reduces the negative effect of ungrazed material on net herbage production. There is more evidence of an effect of mixed grazing on the botanical composition of the pasture. A potential for greater clover growth under goat grazing is suggested by the presence of a greater number of rooted white clover stolons (Townsend and Radcliffe, 1990) and a greater clover proportion in mixed cattle-sheep grazed swards (Nolan and Connolly, 1991). Similarly, the reduced content of weed species in goat grazed pastures referred to earlier illustrates mixed grazing effects on pasture composition.

Recent work (Williams and Haynes, 1995) suggests differences between species in the effectiveness of their dung to influence soil fertility and pasture production with that of deer being superior to cattle or sheep. However, it is unlikely that the main reason for using mixed grazing will be to enhance pasture production. An important feature of any effect of mixed grazing on pasture production and composition is the impact is on future grazings of the pasture and is the basis of using grazing species to "groom" pastures for future use by other classes of stock.

INTERPRETING THE RESULTS OF MIXED GRAZING EXPERIMENTS

There are a number of difficulties in interpreting the results of mixed grazing studies. For example:

(i) Species equivalence

Changes in effective grazing pressure, either through the mix utilising a higher proportion of the herbage resource, or from an inappropriate substitution rate of one species to another, can induce changes in animal production attributable more correctly to the change in grazing pressure than mixed grazing *per se*.

Connolly and Nolan (1976) warned of the difficulty and dangers in deciding on the "equivalence" of one species to another in determining substitution rates in mixed grazing experiments. They point out that "if there is an effect of mixed grazing on intake, there is no unique (or stable) livestock equivalent which can be used as a general index of interchangeability between animal species" (Nolan and Connolly, 1989). Their solution to avoid such "passive" effects was to make no preconceived calculation as to equivalence but to compare mixtures over a wide range of species ratios and stocking rates. Increased productivity due to mixed grazing can then be measured as the increase in stocking density which can be sustained at a level of production per animal equal to that of the species grazing alone. This approach requires large scale field experimentation (Nolan and Connolly, 1989) and the derivation of response models (Connolly, 1987).

An alternative approach developed to avoid pre-determining species equivalence is to equate grazing species in terms of a common effect on the herbage biomass. This involves equalising the rate of disappearance of pasture mass across species. Consequently the intake of the group of animals within a species is equivalent while allowing the specific response of individuals within the species to be expressed. Substitution rates or "equivalence" can be back-calculated or modelled and a mixed grazing effect identified as any change in the pasture conditions under mixed grazing compared with mono-grazing. Early results of such an approach, using "rate of disappearance of pasture mass" as the equilibrating pasture variable have been reported for cattle, sheep and goats grazed alone (Collins and Nicol, 1986).

In practice, greater utilisation of a pasture through mixed grazing, can maintain levels of individual animal production associated with a lower grazing pressure of the single-grazed species (Thompson and Power 1993), but seldom does the output per hectare from the mixture exceed that achieved by an equivalent higher grazing pressure of the more productive animal species under single grazing (Nolan and Connolly, 1989).

(ii) Intake and diet selection

Measuring effects of mixed grazing in terms of liveweight gain provides relatively little insight into the interaction between the grazing strategies of the animals involved. Using liveweight gain as an output measure, even where good measures of diet selection and pasture composition are gathered, usually commits the experimenter to relatively steady state conditions for a long period of time. This limits the information which can be gained on the dynamics of the interaction between the grazing behaviour of species as herbage conditions change. For example, none of the detailed studies on factors controlling intake rate (bite weight, bulk density etc.) have been done on mixed grazed swards. Because most of the work on mixed grazing has been made in relatively steady states (for example, continuous grazing, fixed stocking rate), the dynamics of the redistribution of resources between competing/complementary species cannot be readily investigated.

It is a better understanding of the dynamics of responses in diet selection and intake of the animals and composition of the swards under mixed grazing which will give the greatest advances in our appreciation of mixed grazing.

MODELLING MIXED GRAZING

The results of mixed grazing experiments and observations on diet preferences have been used to model optimal mixtures using linear programming techniques (Connolly, 1974; Bastian et al., 1991) and response relationships derived from large mixed grazing experiments have been used to determine relative resource total (RRT) (Nolan and Connolly, 1987) to assess the efficiency of mixed grazing.

More recently, the percentage contribution of various plant species to the herbage available and to the diets of the grazing animal species have been used to derive a plant value index (PVI) which can be used to predict the likelihood of complementarity or competition in specific mixed grazing environments (Wright and Connolly, 1995).

To date, however, there does not appear to have been any formal attempt to develop mechanistic models which simulate responses to mixed grazing as has been done for single species grazing on relatively simple swards (Parsons et al., 1994) or to introduce mixed grazing to more general models of livestock systems (Finalyson et al., 1995). Such models require good data on the interaction between species and classes of stock on diet selection and dry matter intake under changing herbage availability if they are to be useful in predicting the outcome of mixed grazing. It is this dynamic interaction of the grazing behaviour of the animals involved which determines the extent to which competition and/or complementarity will be the outcome of mixed grazing. It is very questionable whether sufficient data exist to allow the development of such models. Derivation of such data is one of the major developments needed in the advancement of our understanding of mixed grazing.

CONCLUSIONS

Mixed grazing is a complex interaction between the grazing behaviour of the grazing species and the herbage resource which can result in competition or complementarity in resource use. The result of competition is a quantitative (intake) and/or qualitative (diet composition) redistribution of the resource between the species. Complementarity, an increased utilisation of the resource depends on heterogeneity in the herbage available and little overlap in the dietary preferences of the species.

The grazing species, their ratio, the grazing pressure and the grazing management system can all affect the balance between competition and complementarity and thus outcome of mixed grazing. The choice of mixed grazing system must reflect the objectives of the resource manager, their herbage resource and their priorities for stock classes. These objectives will differ with season, environment and financial and social obligations.

Further development in our ability to predict the outcome of mixed grazing under a wide range of conditions depends on a better understanding of the dynamics of the interaction between animals and the pasture under mixed grazing.

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Table 1
The distribution of the New Zealand sheep, beef cattle and deer populations to various farm classes. (Source: NZ Agricultural Statistics, 1994.)

Farm Type		% Sheep	% Beef Cattle	% Deer
Sheep		33.6	3.6	1.6
Beef		1.1	23.0	0.4
Deer		0.8	0.8	56.4
Sheep	+ Beef	29.4	22.4	3.0
	+ Other	6.1	1.3	7.4
Beef	+ Sheep	10.9	22.4	1.2
	+ Other	0.3	3.8	2.2
Mixed Livestock		10.3	12.2	20.2
All other farm types		7.5	10.5	7.6
Total		**100**	**100**	**100**

Where: Single species farm type (eg sheep) indicate >75% of gross farm income from that species.
Two species farm type (eg sheep + beef) represent >50% from first species and >25% from second species.
Mixed livestock - no single livestock >50%.

Table 2
Experimental treatments used in a sample of mixed grazing studies (n = 21)

Treatment	Proportion of studies
Species organisation	
concurrent grazing	0.85
sequential grazing	0.24
Grazing management	
continuous grazing	0.52
rotational grazing	0.36
Stocking pressure	
high stock performance	0.33
moderate stock performance	0.71
low stock performance	0.19
Species combinations	
sheep and cattle	0.66
sheep and goats	0.24
cattle and goats	0.09
cattle and cattle	0.19

Note: Total sum is greater than 1.0 where some studies involved more than one comparison.

Table 3
Methods of applying mixed grazing

Method		Definition
Concurrent	- continuous	Simultaneously grazing by species for an extended period of time (weeks) on a sward maintaining reasonably constant morphology.
	- rotational	Simultaneous grazing by two or more species under rotational grazing where herbage biomass is depleted over a short period (days) and regenerates between grazing.
	- intermittent	Continuous grazing by one species with the introduction of another species sporadically.
Sequential	- continuous immediate	Immediate replacement of one grazing species for another on a continuously grazed pasture.
	deferred	Replacement of one species for another on a continuously grazed sward after a period to modify the sward (usually increase sward height)
	- rotational immediate	An immediate following of one species by another within a grazing rotation - the Leader/Follower method.
	alternate	Grazing species alternate in the rotational grazing sequence.

Table 4
Hypothetical ranking of mixed grazing methods on the opportunity provided under mixed grazing for dietary benefits to accrue to one species at the expense of another

Opportunity	Method
Greatest	Sequential - rotational - immediate (leader-follower)
	Concurrent - continuous
	Concurrent - intermittent
	Sequential - continuous - immediate
	Sequential - continuous - interval
	Concurrent - rotational
Least	Sequential - rotational - alternate

Figure 1
Schematic model of the interaction between diet and herbage heterogeneity and complementarity and competition between grazing species. (See text for explanation.)

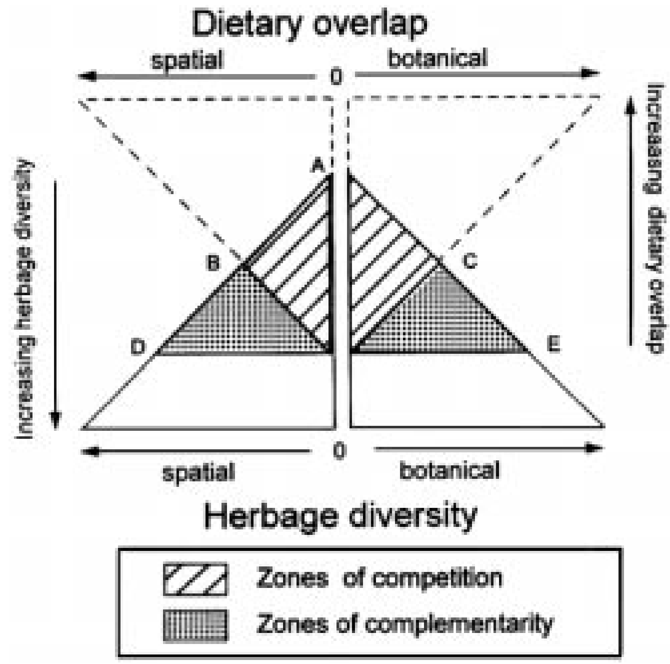

Figure 2
The proportionate contribution of 5 sward horizons to the diet of cattle, sheep and goats grazed alone or in mixtures (from Nicol and Collins, 1990). Hatched areas represent the contribution of sward horizons defined to the right of the figure. CA, SA and GA signify treatments of cattle, sheep and goats respectively grazing alone, CS that of cattle in the presence of sheep and SC, sheep in the presence of cattle.

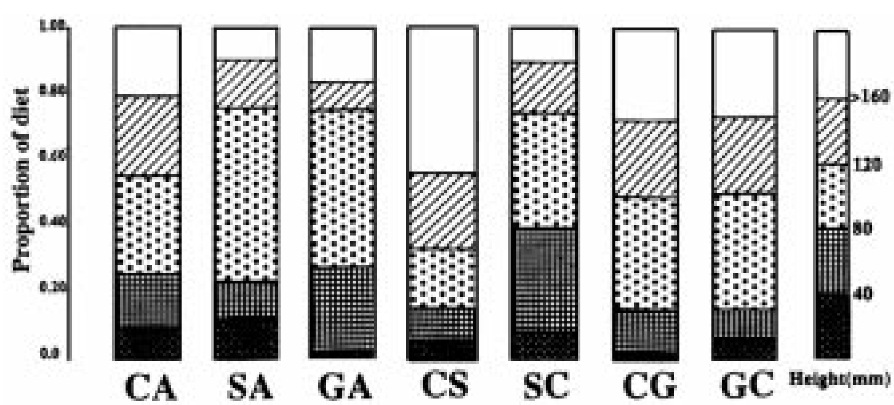

Figure 3
Predicted average daily gain (ADG) to lamb weaning of lambs and steers for low (—), medium (- - -) and high (¹¹¹¹) stocking rates (from Nolan and Connolly, 1989). Steer ADG is curvilinear.

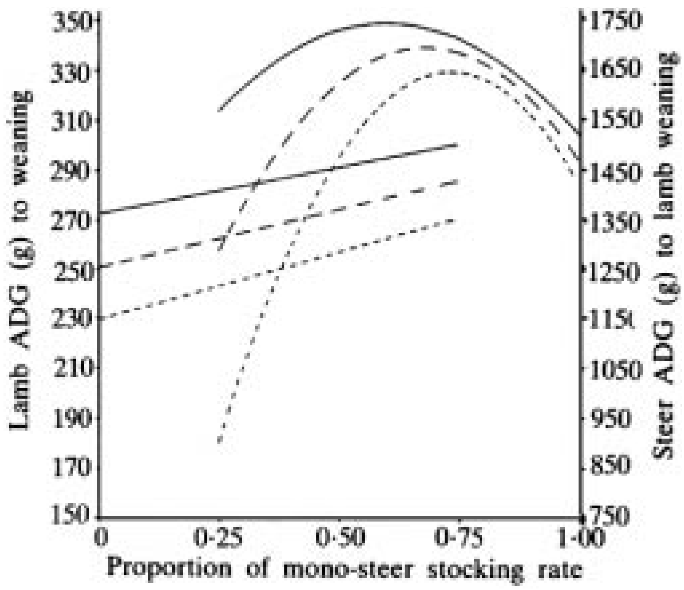

Figure 4
Digestible dry matter intake of cows and calves grazed alone or with sheep on a decreasing pasture mass (from Nicol and Souza, 1993). ACA and ACS represent adult cattle grazed alone and with sheep respectively. YCA and YCS represent the companion treatments with young cattle.