SOME ASPECTS OF GRAZING ECOSYSTEMS

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INTRODUCTION

The conversion of plant material to meat and milk by ruminants is one of the main ways in which the demand for energy and more especially protein for human consumption is met.

While research in soil, plant and animal sciences is all more or less relevant to this conversion process a considerable amount of the agricultural research effort in Australasia has been directed more specifically to the grazing situation.

Much of this work has been concerned with specific components of the grazing ecosystem such as the factors limiting pasture production (Brougham 1968), the definition of those plant factors contributing to nutritive value (Butler et al. 1968; Minson 1968), animal nutrition (Moir 1968) and pasture establishment (Swain 1968). While such research is basic to the understanding of the processes operating within a grazing system it must be complimented by a recognition of the interactions which exist within such grazing ecosystems and the way in which such interactions can affect interpretation of evidence from isolated parts of the grazing ecosystem. For example, the adoption of defoliation systems based on evidence from experiments of which grazing animals are not an integral part is often difficult to reconcile with the reality of having to graze a more or less fixed number of animals on a fixed area of land over a long period of time (Campbell 1969).

In an effort to take account of the interactions which may invalidate conclusions based on evidence from component parts of the grazing ecosystem, the "whole-farm" approach to experimentation has been evolved. However in many cases such experiments have been designed to study the importance of different management factors on animal production from a given area of land (McMeekan 1961; Willoughby 1968) rather than to study the inter-relationships occurring between the soil, plant and animal components of the ecosystem. For example there is little information available on these inter-relationships from over 150 experiments of this kind carried out in Australia, evaluation of treatments having been carried out almost entirely in terms of animal production (Allden 1968).

The grazing ecosystem comprises soil, plant, animal and climatic components. These components will have varying levels of interdependence at any one time depending on the pattern and level of input of each component up to that time. For example the way in which the grazing animal defoliates, excretes and treads will, both by its indirect and direct effects on the plant community, affect future pasture productivity. This will have reciprocal effects on animal production and soil characteristics which in turn will affect pasture productivity and so on. However since plant productivity will also depend on climatic inputs the extent to which it is effected by the animal and soil components of the ecosystem will vary. Thus in a four month growing season with annual species, the grazing animal may affect future pasture productivity during the growing season but during the senescent eight month period the animal's effect is limited to its effect on the seed supply (Arnold 1968). On the other hand the effects of the soil and animal components on pasture productivity may be expected to operate more continuously in an environment where climate only has slight effects on seasonality of pasture production. In a similar way pasture production at a particular time, and hence feed supply at that time, may have disproportionate effects on animal performance over an entire productive cycle.

In addition the level of interdependence will vary with the extent to which each component of the ecosystem has the capacity to buffer itself against the effects of other components. For example the grazing animal may counteract the effects of fluctuating feed supplies in several ways including recycling of nitrogen, sodium and phosphorus, alteration of grazing behaviour, compensatory growth and mobilisation of body reserves. In the same way changes in the botanical composition, morphology and growth rate of the plant community buffer the effects of other ecosystem components. However such mechanisms will become of limited importance as grazing pressures increase with the result that interactions between components of the ecosystem increase with increasing grazing pressure (Morley 1966; Arnold 1968).

Thus the grazing ecosystem involves many components each affected by several more or less continuous but variable inputs as well as by its variable interactions with the other components of the ecosystem. It is not surprising that such dynamic systems have been subject to so little research given their complex nature, the lack of suitable measuring techniques, the costs involved and their lack of "publication value" (Willoughby 1968).

The work presented in this thesis was designed to introduce the author to some of the techniques available for, and problems in, studying grazing ecosystems. It was also designed to provide information on some of the basic parameters of the grazing situation in one particular environment.

CHAPTER I

REVIEW OF LITERATURE

The aim of this review is to provide a basis from which the results of the present experiment can be discussed. Section A deals with the effects of the grazing animal on pasture production with special reference to increasing stocking rates.

Section B considers the behavioural response of grazing animals to different pasture conditions while Section C covers the changes in animal productivity which occur as stocking rates increase.

In Section D body growth and wool growth of sheep are considered and in Section E the use of oesophageal fistulated sheep and methods of measuring herbage intake are discussed.

SECTION A

The grazing animal exerts its influence on plant communities by the actions of defoliation, excretion and treading. Apart from their direct effects, these activities may also influence the plant community by modifying its micro-environment.

Grazing may affect the botanical composition (Jones 1933), the rates of tiller and leaf production (Brougham 1959) and the rates of senescence and decay (Hunt and Brougham 1967) of a pasture as well as the extent to which regeneration and reproduction of pasture species takes place (Rossiter 1966). All these effects may contribute to the seasonality and level of production of a pasture.

This section attempts to summarize current knowledge of the separate effects of defoliation, excretion and treading on pasture productivity. The implications of these effects are then considered in relation to increasing stocking rates.

(a) Defoliation

The major variables in defoliation which affect the productivity of a particular pasture are the intensity, frequency, timing and pattern of defoliation. Before discussing these it is perhaps useful to make a distinction between short and long term responses to defoliation.

When a pasture is defoliated the immediate or short term response is mainly a function of rate of regrowth. Long term responses reflect the accumulated effects on botanical composition and plant viability.

The effect of defoliation on pasture production has been investigated in numerous experiments giving rise to many conflicting results.

Both increases (Ridgman 1960; Appadurai and Holmes 1964) and decreases (Jacques and Edmond 1952; Langer and Steinke 1965; Auda *et al*. 1966) in yield have been noted with increasing intensity of defoliation while in some cases yield may be unaffected by intensity of defoliation (Bryan and Sharpe 1965; Bernardon *et al*. 1967).

Similarly increasing the frequency of defoliation may result in a decrease (Woodman and Norman 1932; Burger *et al*. 1958), an increase (Burton *et al*. 1963; Clapp *et al*. 1965) or little change (Brougham 1959; Holt and McDaniel 1963) in pasture yield.

Interpretation of experimental results may be complicated by specific and varietal differences in morphology. For example, defoliation to a constant height will remove a greater percentage of the above ground parts of erect than prostrate varieties (Jones 1959) possibly causing a difference in response. Since intensive grazing may induce normally erect varieties to assume prostrate habits of growth (Kydd 1966a) similar effects may occur on a within variety basis.

Moreover the possibility of specific and varietal differences in physiological response to defoliation must not be excluded.

However part of the explanation for these contradictory results lies in the interaction between severity and frequency of defoliation. The regrowth curve of defoliated pasture is broadly sigmoid in shape having consecutive phases of increasing, constant maximum and decreasing growth rates (Brougham 1955; 1956b). Sward productivity, in a particular environment, will therefore be a function of the maximum growth rate, how soon it is reached and for how long it is maintained (Evans _et_ _al_. 1964). Since the intensity of defoliation may influence how soon the phase of maximum growth rate is reached (Brougham 1956a) and the frequency of defoliation may influence whether this growth phase is reached and for how long it is maintained, it follows that variable interactions may occur between the intensity and frequency of defoliation.

For instance, Brougham (1959) has shown that severe but infrequent defoliation of a short-rotation ryegrass/clover sward resulted in higher yields than were obtained with more frequent defoliations irrespective of their severity. However where defoliation was not severe, yields were not affected by frequency of defoliation. Where rates and periods of regrowth differ interactions between intensity and frequency of defoliation may give different results as shown by the work of MacLusky and Morris (1964). The suggestion that effective leaf area duration may be a main determinant of pasture yield (Campbell 1967) warrants further investigation.

Rates of regrowth will depend on environmental conditions as well as on the physiological and morphological properties of the pasture species. Studies of the physiological factors involved have been confined largely to considerations of reserve substances and residual leaf area although the role of root activity has received more attention recently.

Considerable importance was given to the role of reserves, especially "available" carbohydrate reserves, in promoting regrowth (Weinmann 1961) but little critical experimentation occurred until May (1960) emphasised the indirect nature of most of the evidence available up to that time.

Direct evidence obtained by the use of carbon balance (Davidson and Milthorpe 1966b) and autoradiographic (Marshall and Sagar 1965) techniques has indicated that reserve substances may contribute, in varying degrees, to regrowth over the first few days after defoliation even if only as respiratory substrates (Alberda 1966; Davidson and Milthorpe 1966a; b; Mitchell and Denne 1967). The importance or otherwise of such a transitory effect is still not clear. If, as Davidson and Milthorpe (1966a) suggest, the main factor controlling regrowth is the rapid development of a photosynthetic surface then reserve substances may be important even though their absolute contribution to plant growth is small.

The concept of leaf area index (LAI) and its association with growth rate (Watson 1947) has been extended to the pasture situation in an attempt to explain the control of rate of regrowth (Brougham 1956a; Donald and Black 1958; Black 1963). Although the concept has been oversimplified (Brown and Blaser 1968) rate of regrowth may be largely controlled by residual leaf area following defoliation (Brougham 1956a; Davidson and Donald 1958). However there may be no association with residual leaf area (Anslow 1965), presumably when light is not a major limiting factor for growth.

By comparison with these two facets of regrowth, the extent to which root activity limits regrowth appears to have been overlooked. Root growth is normally affected to a greater degree than shoot growth (Mitchell 1954) the effect being proportional to the frequency and severity of defoliation (Troughton 1957).

The growth of roots into fresh portions of soil may be slowed (Mitchell and Denne 1967) and in some cases the absorptive zone may even be reduced (Oswalt _et al_. 1959). This can be expected to result in reduced mineral uptake (Mitchell and Denne 1967) and will be accentuated by any reduction in the absorptive capacity of the roots themselves as has been shown to occur for water (Jantii and Kramer 1956) and phosphorus (Davidson and Milthorpe 1966b).

It is to be expected that rate of regrowth will depend at least to some extent on the interaction between the above factors.

Although scarce, what evidence there is (Ward and Blaser 1961; Davidson and Milthorpe 1966a; Humphreys and Robinson 1966) suggests that in regrowth residual leaf area and reserve substances interact to a variable extent depending on their levels immediately after defoliation.

However once the development of a new photosynthetic surface has begun, the rate of regrowth may be limited by the level of root activity despite the fact that nutrients and water may be readily available (Davidson and Milthorpe 1966b).

Rate of regrowth may be affected by factors other than those already discussed.

Thus removal of expanding or meristematic regions of a pasture plant may be important. For instance, if the apical meristem is removed prior to flowering the rapid growth rate of the reproductive tiller is unlikely to be compensated for by the growth rate of the new vegetative tillers formed at the base of the destroyed tiller (Jones 1959). Any such effect will be variable (Jones 1959) since the number of elevated growing points will vary throughout the year both between and within grass varieties (Brougham 1966).

While the intensity of defoliation interacts with frequency of defoliation to influence pasture regrowth in the short term it may also influence long term productivity by its effect on the pasture micro-environment and hence on botanical composition.

Intense defoliation will generally improve the light environment at the bottom of the sward and may therefore encourage clover growth in grass-clover swards (Jones 1933; Donald 1956; Brougham 1959). Such an environment may be expected to enhance tillering (Evans et al. 1964) but the death of tillers following frequent, intense defoliation (Brougham 1959) means that the net effect is variable (Langer 1963).

Close defoliation may also reduce the buffering effect of vegetation. This may lead to increased drying out of the soil near the surface and to a rise in its temperature (Mitchell 1957). Both these factors may restrict pasture growth (Brougham 1959) as may the unavailability of nitrogen induced by such conditions (Mitchell 1957). Run-off and liability to erosion may also be increased (Costin 1964).

While the extent of these effects will depend on the climatic and edaphic environments, it is clear that they may affect the competitive relationships between components of a pasture thereby influencing botanical composition.

The importance of the frequency of defoliation was implied when its interaction with intensity was considered. Thus too frequent defoliation may prevent the maximum rate of regrowth being achieved or it may shorten the potential duration of this phase. Also if defoliation is too frequent, recovery of reserves and roots may not occur and if these are important to subsequent regrowth a loss in productivity may occur subsequently.

However if the period between defoliations is too long losses due to death and decay may be considerable (Hunt 1968), although the reconciliation between the avoidance of such losses and maximum productivity is far from clear (Campbell 1964). L.A. Hunt (1965) has suggested that many of the contradictory results obtained in the defoliation experiments noted at the beginning of this section may be due to the changing relationship which occurs between the rates of dry matter decay and accumulation under different climatic conditions.

Infrequent defoliation may also lead to shading in the lower part of the sward. This will result in the exposure of the photosynthetically inefficient components of the sward on defoliation (Brown and Blaser 1968) quite apart from the possible effects on tiller density (Mitchell and Coles 1955; Langer 1963). If this latter effect occurs in the autumn the peak of spring growth may be lowered because the number of fertile tillers is lowered (Ivins and Drake 1964).

Similarly a policy of infrequent defoliation may preclude changes in the botanical composition of pasture necessary for sustained production in a subsequent period (Brougham 1960).

The timing of defoliation with regard to elevated growing points has already been mentioned, but its implications in terms of botanical composition and hence future pasture productivity need emphasising.

Under veldt conditions Booysen _et al_. (1963) indicated that the effects of defoliation on the elimination or survival of a particular species would be largely dependent on the timing of defoliation relative to the accessibility of growing points and seed production.

The effects of timing of defoliation on botanical composition were clearly demonstrated by M. Jones in 1933 and the importance of the timing of defoliation in the development of productive hill pastures in Wales has been shown (Jones 1967).

This and related work has recently been reviewed by Charles (1968) who stresses the susceptibility of plants to hard and continuous defoliation during the early stages of growth. Thus where differences in the seasonal growth pattern of pasture components exist and intense grazing occurs during the early growth of particular components, changes in botanical composition are likely to occur.

An interesting example of a case where botanical composition may not be affected to any great extent is that of _Phalaris tuberosa_ - subterranean clover - annual grass pastures. Willoughby (1959) was unable to show any large effect of timing or intensity of defoliation on the botanical composition of such a pasture. This appears to be largely associated with the similar pattern of growth of the components of such pastures as well as the ineffectiveness of selective grazing where growth rates of all components are far in excess of consumption. However such stability may not occur at high stocking rates (Arnold _et al_. 1964a; Morley _et al_. 1969).

The pattern of defoliation of the grazing animal may well affect the response of pasture to defoliation and is therefore not only important in its own right but also in the interpretation, to the grazing situation, of defoliation experiments in which mowing has been used.

Where selective grazing occurs in a pasture, the competitive ability of the selected plant may be reduced in comparison to that of non-selected plants (Norman 1960). This may lead to suppression and even elimination of the selected species from a pasture (Wilson et al. 1969) while differences in selectivity between cattle and sheep may also give rise to differences in botanical composition (Norman 1957). Further discussion of the significance of this effect is more conveniently left until later.

Grazing systems themselves may lead to changes in botanical composition. For instance, changes in the genotypic structure of ryegrass populations may result from different grazing systems (Brougham et al. 1960; Brougham and Harris 1967) while botanical composition may differ between continuous and rotationally grazed situations (Jones 1967). Work at Canberra (Morley et al. 1969) has shown that intensity of rotation may affect botanical composition to the extent that any theoretical advantage in terms of animal production is offset by changes in botanical composition. On the other hand, intensity of rotation may have little effect on botanical composition (Campbell 1969).

The above examples indicate the caution necessary in extrapolation from the mowing to the grazing situation. While the absence of excretal returns may be an important factor in misinterpretation and the possible effects of treading cannot be excluded, the pattern of defoliation is likely to be most important.

In this respect mowing and grazing will differ to the extent that grazing management allows defoliation to be incomplete and non-instantaneous.

The integrated nature of the grass plant (Sagar and Marshall 1966; Marshall and Sagar 1968) and the different photosynthetic and export capacities of the different leaves of a tiller (Milthorpe and Davidson 1965) indicate likely different physiological reactions to mowing and grazing. Recent work (Smith 1968) tends to confirm this reasoning. The position is further complicated by the interactions which may occur between grass varieties and methods of defoliation (Jones 1959).

One of the best examples of the difficulties of interpretation of mowing experiments is provided by defoliation of lucerne. Here the very marked preference by sheep for leaf (Arnold 1960a) and new shoots (Peart 1968) emphasises that the period of grazing rather than the period between grazings is the critical factor in lucerne survival. Such a situation would occur wherever selection for young growing tissue was so marked that regeneration of the plant was seriously affected. Because such a distinction is impossible in mowing trials, its importance cannot be evaluated.

It should be clear from this discussion that useful prediction of the consequences of a particular defoliation system in any one environment is difficult. However maintenance of sward productivity will depend on the maintenance of viable plants and especially viable root systems (Davidson 1968). This may be achieved either by management or by selection, normally natural, towards pasture plants capable of resisting frequent defoliation.

(b) Excretion

The significance of the grazing animal in the nutrition of pastures has been the subject of some research effort since the investigations of Sears and his co-workers in New Zealand (Sears and Goodall 1948; Sears and Thurston 1952). As a result of this, it is now clear that the grazing animal may play a variable role in nutrient cycling in the grazing ecosystem. This occurs for several reasons.

The quantity of nutrients returned to a pasture as excreta will depend on the type and physiological state of the stock grazing that pasture (Sears 1950; Davies et al. 1962) as well as on the amount of pasture ingested and its nutrient content (Barrow and Lambourne 1962).

The availability of returned nutrients for plant growth will depend on the form in which they are excreted. Thus the plant nutrients in urine - a high percentage of the excreted potassium and sodium (Davies et al. 1962) plus variable percentages of nitrogen and sulphur (Barrow and Lambourne 1962) - are readily available (Barrow 1967) as is the inorganic phosphorus in the faeces when mixed with soil (Bromfield 1961). Faecal nitrogen is of low availability requiring prolonged mineralisation before it can be utilised (Sears and Newbold 1942; Walker et al. 1954), but little is known of the availability of the other nutrients excreted in the faeces (Barrow 1967). These differences in availability may mean that for some nutrients pasture responses occur early in the growing season and for others later in the season, thereby causing differences in the effects of grazing on pasture requirements. This question has been discussed in detail by Barrow (1967).

Loss of nutrients from the ecosystem may be caused by volatilisation and/or leaching. For instance, up to about 80% of urine nitrogen (Watson and Lapins 1969) and faecal nitrogen (Gillard 1967) may be lost by volatilisation, depending on environmental conditions. Losses through leaching will depend on factors such as the reaction of the particular soil type with the ion in question, rainfall and water holding capacity of the soil (Barrow 1967).

The importance of the "bottlenecks" in energy flow of the ecosystem caused by slow decomposition of organic matter has been noted by Macfadyen (1961) and may become a factor nullifying nutrient circulation via the animal where faecal pads decompose slowly (Gillard 1967). The invertebrate fauna may constitute an important part of the ecosystem in such cases (Bornemissza 1960; Stockdill and Cossens 1966; Gillard 1967).

The deposition of returned nutrients at high concentrations (Doak 1952; Davies et al. 1962) and in a non-random fashion (Sears 1950; Hilder 1966) has important implications for the effectiveness of nutrient cycling via the grazing animal.

For example, the high concentrations of returned nutrients may encourage losses from the ecosystem (Barrow 1967) and implies that only a proportion of the pasture being grazed will receive either dung or urine (Foot 1963). Non-random distribution of excreta gives rise to fertility transfer and may reach the extreme situation reported in Australia (Hilder 1966) where rapid depletion of nutrients from most of a grazed area occurs. Fertility transfer will be largely a function of animal behaviour as influenced by type and breed of stock, topography, weather, flock size, vegetation, paddock size, management etc..

Investigations carried out in New Zealand (Sears and Goodall 1948; Sears and Thurston 1952) and Britain (Watkin 1954; Wheeler 1958; Herriott and Wells 1963) using temperate grass/clover swards have indicated further factors affecting the efficiency of nutrient circulation through the animal.

For example, the response to excretal returns may be essentially a response to nitrogen (Watkin 1954; Wheeler 1958) in which case the resultant dry matter yield will reflect the extent to which symbiotic fixation of nitrogen is reduced and the extent to which excretal and more especially urine nitrogen compensates for this reduced fixation (Watkin 1954; Brockman and Wolton 1963). Since many variables (Walker 1956a; Shaw et al. 1966) can affect the degree of clover suppression and hence symbiotic fixation in a mixed sward it is clear that where nitrogen is the main limiting factor to pasture growth, the effects of excreta will be variable in terms of dry matter production.

In other cases other nutrients, for example phosphorus (Sears 1953), may be the main limiting factors to growth in which case responses to excreta may be different to those noted above. It is important to note that response to excreta will be a function of the species present in the pasture (Watkin 1957;

Davidson 1964).

This discussion has indicated that nutrient returns act through their effect on one of the many factors limiting growth. If factors other than nutrients are limiting pasture growth then return of excreta may have little immediate effect although some residual effects may occur. Where nutrients are a major factor limiting growth then return of excreta may enhance production (Sears and Goodall 1948) or merely result in a change in botanical composition (Sears and Thurston 1952; Watkin 1954) depending on factors such as the amount and form of nutrients excreted, percentage recovery of these nutrients, botanical composition of pasture, soil type and fertility transfer.

A further aspect of this question is the way in which soil fertility changes under grazed pasture. This feature and its implications have been discussed for New Zealand (Walker 1956b; Sears 1960) and Australian conditions (Moore and Biddiscombe 1964).

(c) Treading

Investigations into the effects of treading on pasture production have been largely confined to New Zealand conditions.

From a recent review (Edmond 1966) it is clear that the influence of treading on pasture regrowth is likely to depend both on the direct effects on plants and soils as well as on the interaction between them.

Edmond (1966) considers that loss of production is likely to occur in all grazed pastures although its extent will depend on the amount of treading (Edmond 1958), moisture content (Edmond 1962; 1963), soil type and fertility level (Edmond 1966). Apart from the physical effects, the most common effects on pasture appear to be a modification of plant competition (Edmond 1964) and a decrease in tiller and clover node numbers (Edmond 1963).

Interpretation of these results requires caution. The technique used neglects the protective effect of herbage cover noted in other experiments (O'Connor 1956; Brown 1968) and it also appears to accentuate the treading action of sheep (Edmond 1958). Further, the extent to which pastures may adapt to treading so that its detrimental effects are lessened is not known. Finally, by isolating the effect of treading, any interaction - beneficial or detrimental - with defoliation and return of excreta is not measured. As Edmond (1962) points out the technique is likely to maximize treading effects.

Consequently it is not surprising that where conditions and techniques vary inconsistent results are obtained (Scott 1963; Campbell 1966a; Edmond 1966). It is pertinent to note that in a field scale trial treading over the winter period has had no detrimental effect on animal production (McQueen 1965; pers. comm.) although interpretation of this result requires caution (Edmond 1965; Campbell 1966a).

(d) Stocking rate

It should be clear that this evaluation of the separate effects of defoliation, treading and excretion represent a considerable oversimplification of the influence of the grazing animal on plant communities. In some cases one particular factor may be of overriding importance while in others either positive or negative interactions may occur.

Further discussion of the effect of grazing on plant communities will be confined to the possible effects of increasing stocking rates on sown pastures in Australia, New Zealand and Britain.

When stocking rate is increased not only will the direct effects of, and interactions between, defoliation, treading and excretion be modified but the percentage utilisation of feed produced will also be increased. Further as this percentage increases and the periods of feed shortage increase, practices such as supplementary feeding, conservation and grazing management become more critical in their contribution to the outcome of a particular stocking rate.

Thus it is to be expected that the effects of stocking rate on pasture productivity are complex.

The way in which defoliation of a pasture changes as stocking rates increase is only partially understood. Limited information (Hodgson 1966; Hodgson and Ollerenshaw 1969; McIvor pers. comm.) suggests that in pure grass swards the frequency of tiller defoliation increase with increasing stocking rates while any increase in intensity of defoliation may be offset by modification of the growth form of pasture components (Kydd 1966a) or by an increase in those pasture components capable of resisting grazing (Moore 1966). This adaptation of a pasture to high stocking rates has recently been demonstrated at Hurley (Kydd 1966b) where sheep at a high stocking rate did not, or were unable to, harvest as high a percentage of the available feed as sheep on a low stocking rate despite the fact that less feed was available at the high stocking rate.

Any such effects on the intensity and frequency of defoliation will be modified by the way in which the selective grazing pattern of the animal is altered. For instance, if the selective grazing pattern of lower stocking rates is maintained then at least the frequency of defoliation of the grazed parts of the pasture may be increased. However selectivity is normally reduced as stocking rates increase (Willoughby 1959; Suckling 1964a; Arnold et al. 1964a), so it is conceivable that, as stocking rates move from low to intermediate levels, intensity and/or frequency of defoliation are not necessarily increased. However it seems reasonable to assume that when stocking rates are increased to very high levels, at least the frequency if not the intensity of defoliation will be increased. This is supported by indirect evidence from the changes which occur in pasture availability as stocking rates rise.

As levels of stocking increase, pasture availability tends to drop (Arnold et al. 1964a; Anon. 1967; Bublath 1969) although the form of the relationship appears to have been defined in only one study. Campbell (1966b) has shown that a point is reached where a sharp drop in availability occurs with only a small increase in stocking rate, leading to abrupt changes in grazing pressure. Differences in the way in which a pasture is defoliated may be expected where such changes take place.

The competitive effects in a sward may be modified by such a changing pattern of defoliation. For instance, the time during which competitive forces act between defoliations may be reduced while plants may modify their growth forms, in response to the pattern of defoliation, so as to become more resistant to grazing (Kydd 1966a).

The reduction in selectivity may alter the subsequent productivity of pasture in both beneficial (Suckling 1964a) and detrimental ways. Such detrimental changes may occur where carry over of feed (Wilson et al. 1969) or seeds (Rossiter 1966) is reduced thereby lowering future productivity.

If selective grazing persists to any great extent as stocking rates increase, then the chances of overgrazing leading to loss of pasture stability and consequent loss of productivity are increased (Morley 1966a).

The effect of stocking rate on nutrient cycling may be variable. For instance if stocking rate is increased in a situation where fertility transfer occurs, then it might be expected to accentuate the loss of fertility, although the data presented by Hilder (1966) are inconclusive on this point. If, on the other hand, no fertility transfer is occurring increases in stocking rate may be beneficial in terms of an increase in pasture production through an increase in the quantity of nutrients returned (McLachlan and Norman 1966) and/or wider distribution of the excreta produced (Petersen et al. 1956).

Any effects of treading will be increased by stocking rate increases both because there are more hooves per unit area (Edmond 1966) and because animals tend to forage for longer periods at high stocking rates (c.f. Section B).

The effect of increasing stocking rates on pastures will depend on the interaction between the above factors. For instance, the effects of high stocking rates on the physiology of pasture plants may limit their response to any increased circulation of nutrients occurring under such conditions (McLachlan 1968). Another example is the positive interaction which may occur between the separate components of grazing to give rise to high producing grass/clover swards in the North Island of New Zealand (Sears 1956).

In a recent review Moore (1966) concluded that in the more mesophytic temperate regions grazing animals improve the quality and quantity of their feed supply. One of the main interests of stocking rate experiments is the extent to which this process can be maintained, as grazing pressure increases. Unfortunately few stocking rate experiments have had more than a cursory interest in pasture production despite the fact that the deficiencies of such an approach have been stressed (Campbell 1961).

At this point it is appropriate to mention some of the basic requirements of stocking rate experiments. The planning of such experiments has recently been reviewed (Morley and Spedding 1968) but the importance of long term rather than short term trials needs stressing. For instance, long and short periods of heavy grazing may have very different effects on pasture growth (Arnold 1964d) while grazing animals may show different responses when subjected to the same stocking rate for different periods of time (Willoughby 1959). It should also be noted that interpretation of unreplicated trials is limited (Arnold et al. 1964a), although even in replicated trials variations in site productivity may limit extrapolation of results (Morley 1966b).

Where components of pasture productivity have been studied under different stocking rates, results have been variable. Changes in botanical composition have been determined in some experiments and those occurring in annual pastures in Southern Australia have been reviewed by Rossiter (1966).

With increasing stocking rates there is a general decrease in the proportion of annual grasses and an increase in plants such as capeweed (Cryptostemma calendulacea R.Br.) and geranium (Erodium spp.) while subterranean clover (Trifolium subterraneum L.) remains largely unaffected. Of the annual grasses, silvergrass (Vulpia myuros L.) is least affected and may even increase. This results in pastures dominated by herbaceous plants in contrast to grossly understocked pastures which are normally dominated by ripgut brome (Bromus rigidus Roth.) and lack clover.

In an experiment at Werribee, Victoria (Sharkey et al. 1964) it was noted that at a high stocking rate Wimmera ryegrass (Lolium rigidum Gaud.) and subterranean clover (Trifolium subterraneum L.) largely disappeared from a pasture in which those two components had been predominant being replaced mainly by stonecrop (Crassula spp.), silvergrass (Vulpia spp.), loosestrife (Lythrum spp.) and annual poa (Poa annua L.). This disappearance was attributed to several factors including a decrease in seed production, increases in seed consumption, consumption of seedlings and limitation of leaf area of established plants. This was in contrast to the low stocking rate where the ryegrass became dominant, probably due to its competitive advantage for incident light. At the intermediate stocking rate changes in botanical composition occurred but were not progressive.

On the other hand Arnold et al. (1964a) found that as stocking rate increased the percentage of clover in a Phalaris tuberosa - subterranean clover - annual grass pasture increased until it became dominant at the highest rate of stocking. Although the same grass species remained at all stocking rates, annual grasses tended to increase at the expense of Phalaris especially at the highest stocking rate (McManus 1966). At very high stocking rates such differences may not occur (Morley et al. 1969).

In terms of increasing the content of subterranean clover and decreasing the content of grasses, this result has been repeated in stocking rate trials in Victoria (Anon. 1967).

One of the most interesting features of these experiments is the difference in response of subterranean clover to high stocking rates. Such factors as soil nitrogen supply, seed supplies and the degree to which non-legumes can adapt to high grazing pressures may contribute to this variation (Rossiter 1966).

At Hurley (Kydd 1966a) changes in the botanical composition of a perennial ryegrass (Lolium perenne L.)/white clover (Trifolium repens L.) sward stocked at two different rates were followed over a five year period. Nitrogen was applied at the rates of 182 and 142 kg/ha/year to the high and low stocking treatments respectively. Ground cover assessed in spring increased during the experimental period from about 40% to 80% and 70% on the high and low treatments respectively. The clover disappeared after two years while Poa spp. increased throughout to contribute about 57% and 43% of the ground cover in high and low stocked areas. As each season progressed the ground cover of perennial ryegrass increased while that of Poa spp. decreased.

An experiment on hill country in New Zealand (Suckling 1964b) compared four stocking rates - 3, 4, 5 and 6½ ewes per acre - with and without cattle. The cattle were used as required to remove rank growth. At the start of the trial the pasture over the area appears to have been ryegrass dominant and had a clover dry matter content of about 6%.

Where sheep were grazed without cattle, accumulation of rank growth occurred except at the highest stocking rate but even here coarse weeds tended to increase. Where cattle were used accumulation of rank growth was reduced although rushes tended to increase with stocking rate because cattle could not be grazed on the areas for long enough to reduce their incidence.

Changes in botanical composition with different stocking rates were largely a function of pasture utilisation. Where utilisation was poor, the clover and ryegrass content of the pasture decreased while the content of other grass species such as Chewing's fescue (Festuca rubra L.) and browntop (Agrostis tenuis Sibth.) increased. On the other hand clover and ryegrass content increased with increasing utilisation although clover content was slightly depressed at the highest stocking rate.

There appears to be little data on the growth of pastures under different stocking rates. This may well reflect the difficulties of making such measurements under the continuous grazing conditions which are frequently used in stocking rate experiments.

Using the Australian "difference" method (Lynch 1960), Bublath (1969) showed in a short term trial that, in spring, growth of a particular pasture type was generally higher at a low stocking rate than at a high stocking rate. During winter differences within pasture types were negligible.

Under rotational grazing, Campbell (1969) noted that high stocking rates tended to depress pasture production although the differences did not reach significance in some seasons, notably the autumn. In another experiment the same worker (Campbell 1966c) found that net pasture production was increased by about 600 lbs. D.M./acre/annum at a low compared to a high stocking rate. However this difference was not significant while year x treatment interactions complicated interpretation.

Further evidence of the reduction in pasture growth at high stocking levels comes from studies in which growth rates of pastures, previously stocked at different rates, have been measured over short periods in the absence of stock (Arnold 1964d; McLachlan 1968) although this may not always occur (Spedding et al. 1967).

There is also the possibility that increasing stocking rate from very low levels will result in increased pasture growth. This may occur when the increased stocking rate results in a sward containing less dead and senescent material and being, as a result, more efficient in terms of photosynthesis (Campbell 1964).

The changing distribution of pasture growth throughout the year is an important characteristic of pasture but here again evidence of changes in this characteristic appears to be limited. In an experiment with dairy cows at Ruakura Campbell (1966c) found that within management systems, heavy stocking generally reduced the proportion of annual net production obtained in summer. The significance of such changes will depend on the extent to which they affect synchronisation of herbage production and animal nutrient requirements.

Up to this point pasture production has been considered almost exclusively in terms of dry matter. This represents a considerable over-simplification in terms of nutritive value and hence animal production.

The nutritive value of pasture has been reviewed recently by several workers (Raymond 1963; McDonald 1968; Corbett 1969) so only a few relevant points will be considered here.

Nutritive value has been defined both in biological (Minson 1968) and chemical terms (Tribe et al. 1963) but it is important to recognise the relative nature of the term. For instance, it is conceivable that two different feeds may have similar values for maintenance but dissimilar values for fattening. As well as this, interactions between type of stock and nutritive value may occur as in the case where plant oestrogens may be harmful to breeding stock but beneficial to fattening stock (Johns 1963).

For present purposes it should be noted that nutritive value is not only a function of the proportion of feed made available to the animal by digestion and the suitability of the digested nutrients for the various metabolic processes but also of the extent to which such a feed can be ingested.

Considerable research effort over recent years has aimed at a clearer understanding of those inherent plant properties important in nutritive value but has progressed little beyond establishing animal production differences between different pasture plants.

There is now considerable evidence to indicate the superiority of legumes relative to grass in supporting high growth rates in grazing animals (Jones 1932; Christian and Shaw 1952; Fernando 1961; McLean et al. 1962; 1965; Hight and Sinclair 1965; 1967; Gallagher et al. 1966; Wilson 1966; Butler et al. 1968; Ulyatt 1969) while differences in animal performance have also been noted between ryegrass varieties (Wilson 1967; Alder 1968; Butler et al. 1968), between grass species (Castle et al. 1962; Milford and Minson 1966; Greenhalgh 1966; Gallagher et al. 1966; Alder and Cooper 1967) and between legumes (McLean et al. 1965).

In most cases an attempt has been made to associate animal performance with chemical constituents of the feed and/or digestibility, volatile fatty acid production and intake. Despite this few satisfactory explanations of nutritive value have been forthcoming and even in the prolonged research programme at Palmerston North (Butler et al. 1968) it is only now that any real progress is being made towards definition of those factors contributing to differences in nutritive value of the pasture species involved (Ulyatt 1969).

Apparent digestibility is perhaps the most useful single measure of nutritive value of pasture (Ivins 1960; Coop 1967; Corbett 1969) although the limitations of such a measure are increasingly understood (Miles et al. 1969). For this reason the seasonal changes in digestibility of pasture plants and their components have been studied, especially since the development of reliable in vitro digestibility techniques.

Thus, the digestibility of the first growth of grasses and clovers decreases with advancing maturity with each variety having a characteristic relationship between its digestibility and stage of growth (Harkess 1963; Minson et al. 1964; Milford and Minson 1964). These digestibility patterns arise from changes in the proportions and digestibilities of the component parts of the various forages (Pritchard et al. 1963; Terry and Tilley 1964). Where grasses have been cut at monthly intervals following removal of first growth, the first monthly regrowth has had a higher digestibility than subsequent regrowths in most cases although the mean digestibility of all regrowths varied between grasses (Minson et al. 1964). Perhaps the most interesting result from these studies is that digestibility of a herbage is not necessarily related to the proportion of leaf it contains especially when stems and flowering heads are immature (Minson et al. 1964).

The relevance to the grazing situation of such differences and changes in nutritive value is difficult to assess for several reasons.

In those studies designed to measure specific and varietal differences in nutritive value the aim has generally been to ensure that intake is not limited by low pasture availability. Because of this interpretation must take into account at least two factors.

In the first case this type of evaluation ignores agronomic properties such as dry matter production and persistance. This may lead to large stocking rate x species interactions in terms of animal performance (Bublath 1969). In the second case, such evaluations take no account of the possibility of grazing pressure x species interactions. Thus grazing pressure may have varying effects on the rate at which different species and varieties mature, possibly being a function of the way in which the different growth components of each variety are affected by different grazing pressures.

Extrapolation from pastures of a single species to the mixed pastures which are normally grazed may be complicated by selective grazing and possible interactions between feeds in terms of nutritive value (Rattray and Joyce 1969).

Changes in digestibility, and by implication in nutritive value, appear to have only been studied in mowing trials. The relevance of these will depend both on the selective grazing habits of animals and on the differences in regrowth which arise as a result of differences between mowing and grazing. Some of these differences have already been discussed but there is no information on the effects of grazing on the proportionate growth of plant components. This may well be of importance in nutritive value (Terry and Tilley 1964).

Where selective grazing occurs, the relevance of changes in nutritive value which occur under cutting regimes is doubtful. Grazing animals tend to select feed of a higher nutritive value than that available especially when grazing pressure is low (c.f. Section B) so that any change in nutritive value with maturation of feed may be of little consequence. This appears to be one of the reasons for the better liveweight gains of sheep on long rather than short pasture despite the fact that the latter may have a higher nutritive value (Clarke 1959; Hight and Sinclair 1965; 1967; Gallagher _et al_. 1966).

However selective grazing may have detrimental effects when pasture growth rates decrease. Thus, when selective grazing occurs the herbage available after grazing will tend to be more mature than that present before grazing. Furthermore this remaining herbage will continue to mature. Thus the regrowth will consist of varying proportions of young and old herbage. This will be subjected to another cycle of selective grazing leading to a greater accumulation of mature herbage and so on. Provided growth of young herbage matches or exceeds animal requirements the increasing maturity of the pasture as a whole may not affect animal performance. However in periods of slow growth grazing pressure will increase and if rejection of the accumulated mature herbage continues intake and hence animal performance may suffer markedly (Arnold _et al_. 1964a).

From this discussion it is clear that nutritive value is as yet ill-defined and factors causing differences between pasture species in nutritive value are not well understood. Further, interpretation of changes in nutritive value due to grazing will require basic knowledge of the way in which grazing affects the growth components of pasture plants.

Only when such knowledge is available will it be possible to take account of nutritive value in grazing management in a more precise way than is done at present.

There is little evidence of the extent to which changes in nutritive value occur with increasing stocking rates.

If defoliation occurs more frequently and/or more intensely as stocking rates increase, then it is to be expected that the time during which maturation of herbage occurs will be reduced. This will result in an increasing proportion of young growth in the pasture and by implication a sward of higher nutritive value.

Changes in botanical composition may also be expected to result in changes in nutritive value. However the importance of such changes may be small where high stocking rates prevent the full expression of specific and varietal differences in rate of change of nutritive value which occur with increasing maturity.

Direct evidence of such effects is scarce and generally unsatisfactory. Thus differences in diet digestibility between stocking rates which are estimated from faecal nitrogen measures (Arnold et al. 1964a) are suspect since faecal nitrogen is affected by pasture availability, intake level (Langlands 1969) and soil intake (Lambourne pers. comm.).

Evidence from Hurley (Spedding et al. 1967) indicates that the digestibility of herbage available at a low stocking rate was similar to that at a high stocking rate early in the growing season but declined at a greater rate as the season progressed. However the relevance of this to the grazing animal is not clear.

It should be appreciated that the nutrition of the grazing animal is a function of both the quantity as well as the quality of feed. Thus both these factors must be considered together although the linear relationship which often occurs between dry matter and digestible organic matter production per acre may allow some simplification in the definition of objectives for the nutrition of grazing animals (Campbell 1961).

Plant communities respond both to climatic and edaphic factors as well as to grazing and the outcome in any particular case will be due to the interactions between these factors.

The response of plant communities to light, temperature, rainfall and nutrient supplies results in seasonal patterns of growth. Grazing may influence the utilisation of all climatic factors and further may affect the rates of growth, decay and regeneration as well as the competitive relationships between the components of a pasture.

As stocking rates rise, pasture availability tends to decrease and this may have important effects on the micro-environment of the sward. For instance it has been suggested (Moore 1966) that the wide diurnal temperature ranges at the soil surface and the restriction of roots of heavily grazed plants to the top layers of the soil may promote the mineralisation of nutrients and their efficient uptake. It might also be expected that the susceptibility of such swards to climatic factors is increased.

Increased stocking rates may lead to changes in botanical composition of a sward but the importance of such changes is not clear (Carter 1968). Where the legume content of the pasture is affected then the effect on pasture production may depend on factors such as soil type, nitrogen availability and nitrogen circulation. Where grasses are involved then the effect may be a function of the relative productivity of those species which are increasing and decreasing in the sward. However the similarity in production of most of the common pasture species (Vartha 1966; Lynch 1966; Anslow and Green 1967) suggests that this effect may not be very important (Spedding 1966; Ormrod 1966).

The way in which these changes in productivity will be reflected in terms of animal production is dealt with in Section C.

SECTION B

The grazing animal is normally confronted with marked seasonal changes in pasture composition, availability and structure. The extent to which the animal adapts to these changing conditions may well determine the extent to which its intake and hence productive potential is realised. Such adaptation depends on the way in which the animal seeks, selects and ingests its food. The behavioural pattern involved has been called ingestive (McBride *et al.* 1967) or phagic behaviour (McClymont 1967).

Factors affecting the level of intake in ruminants and the possible mechanisms whereby they act have been reviewed at regular intervals (Balch and Campling 1962; Conrad *et al.* 1964; Montgomery and Baumgardt 1965; Campling 1966) but few reviews have been concerned with the interrelationship between phagic behaviour and intake although its possible importance has been recognised for some time (Johnstone-Wallace and Kennedy 1944). Recently McClymont (1967) proposed a model integrating the stimuli involved in the expression or otherwise of phagic behaviour and by inference the stimuli controlling the intake of the grazing animal.

In this section only those intake factors peculiar to the grazing situation will be considered.

(a) Social interaction

Some field observations and a little experimental evidence suggest that social interactions within a flock or herd can affect the intake of certain members of such a group.

The term "social facilitation" was coined by Tribe (1950) to describe the situation in which the behaviour of one group of sheep is influenced by that of another. For instance, Tribe (1950) found that supplementary-fed ewes grazed longer when in the presence of unsupplemented sheep than when alone. Holder (1962), on the other hand, noted that the grazing time of unsupplemented sheep was reduced when they grazed together with supplemented sheep. In such cases, the effect on intake will depend not only on the change in grazing time but also on the change in rate of intake.

Where intensive pasture utilisation is achieved by the use of high stocking rates, observation suggests that a proportion of the flock or herd may not thrive. This may be due to stress factors, associated with high population density and/or reduced feed supply, leading to reduced intakes by animals low in the social order.

(b) Selective grazing

When the grazing animal shows preference for particular pasture components, selective grazing is said to occur. Selective grazing can exist between pasture species, within species and within single plants but the causal factors are only imperfectly understood.

The terminology used in describing selectivity is confusing. "Palatability" defined as "the readiness with which a food is selected and eaten" (Jones 1952) is too imprecise to be useful while in other cases it is equated with voluntary food intake (Blaxter et al. 1961; Campling 1964) and like "acceptability", "nutritional wisdom" and "specific hunger" it is interpretative (McClymont 1967).

McClymont (1967) has suggested that "palatability" should be confined to the property of food for eliciting olfactory, gustatory, tactile and kinesthetic stimuli which affect its relative edibility while "unpalatability" should be used to describe the property of food for eliciting similar stimuli which affect its absolute edibility. Relative and absolute edibility are used to describe the difference in relative amounts of various feeds eaten by a particular animal when they are equally available or are the only feed available.

Thus palatability becomes one of several factors affecting relative edibility while unpalatability contributes towards absolute edibility and a distinction is made between multi-choice and no-choice situations.

In a no-choice situation the absolute edibility of a grazed pasture species may be influenced by its digestibility (Corbett et al. 1963) although this need not occur especially at high levels of digestibility (Hutton 1962; 1963) where physiological regulation of intake appears to supercede regulation by physical effects (Corbett 1969). Other factors contributing to absolute edibility include the crude protein content of the feed (Blaxter and Wilson 1963; Milford and Minson 1964; Weston 1967), deficiencies or excesses in mineral content (Underwood 1966), pasture availability (Arnold and Dudzinski 1966) and possibly dry matter content (Arnold 1962; Davies 1962) and the physical structure of the feed (Osbourn et al. 1966). Any difference in absolute edibility remaining between feeds when these factors have been taken account of, may be attributed to unpalatability differences although euphagia (food selection directed towards optimal nutrition and avoiding intoxication) may also be important in particular cases (Murnane 1934; Arnold 1964b).

Recently Greenhalgh and Reid (1967) showed that digestibility and unpalatability differences between oat straw and dried grass were of about equal importance in causing the differences in voluntary intake obtained with these two feeds. However it is not clear whether differences in the physical structures of the two feeds contributed to the unpalatability differences.

In the case of relative edibility, conclusive evidence of the importance or otherwise of palatability is difficult, if not impossible, to obtain. However where the definition of palatability is applied a little less rigorously, then palatability differences may well be important as when sheep prefer to starve rather than eat certain types of plant (Arnold 1964b).

There is little information on the relationship between the absolute and relative edibility of a particular feed. Arnold (1964b) showed that the ranking of absolute edibility of four pasture species did not correspond with their relative edibility ranking. On the other hand he also quotes data indicating a close relationship between relative and absolute edibility in different strains of *Phalaris arundinacea*. In other words high intake of a feed in a no-choice situation does not necessarily indicate high intake in a multi-choice situation and conversely low intake in a multi-choice situation is not necessarily indicative of low intake in a no-choice situation.

Selective grazing is basically an innate response to appropriate stimuli acting through the special senses (McBride *et al*. 1967). While it is known that these senses (sight, touch, taste, and smell) are involved in selective grazing (Tribe 1946; Tribe and Gordon 1946; Arnold 1966a; 1966b), with the possible exception of sight, little real understanding of their importance, either collectively or relative to one another, has emerged.

This innate response may be modified by learning (McClymont 1967) and the physiological needs of the animal (Heady 1964; McBride *et al*. 1967).

For instance, the previous grazing experience of sheep, especially during early life, may influence their selective grazing habits (Arnold 1964b) and old sheep may not adapt to new pastoral situations (McBride *et al*. 1967). Although limited there is little evidence for the hypothesis that ruminants exhibit euphagia (Arnold 1964b; McBride *et al*. 1967; McClymont 1967).

While it has been asserted that the physiological demands of an animal will modify preference rankings (Heady 1964; McBride *et al*. 1967), there is very little evidence to support this. One of the few examples is where differences in diet selection have been noted between growing sheep of different ages (Arnold 1966c) although the physiological status of ewes appears to have a negligible effect on diet selection (Cook *et al*. 1961; McManus *et al*. 1968).

There is considerable variation in the selectivity of grazing ruminants. Thus selectivity may vary between cattle and sheep (Cook *et al*. 1963; Van Dyne and Heady 1965a), between breeds of cattle (Elliott *et al*. 1961) and sheep, between individuals in a herd or flock (Arnold 1964a; Van Dyne and Heady 1965a) and at different times for the same individuals (Arnold 1964a).

Selective grazing may also be influenced by other factors. For instance, chemical properties of pasture components (Roe and Mottershead 1962; Bland and Dent 1964) as well as external factors such as excretal contamination (Greenhalgh and Reid 1969) and soil fertility (Cook 1959) may be important in some situations. Availability of a component in terms of frequency of occurrence, yield relative to other components, accessibility and as influenced by the relative edibility of surrounding plant material may also be important (McBride et al. 1967). Similarly the physical environment (e.g. topography, distance from water, shelter, track) will affect selectivity within a paddock (Arnold 1964b).

Although these and perhaps other as yet undefined factors influence selectivity, individual species will remain within broad groupings of high, medium and low relative edibility (McBride et al. 1967).

The possible influence of selective grazing on voluntary food intake must be considered in terms of both the quantity and quality of the material ingested.

At the single plant level cattle and sheep generally eat leaf in preference to stem and green (young) material in preference to dry (old) material. As a result the ingested material is generally higher than the material offered in nitrogen, sugars, gross and digestible energy but lower in crude fibre (Arnold 1964b; Fontenot and Blaser 1965). Ingested feed may be only slightly more digestible than offered material when this consists largely of new growth (Fels et al. 1959) but where scope for selection and the range of material is large the digestibility of ingested feed may be 15 units or more above that of offered material (Tayler and Deriaz 1963). While the material eaten is often of higher nutritive value than the material on offer, this need not necessarily occur as when, for example, animals selectively graze toxic plants (McBride et al. 1967) or remove all the material offered.

The effect of selective grazing on the quantity of material ingested is more difficult to assess. The grazing animal is likely to be faced with a multi-choice situation; a no-choice grazing situation existing rarely, if ever. In the multi-choice situation the grazing animal may or may not be able to satisfy its appetite by grazing only preferred pasture components. In the latter case relative edibility differences between components tend to be reduced (Arnold 1964b; Leigh and Mulham 1966a; 1966b; 1967; Robards et al. 1967).

How these situations will be reflected in terms of intake is not known.

There is no evidence that high palatability *per se* affects intake of grazing animals (McClymont 1967) nor does there appear to be any evidence on the possibility of interactions between selected pasture components affecting intake. Where preferentially neglected species are eaten the animal appears to compromise so that much of the grazing time is spent eating comparatively scarce but preferred species and only a short time is spent grazing more abundant but disliked species (Arnold 1964b). In such situations intake may be depressed to a variable extent depending on the preference rankings of the pasture components present and on the difference between them in nutritive value.

(c) Pasture structure

It has been appreciated for some time (Johnstone-Wallace and Kennedy 1944) that the intake of the grazing animal may be affected by the physical distribution of the pasture on which that animal grazes.

However information on this subject is limited and most of that available refers to the gross measurement of pasture availability, little consideration having been given to the complexities involved until recent work at Canberra (Arnold and Dudzinski 1966; 1967a; 1967b; Arnold *et al*. 1966) and Adelaide (Whittaker 1965).

It is not easy to interpret experiments concerned with the possible relationship between intake and the physical distribution of pasture. Intake may be influenced by factors other than the physical distribution of pasture and should these change during the course of an experiment then variable period x treatment interactions may occur. Intake measurements are subject to considerable errors and since different workers use different methods, many results are not strictly comparable. Where pasture availability is used to describe pasture distribution then the method by which different pasture availabilities are obtained may be important. Thus cutting, grazing and fertilising a pasture may all have different effects on the structure of the sward although they may result in similar levels of availability. Further, availability is a function of the level to which the pasture is cut - different workers cut to different levels.

Interpretation of relationships between intake and herbage availability may be complicated because availability can be expressed either per unit area or per animal. For instance high availability per animal when availability per unit area is low may require a different interpretation to the situation where high availability per animal is associated with high availability per unit area (Hodgson and Wilkinson 1968).

A further complication in interpreting such relationships exists when selective grazing occurs. Thus most Australian workers have found more meaningful relationships where availability is expressed as green rather than total herbage. This occurs presumably because of the high selectivity shown by sheep for green rather than dry plant material.

Since the initial work of Willoughby (1959) demonstrating an asymptotic relationship between animal performance and herbage availability, many similar studies with sheep have confirmed this relationship (Williams 1964; Sharkey and Hedding 1964; Arnold 1964a; Bishop et al. 1966) although Spedding et al. (1966) were unable to show this - possibly due to insufficient levels of availability being used.

That a similar relationship holds for intake and herbage availability is not so easy to demonstrate. Limited data from experiments with cattle (Waite et al. 1950; Halley 1955; Hull et al. 1961; Greenhalgh 1966) indicate an asymptotic relationship between intake and pasture availability although this has not been found in all cases. Thus Van der Kley (1956), using dairy cattle data, showed that intake was maximised at approximately 2250 lb. DM/acre and beyond this value appeared to drop. In another case (McLusky 1955) a linear relationship was found between intake and availability although the range of dry matter yields used was not given by the author.

Similar asymptotic relationships between pasture availability and intake have been demonstrated for sheep and are summarised by Arnold and Dudzinski (1967b). Again such relationships have not been found in all cases. Thus Wheeler et al. (1963) were unable to demonstrate a relationship between availability and intake over a range of conditions. However the large bias which may occur in the method that was used to determine intake especially when pasture availability is low (Young and Corbett 1969) throws doubt on the validity of this conclusion. In another case (Arnold 1966c) no clear relationship was found between the intake of lambs and pasture availability. Here it was suggested that selection for green matter was hampered by the large bulk of dry feed present thereby distorting any basic asymptotic relationship.

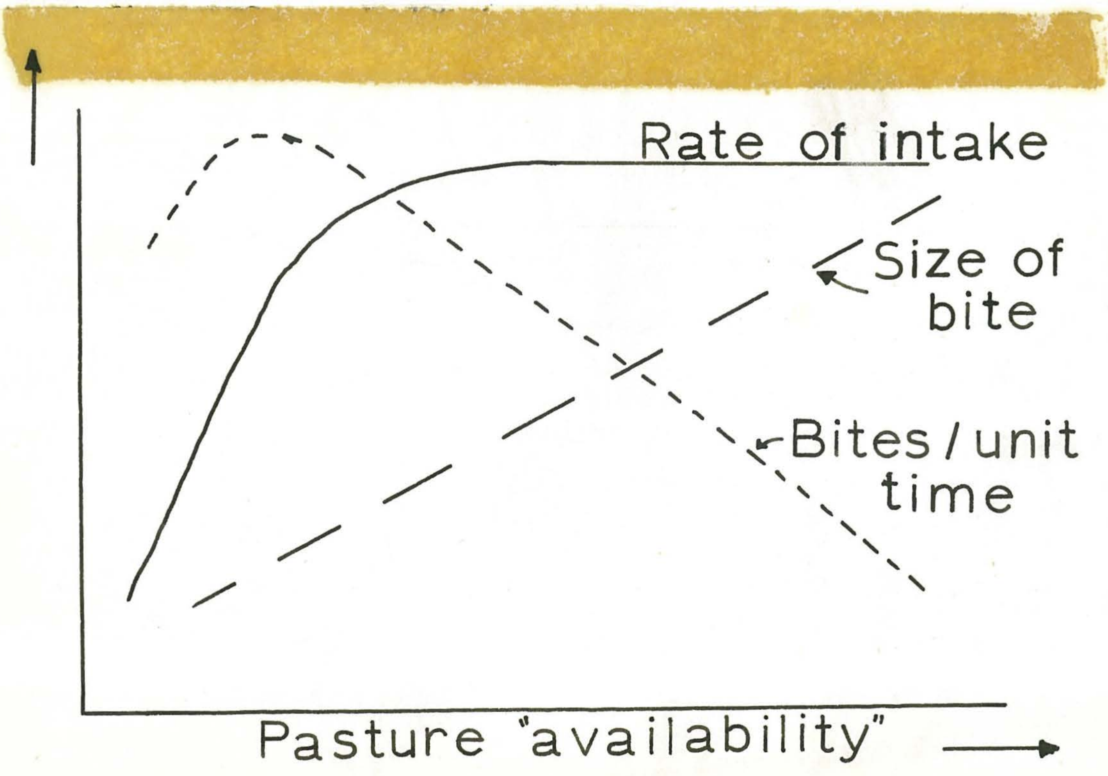
Recent results (Arnold and Dudzinski 1966; 1967a; 1967b; Arnold et al. 1966) indicate the many variables which can affect the shape and position of the availability - intake asymptote. These include physiological status of the animal, pasture type and structure, season, year and possibly breed.

The basis of the asymptotic relationship which is normally found between availability and intake has been partially elucidated by work with sheep.

Daily food intake is a product of the hours spent grazing per day and the rate of intake per hour. As pasture availability drops so grazing time increases to a limit presumably determined by fatigue (Allden 1962; Arnold 1960b; 1963; 1964a; Whittaker 1965), the maximum grazing time recorded for sheep being about 13 hours (Arnold 1964a). Rate of intake appears to vary with the physiological condition of the animal. For example, ewes in early lactation may have a lower rate of intake than ewes in later lactation (Arnold and Dudzinski 1967a) while fat ewes appear to have lower rates than thin ewes (Arnold and Dudzinski 1966).

Rate of intake is the product of size of bite and number of bites per unit time. For a particular animal, size of bite will depend on the structure of the pasture - that is on its height, density and spatial arrangement (Arnold and Dudzinski 1967a). In any particular situation any one of these factors may be the main determinant of intake per bite. For instance, Whittaker (1965) concluded that for his conditions tiller length was a good measure of the intrinsic availability of pasture as measured by size of bite. However tiller length is only likely to be important up to a point - beyond this it may become unimportant or even hamper intake especially in young animals (Arnold 1964c; Whittaker 1965).

While size of bite is largely governed by pasture structure, the grazing animal can change its rate of intake by altering the number of bites taken per unit time. The following graph derived from Whittaker (1965) illustrates the adjustment which may be made by the animal in response to changing pasture structure.



Thus the grazing animal can change its grazing time and/or rate of intake and so maintain a relatively constant intake over a wide range of pasture conditions. Where the adaptability of the animal is limited by fatigue intake will no longer be maintained thereby giving rise to the asymptotic relationship which is often demonstrated between availability and intake.

SECTION C

Stocking rate (the number of animals per unit area of land - Mott 1960) is the major factor in determining the efficiency of conversion of pasture to animal products and has a much larger effect than changes in grazing management per se (McMeekan 1956; Wheeler 1960) although these may assume increasing importance at high stocking rates (Morley and Spedding 1968).

Changes in animal performance are associated with changes in stocking rate. As stocking rates increase from very low levels, production per animal may remain unchanged (Cowlishaw 1969) or it may even increase (Arnold et al. 1964a) as a result of changes in the structure of the sward (Arnold 1964a) and/or an increase in the amount of higher quality feed available (Suckling 1964b).

Higher stocking rates give rise to depressions in animal performance and it has been postulated that this fall in performance will occur at an increasingly rapid rate (Mott 1960; Morley and Spedding 1968). Petersen et al. (1965) postulated that animal performance is maintained at a constant level until a stocking rate is reached at which it drops abruptly. However this proposal may be questioned since the model it is based on ignores the dynamic nature of the processes involved.

Riewe (1961) and Cowlishaw (1962) were unable to show from their data that the relationship between stocking rate and liveweight gain per animal was other than linear. However in a more recent review Cowlishaw (1969) was able to demonstrate discontinuities in the rate at which liveweight gain per animal decreased with increasing stocking rates in some instances although in most cases the relationship was again linear.

Such changes in animal performance will be reflected in the response of animal production per unit area to stocking rate. Thus as stocking rates rise, production per unit area will rise until production per animal drops to such a low level that production per unit area drops. Such falls in production per unit area have been noted for milk (McMeekan 1961), beef (Cowlishaw 1969) and lamb production (Davies 1968).

The exact nature of the response curve beyond the point of inflexion is not known. Arnold (1968) considers that the type of curve postulated by Mott (1960) is unlikely to exist. Rather a crisis point at which all animals will die will be reached and production per unit area may remain high up until this point. However this type of argument may be largely academic if, as it seems from the analyses of Watson (1965), Chisholm (1965) and Byrne (1968), maximum sustained profitability per unit area is reached well before the point of maximum production per unit area. In this case the slope of the linear phase of the response curve would be of most interest to the biologist.

Average response curves for the various animal production processes indicate that response in terms of wool per acre is linear up to very high stocking rates. In terms of milk, lamb or beef production per unit area the linear phase of the response is shorter and becomes curvilinear at lower stocking rates. Variability of response is least for wool production although data for other productive processes are scarce (Arnold 1968).

The increase in production per unit area associated with increasing stocking rates is generally ascribed to the increased proportion of pasture growth which is harvested at high stocking rates (McMeekan 1956; Wheeler 1960; Spedding 1965a). While this explanation appears reasonable it is pertinent to note that there is little direct evidence for it, a situation which probably reflects the inadequacy of the techniques at present available for collecting such evidence.

One of the few attempts to measure the proportion of pasture harvested at different stocking rates was made at Ruakura (Campbell 1966d). In this case an increase in stocking level within a grazing system resulted in an increase in the "average percentage utilisation" at each grazing. It is interesting to note that at Hurley (Kydd 1966b) utilisation (defined in the same way) decreased as stocking level increased although it is not clear to what extent this result was affected by different grazing systems at the two stocking rates.

While production per unit area may provide a useful simplification of the biological objectives of a pastoral enterprise, in practice a compromise between production per animal and per unit area must be achieved. Such a compromise may be easily reached in some cases, for example where wool production is of primary interest. In other cases, as in lamb production (Spedding 1965a), a satisfactory compromise may be difficult to achieve.

The key to the outcome of increasing stocking rates is the rate at which animal performance drops. This is largely a function of the nutrient supply made available to the grazing animal and the efficiency with which it is converted to useful production.

In section A an attempt was made to indicate the ways in which the grazing animal influenced its feed supply while section B was largely devoted to the effect of selective grazing and pasture structure on the grazing animals intake. These two aspects of the grazing ecosystem determine the animals' nutrient supply.

There is little evidence for the changes which occur in seasonal and total production of pastures as stocking rates increase although more data is available on the changes which occur in botanical composition and pasture availability. While the different consequences of some of the possible changes in pasture productivity have been discussed by Allden (1968) a point will be reached when intake is restricted by availability of pasture and competition between animals for feed. The inflexion in the response curve relating animal output per unit area to stocking rate might be expected at about this point. However prior to this production per animal may well drop if, as is generally the case, pasture is not homogeneous for quality. This is because each animal will receive less of the fractions of high nutritive value (Spedding 1965a). A fall in animal performance may also be expected where intake of the individual is limited by selective grazing or pasture conditions. For example, pregnant and lactating Border Leicester x Merino ewes grazing a Phalaris - subterranean clover pasture are unable to meet their intake potential when availability is lower than 2,000 lb. dry matter (Arnold 1963a).

Thus the intake of the individual animal may be expected to fall as stocking rates increase although Arnold (1964a) suggests that this may not occur as stocking rates rise from very low levels. While there is some direct evidence of changes in intake with stocking rate (Arnold et al 1964a) this, as will be discussed later, is of questionable validity.

The efficiency with which nutrient intake is converted to useful production at different stocking rates will depend on several factors including the type of production involved. As stocking rates rise and the periods of feed shortage increase, different productive processes will be affected in different ways. A distinction may be made between liveweight gain and milk and wool production. All are continuous functions of the level of nutrient supply but whereas liveweight gain is a reversible process, milk and wool, once elaborated, are not catabolised (Lambourne 1968). Similarly the level of nutrition may have disproportionate effects on annual productivity where production depends on adequate nutrition during particular phases of the productive cycle (Willoughby 1959; Campbell 1966e).

Any changes in the feed conversion efficiency which occur with changing stocking rate will be reflected in the rate at which animal performance drops. The maintenance requirements of ruminants may have large effects on the efficiency with which feed is converted to useful production (McMeekan 1956) and it is for this reason that several attempts have been made to measure the changes which may occur in the maintenance requirements of grazing sheep with changing pasture conditions.

Initial work indicated that maintenance requirements per unit metabolic body size were greatly increased where pasture availability was low (Lambourne and Reardon 1963b; Coop and Drew 1963; Arnold et al. 1964a). However the recognition of large biases in the method used to measure intake in these studies has cast considerable doubt on the validity of this conclusion (Lambourne pers. comm.; Langlands 1969; Young and Corbett 1969). Recent measurements of energy expenditure both by respiratory gaseous exchange and a carbon dioxide entry rate technique indicate that pasture availability has little effect on maintenance requirements (Young and Corbett 1969).

This latter result is surprising given the low levels of pasture availability reached and the low body weights of the sheep used. These might be expected to increase maintenance requirements due to an increase in foraging time (Moir 1968) and the increased vulnerability of the animals to adverse climatic conditions (Young and Corbett 1969). Further clarification of this result is required. It may include considerations of the increased efficiency of food conversion to wool (Piper and Dolling 1969) and perhaps to milk (Wallace 1961) which may occur at restricted levels of intake such as those noted by Young and Corbett (1969) at low levels of pasture availability. It has also been suggested that the lower liveweights which often occur under high stocking rate conditions may result in increased efficiency of feed conversion in dairy cows (McMeekan 1956). However it is unlikely that such mechanisms will apply equally to all productive processes and under all conditions.

Efficiency of feed conversion may also be affected by the influence of stocking rate on the incidence of disease. Differences in plane of nutrition due to stocking rate may have variable interactions with the incidence or severity of disease (Hunter 1952) while increasing stocking rate may increase the incidence of disease if it is associated with increasing physical contact between animals (Spedding 1965b). There is only limited information on the effect of stocking rate on nematode infection. Under Australian conditions it appears that there is little effect with mature sheep (McManus and Arnold 1965; Southcott et al. 1967) although substantial worm burdens may build up in young sheep at higher levels of stocking (Arnold 1963a) possibly due to their poorer immunity status (McManus and Arnold 1965).

From this discussion it is clear that the rate at which animal performance falls with increases in stocking rate will depend on several factors. In addition to those already discussed, previously ignored factors such as the ingestion of soil (Ludwig et al. 1966; Healy 1968) may become important while practices such as grazing management, conservation and timing of operations may contribute increasingly to results.

Thus in a beef production experiment (Conway 1963) it was found that the fall in animal performance was less in the first year of the experiment than in the subsequent two years. This may have been due to the cumulative effects of overgrazing on pasture production (Cowlishaw 1969). In another trial (Sarvis 1941 quoted by Cowlishaw 1969) the difference in rate at which animal performance fell appeared to be most closely related to rainfall.

This discussion has been characterised by its use of generalisations. This is a reflection both of the lack of knowledge of relationships in the grazing ecosystem as well as the highly variable response curves involved.

It has already been noted that highly stocked pastures are likely to be more responsive to the total environment than low stocked pastures while the critical periods in animal nutrition are likely to increase with stocking rate. Taken in conjunction these two factors indicate that variability of response is likely to increase with stocking rate and this in fact appears to occur (Arnold 1968).

The possible factors involved in variability of response have been discussed in general terms by Morley (1966a, b) but detailed study is required before progress can be made in identifying those factors which are important.

SECTION D

(a) Body growth of sheep

The body growth of sheep will vary according to genetic (Bowman 1967), and sex differences (Bradfield 1967) as well as with nutritional and other environmental factors (Blaxter 1962).

The effect of maternal nutrition on prenatal growth and development in the sheep as well as prenatal influences on postnatal productivity have been reviewed by Everitt (1967b). The purpose of this section is to briefly summarise similar data for the effects of postnatal nutrition especially during the first eighteen months of life.

Work with farm animals including pigs (McMeekan 1940a; b; c), sheep (Wallace 1948; Palsson and Verges 1952), goats (Wilson 1958a; b; 1960) and poultry (Wilson 1954a; b) has shown that proportional development in animals proceeds in an orderly fashion. Thus waves of high growth intensity commence in the body extremities and converge along the back line to the lumbar region which is the latest maturing part of the animal. The different tissues attain their maximum growth rates in a definite order while the various fat depots are laid down at different rates. Similarly differential growth occurs between the various organs and organ groups.

The effect of nutrition on the above pattern has been the subject of considerable research (Palsson 1955; Wilson 1958a; b; 1960; Butterfield et al. 1966) and it is generally agreed that plane of nutrition affects overall growth rate and fat deposition. However interpretation of the results in terms of other effects on carcass composition and conformation has varied. One point of view (Palsson 1955) maintains that individual organs, tissues and parts of tissues are affected differentially while another (Wallace 1948; Wilson 1960; Butterfield et al. 1966) maintains no such differential effects occur. More recently re-analysis of some of the relevant data (Elsley et al. 1964) has suggested that differences in fat deposition account for most, but not all, of the apparent effects of the varying planes of nutrition on the pattern of development. Fowler (1967) considers that the pattern of development at any one time will also be affected by the functional requirements of the animal at that time.

Palsson (1955) considered that when an animal was kept on a sub-maintenance diet, the different tissues and body regions would be utilised in the reverse order of their maturity.

However it has been found that in mature sheep losing weight fat is not always more severely depleted than other tissues (Kirton and Barton 1958; Hight and Barton 1965) although this may occur (Robinson 1948; Keenan et al. 1969). The pattern of tissue loss in such sheep may vary with initial fatness (Panaretto 1964) and with the changing deficit between nutrient intake and requirements (Russel et al. 1968).

Using two year old steers and young sheep respectively, neither Butterfield (1966) nor Meyer and Clawson (1964) were able to show a differential loss between fat and protein when their animals were losing weight although in the steers late developing muscles lost more weight than early developing ones.

When animals have undergone nutritional restriction and such a restriction is removed, growth rate is often above that normal for animals of similar age which have not had their growth retarded. Such enhanced growth is termed compensatory growth (Bohman 1955) and has been reviewed by Wilson and Osbourn (1960). The extent to which compensatory growth occurs will depend on several factors (Wilson and Osbourn 1960) including: the nature, severity and duration of undernutrition, the stage of development at the commencement of undernutrition, the relative rate of maturity of the species and finally, the pattern of re-alimentation. The mechanisms whereby compensatory growth occurs are not well defined although prolongation of the growth period is important (Wilson and Osbourn 1960) while increased appetite (Wilson and Osbourn 1960) and/or increased efficiency of food utilisation (Meyer and Clawson 1964) may be involved.

In immature animals the composition of weight gain during compensatory growth will normally contain a higher proportion of fat and a lower proportion of protein than in continuously grown animals (Wilson and Osbourn 1960; Meyer and Clawson 1964) although this need not be the case (Butterfield et al. 1966). In mature sheep the proportion of protein in weight regained may be higher than in immature sheep (Keenan et al. 1969) and the same situation may occur in cattle (Butterfield 1966).

The occurrence of compensatory growth in terms other than body composition has been indicated in several studies with sheep. The technique normally used in such studies is to apply the different nutritional treatments to different groups of sheep for a period up to the time when the sheep are 12 - 18 months old. The groups are then brought together and treated alike until the study finishes. Clearly the possibility of premature observations exists when studies are finished before maturity is reached.

Body weight measurements have been used on several occasions to indicate the extent of compensatory growth. Using Corriedale ewes, Coop and Clark (1955) found that a 13.5 kg difference at 12 months of age disappeared

20 months later although in another trial a difference still existed after five years when treatments were imposed up to 18 months. Other studies (Donald and Allden 1959; Bradford et al. 1961; Gunn 1964b; 1967a; Reardon and Lambourne 1966) have shown that nutritional stress during the post-weaning period does not result in reduced mature body weight. However a reduction in mature body weight may occur (Schinckel and Short 1961; Giles 1968) although Schinckel and Short's (1961) experiment only ran for two years, perhaps leading to premature conclusions (Allden 1968c). More recently reports by Allden (1968a; c) have shown that only very severe treatments (growth arrested at 15 kg weight from 60th to 460th day of life) lead to reduced mature (3 year old) body weight in Merino wethers and that pre-weaning (birth to 6 months) undernutrition has a very much more persistent effect than post-weaning (6 to 12 months) undernutrition. This last conclusion substantiates the suggestion of Gunn (1967a) that nutrition over the first six months of life may be more important than over subsequent periods.

Other live body measurements (Gunn 1964b; 1967a; Allden 1968a; c) tend to follow the pattern of body weight compensation and according to Allden (1968a; c) development is retarded uniformly. However Gunn (1965) did not consider that the data he obtained from carcass dissection indicated uniform retardation although interpretation is complicated by the small number of animals used and by the short period over which such measurements were made.

Eruption of permanent incisors tends to be affected to a lesser extent than other body measurements (Gunn 1967b; Allden 1968a; c) while teeth wear may be affected by undernutrition (Coop and Clark 1955). Teeth losses do not appear to be influenced to any great extent by nutritional treatments in early life (Gunn 1967b; Allden 1968c).

The effect of nutrition in early life on life-time lamb production has only been investigated in a few studies. In several of these studies (Bradford et al. 1961; Purser and Roberts 1964; Giles 1968; Gunn 1968) no differences in productivity in favour of the well reared animals was noted. In fact, low plane rearing seemed to be of benefit in the work of Bradford et al. (1961) and Gunn (1968). In their 1946 trial, Coop and Clark (1955) showed only a slight effect of nutrition on life-time productivity but this became more pronounced in the 1949 trial in which the treatment effects were more distinct leading to a higher incidence of barren ewes at two-tooth lambing and a decrease in twinning percentage at subsequent lambings. Reardon and Lambourne (1966) reported that both their low plane groups had a permanently lowered twinning percentage quite apart from the high level of barrenness at the first lambing in animals kept on a low plane from 9 to 14 months of age.

From this discussion it is clear that more work is needed before the effects of nutrition in early postnatal life can be fully evaluated. The expected future nutritional levels of animals should be taken into account when trying to assess these effects.

The stage at which undernutrition occurs may be important in determining not only short but long-term effects on production. A more positive approach than that used up to the present time is required to define these sensitive periods. The problem is no longer how to feed an animal so that it produces at a high level but rather how to use a limited amount of feed to greatest advantage.

In an attempt to unify evidence from a variety of sources Dickinson (1960) proposed a model of growth which has been developed further by Schinckel (1963). This worker incorporated an additional component of sensitivity to stress in relation to physiological age.

While such a model may well prove useful in understanding the effects of undernutrition, research of a more basic nature is required to ascertain the control mechanisms involved in growth and development.

(b) Wool growth

There has been considerable work on the effect of nutrition during early life on subsequent wool production. This has been investigated mainly in terms of follicle initiation (development), follicle maturation (growth of fibres) and ratios of secondary to primary follicles. The normal pattern of follicle and follicle group development has been described by Fraser and Short (1960), although there is some debate as to whether secondary follicles can be initiated after birth. Differences due to the techniques used (Ryder and Stephenson 1968) or real breed differences (Claxton 1963) may be responsible for this.

A certain amount of work has shown that undernutrition in early life is unlikely to have long term residual effects on wool production (Henderson 1953; Hugo 1958; Wildman 1958; 1965; Doney and Smith 1964; Everitt 1967a; Allden 1968c) although it will affect the rate at which follicles mature (Schinkel 1955a; Short 1955). Only where undernutrition is very severe are long term effects recorded (Schinkel and Short 1961; Allden 1968b). Thus Schinkel and Short (1961) showed in their experiment that as adults the progeny of ewes poorly fed during pregnancy produced less wool (8.5%) and had fewer follicles (15%) per sheep. Low levels of nutrition for the first four months after birth resulted in reduced wool growth (12%) at maturity, due to reduced fibre weight (10.5%) and not to follicle loss. Allden (1968b) found that the long term effect on wool production, following restriction from the 60th to 460th day of life, was associated with a non-significant drop in number of fibres per sheep rather than with changes in fibre weight. The author suggests regression of secondary follicles may have taken place. Although Schinkel (1955b) observed such an effect in one study, he was unable to repeat it (Schinkel and Short 1961).

In field trials, the effects of undernutrition in early life have resulted in immediate rather than long term effects on wool production (Coop and Clark 1955; Bradford et al. 1961; Gunn 1968; Allden 1968c; d) although early rather than late restrictions have the more persistent effects (Allden 1968c; d). In one trial (Giles 1968) low plane animals have continued to produce slightly, but significantly, less wool than high plane animals over a six year period.

In addition to these effects wool growth is subject to several immediate effects. Thus hormonal (Ferguson et al. 1965), nutrition (Schinkel 1963), and day length and/or temperature effects (Hutchinson and Wodzicka-Tomaszewska 1961) have all been implicated in the annual rhythm of wool growth, although their inter-relationships are far from clear. Breed (Slee and Carter 1961; Doney 1966), nematode infection (Gordon 1958; Southcott et al. 1967), pregnancy and lactation (Corbett 1964; Doney 1964) as well as the number of lambs reared (McFarlane 1965; Ross 1965) may all affect the extent of variation in the annual cycle.

Increased knowledge of ruminant digestion has allowed a clearer understanding of the relative roles of protein and energy in wool growth (Reis and Schinkel 1963) while the effect of other dietary factors on wool growth has been reviewed by Ryder and Stephenson (1968). For present purposes only those studies concerned with the wool production of the grazing animal will be considered.

For convenience such studies can be divided into those carried out with Merino sheep and those carried out with other breeds of sheep.

In the former case most studies have been carried out in Southern Australia and three main patterns of wool growth have been identified in this area (Williams and Schinckel 1962). The Canberra area is characterised by peak growth in spring and autumn with low growth in between (Arnold and McManus 1960; Arnold et al. 1964a; McFarlane 1965) while at Armidale growth tends to increase gradually to and from a summer plateau (Roe et al. 1959). Peak spring values with lower values in summer and autumn have been noted at several locations (Hutchinson and Porter 1958; Stewart et al. 1961; Squires 1964; Reis and Williams 1965). Other patterns have also been noted in the north-west of Western Australia (Williams and Suijdendorp 1968) and in Victoria (Sharkey et al.

1962). These basic patterns of wool growth may be modified by stocking rate (Arnold et al. 1964a), management systems (McFarlane 1965), the pattern of effective rainfall (Williams and Schinckel 1962) and pasture types (Gallagher et al. 1966).

While rate of wool production might be expected to be closely associated with the stage of growth and protein content of the pasture, it is most obviously associated with the availability of green rather than total forage especially at low levels of availability (Williams 1964; Sharkey and Hedding 1964; Reis and Williams 1965; McFarlane 1965). This merely reflects the very marked preference of sheep for green rather than dead material under Australian pasture conditions (Arnold 1964a). Given the small photoperiodic rhythm of Merino sheep (Hutchinson 1965) and the large seasonal fluctuations in both quantity and quality of most Australian pastures (Donald and Allden 1959; Willoughby 1959) it is not surprising that Williams and Schinckel (1962) should have concluded that the growth rate of wool in grazing Merinos is largely determined by the annual feed cycle. Any such association may be masked if a time lag exists between the cycles of intake and wool growth (Doney and Eadie 1967).

There are few studies of the wool production of grazing sheep in which breeds other than the Merino have been used. In New Zealand the pattern of wool production of Romneys has been reported by Story and Ross (1960) and more recently by Sumner and Wickham (1969) while Coop (1953) reported on the pattern in Corriedales. Other studies include those of Galpin (1947), Doney (1964), Doney and Smith (1961) and Doney and Eadie (1967). In all these studies seasonal fluctuations in wool growth have occurred to a greater or lesser extent.

Comparison with Australian work is difficult due to differences in breed, climatic conditions and pasture types. However the interaction between the annual nutritional and climatic cycles and breed has been investigated in one study (Doney 1966). Thus in predominantly Merino sheep the major influence on wool growth appeared to be nutritional level, notwithstanding the large changes occurring during the annual climatic cycle. In Cheviot sheep, on the other hand, intake and wool growth were only related during the summer period so that when the nutritional cycle was reversed, the cycle of wool growth was eliminated. This lack of response in wool growth to increased nutritional levels in winter has been noted in other hill breeds, the suggestion being that it represents an adaptive characteristic of such breeds (Doney 1964).

Where means of increasing wool production are sought, interpretation should aim at establishing the difference between actual and potential wool production throughout the year. It is interesting to note that in Australia with Merino sheep this difference will be smallest during periods of active pasture growth (Williams and Schinckel 1962) whereas in Scotland the difference appears to be smallest in winter when Blackface sheep show little response in wool growth to winter feeding (Doney 1964). Where the difference is small nutritional improvement is unlikely to increase wool production per sheep but more sheep may be carried (Williams and Schinckel 1962).

In conclusion it seems that the pattern of wool growth of grazing sheep requires careful interpretation. This must take account of factors such as the physiological state of the animals, pasture conditions, interactions between genotype and environment and those between nutrition and climate as well as the time lag in wool growth response to nutritional changes.

SECTION E

(a) The use of oesophageal fistulated sheep

Although the technique of oesophageal fistulation is over one hundred years old (Van Dyne and Torell 1964), it was not until 1954 that its use was reported in sheep (Torell 1954). Since that time both surgical techniques and devices for closing fistulae have been developed to the stage where sheep with oesophageal fistulae can be maintained with comparatively little demand on labour and time, thereby providing a potentially useful method for studying the diet of the grazing animal.

The extent to which this potential is realised will depend both on the normality of the fistulated animals and on the efficiency with which their diet is sampled. These aspects will be dealt with in turn.

There appears to be only one critical report on the normality of fistulated sheep as judged by factors such as grazing times, estimated intakes and productivity (Arnold _et al_. 1964b). These authors point out that, although fistulated sheep can behave in a manner similar to intact sheep, this need not occur always, especially when fistulae are large or when routine care of the fistulae is lax. Conditions of stress, for instance when pasture availability is low or feed is fibrous, might be expected to highlight any difference in performance between fistulated and intact sheep. Because generalisations are impossible, it would seem necessary to assess the performance of fistulated sheep relative to that of intact sheep throughout any trial in order to obtain an indication of their normality.

Work by Peel and Wilson (1964) has largely discounted the evidence used by McManus (1962) to show that loss of saliva leads to rumen disfunction. The former authors also concluded that sheep could tolerate the loss of two litres of saliva over a period of five hours provided the loss of sodium was made good. This emphasises the necessity to provide fistulated sheep with salt licks at all times while ensuring that saliva loss is minimal.

Efficient sampling of the diet of the grazing animal will depend on the extent to which the diet sample collected per fistula represents the diet ingested by a particular group of animals. This will depend on three main factors:-

(i) The use of sufficient animals to measure diet constituents with the desired degree of precision.

There are several reports on this aspect of the use of fistulated animals (Harris _et al_. 1967; Van Dyne and Heady 1965a; b; Arnold _et al_. 1964b;

Langlands 1967a). While generalisations are difficult, these workers suggest that the number of animals required for a given degree of precision will be smaller where pasture availability is low or the opportunity for selective grazing is reduced. Van Dyne (1968) suggests fewer animals are required for sampling chemical constituents of the diet than for botanical components of the same diet.

(ii) The relative nature of the extrusa and ingested herbage.

For the extrusa to be representative of the ingested feed requires that no particular component of that feed bypasses the fistula more than another. This condition appears to be met in sheep fitted with McManus-Hamilton type fistulae, (McManus et al. 1962) where the percentage recovery per fistula is of little consequence (McManus 1961; Arnold et al. 1964b; Grimes et al. 1965), despite the fact that larger fistulae tend to be associated with higher percentage recoveries (Arnold et al. 1964b). Where permanent cannulae are used, unrepresentative samples may be collected (Lesperance et al. 1960), presumably by impairing the lability of the oesophagus.

(iii) Management of fistulated relative to intact animals.

Management of fistulated animals should aim at minimising any differences between these and intact animals in terms of selective grazing. The extent and magnitude of selective grazing is influenced by many factors (Section B) but assuming that both groups of animals are similar in respect of physiological condition, differences in selectivity are likely to arise from short term effects.

Thus Arnold et al. (1964b) were able to show that overnight fasting of sheep resulted in a drop in nitrogen levels in the diet although Langlands (1967a) was unable to reproduce this result even when sheep were fasted for twenty-two hours.

Where fistulated sheep are used as intermittent diet samplers, being introduced to the pasture only a short time before sampling, the diet selected is likely to be different from that selected by sheep accustomed to that particular pasture (Arnold et al. 1964b; Langlands 1967a). How important this factor is when fistulated sheep are grazed on a similar pasture when not being used for sampling is not known.

The time of day when pastures are sampled may be important, since Langlands (1965; 1967a) has demonstrated diurnal changes in the digestibility and nitrogen content of the diet of the grazing sheep.

Efficient diet sampling will also depend on the extent to which changes in the chemical composition of the extrusa are appreciated and allowed for. Such changes may occur both during the collection and preparation for analysis of the extrusa.

(i) Changes during collection

When extrusa is collected it consists of varying proportions of ingested feed, saliva and released cell contents. The amount of salivary contamination appears to vary with the type and amount of feed consumed as well as with other as yet undefined factors. The extent to which cell contents are released will vary with the extent of mastication prior to swallowing but studies on penned and grazing sheep indicate that, on average, released cell contents include about one-third of the nitrogen (Hogan 1965; Doyle 1967) and about one half of the water-soluble carbohydrates in pasture extrusa.

Thus, where the liquid fraction of the extrusa is wholly or partially discarded, loss of released cell contents is likely to occur. On the other hand where the entire sample is kept saliva will contribute endogenous material.

Ash accounts for the greater part of ruminant saliva (McDougall 1948; Lesperance et al. 1960) and is therefore the primary contaminant in extrusa (Van Dyne and Torell 1964). The phosphorus level of extrusa relative to ingested feed is generally increased while calcium levels show little change (Lesperance et al. 1960; Lombard and Van Schalkwyk 1963; Langlands 1966). Increases (Harris et al. 1967) and decreases (Langlands 1966) in potassium levels have been reported. The nitrogen content of extrusa has generally shown little change both in Australian (McManus 1961; Arnold et al. 1964b; Langlands 1966) and American work (Harris et al. 1967) although interpretation of results is often complicated by drainage of the liquid portion of the extrusa prior to analysis.

Because the liquid fraction of the extrusa is likely to be variable both in composition and quantity, the collection of all the extrusa, either as a single sample or as separate solid and liquid fractions, is to be preferred. Salivary contamination can then be allowed for by establishing regression equations between a component in the feed ingested and the same component in the extrusa collected (Langlands 1966) and by expressing results on an ash free basis (McManus 1961).

Enzymic activity will continue during collection and transport to the laboratory so that it is desirable to minimise the length of collection period and arrest enzymic activity as soon as possible after collection (Van Dyne et al. 1964).

(ii) Changes during preparation for analysis

The preparation of extrusa for chemical analysis generally involves drying and since this process can cause changes in the chemical composition of herbage (Raymond and Harris 1954) the conditions of drying must be clearly defined.

Changes which occur include the loss of water soluble carbohydrates (Jones 1962; Burns et al. 1964) and an increase in apparent lignin content (Van Soest 1962). The extent of these changes will depend on the level of enzymic activity, the drying temperature and the rate of moisture loss from the sample (Raymond and Harris 1954). In an attempt to reduce the catalytic action of moisture on chemical changes, some workers (Grimes et al. 1965; Langlands 1966) have separated the solid and liquid fractions of the extrusa immediately after collection.

This review of factors affecting the usefulness of oesophageal fistulated sheep as diet samplers draws attention to several points. The use of regression equations to predict the composition of ingested feed from the composition of extrusa enables the problems arising from chemical changes in feed during collection and preparation for analysis to be overcome. However for their use to be warranted the conditions under which the equations are derived must encompass the conditions under which they are to be used for prediction. For instance, salivary contamination is likely to vary so this variation must be accommodated by the regression equation.

Where the liquid fraction of the extrusa is discarded, a subjective and unrepeatable process is involved. Again the extent to which this subjective action is encompassed by the prediction equation is important.

Several authors have mentioned soil contamination in discussing diet sampling (Van Dyne and Torell 1964; Langlands 1967a; Harris et al. 1967), but there appears to be little published work on the ways in which soil may affect analytical measurements. Langlands (1967a) has expressed values in terms of organic matter "to minimise the effects of soil contamination" but this is not entirely satisfactory because soil makes organic matter contributions to extrusa when it loses weight on ashing. This can lead to misinterpretation of analytical results (Scoffield 1969), depending on the degree of soil contamination and soil type. There is no evidence on the way in which soil nitrogen may affect measures of nitrogen in extrusa. Until work is carried out on this aspect of soil contamination, results obtained under conditions where soil ingestion occurs must be accepted with caution.

In theory, at least, the requirements for efficient use of fistulated sheep are rigorous. This implies that in any particular case the actual procedures to be used must be carefully planned and well defined. At this stage in the development of the oesophageal fistula technique there appears to be a need, not only for the definition of imprecisions in the technique, but also for a comparison of the effects of different collection procedures on particular diet components. This has already been undertaken for *in vitro* digestibility (Langlands 1966). Only when this has been done will it be possible to define procedures for diet sampling which are both practically and theoretically acceptable.

(b) The Measurement of Intake in the Grazing Ruminant

The techniques available for the measurement of intake of the grazing animal can be classified into two broad categories - direct and indirect techniques. The former include pasture sampling and animal weighing techniques while the latter revolve around the estimation of faecal output and feed digestibility.

A. Direct Techniques

I. Pasture sampling

The basic method involved is the "difference" method whereby pasture intake is equated with the difference between the yield of pasture before and after grazing.

Imprecisions in the technique arise when:-

(i) Growth occurs during the grazing period. Protection of areas from grazing allows intake to be estimated from the difference between the herbage yields of caged and grazed areas sampled at the end of grazing. However differences in the relative growth rate of protected and grazed areas (Cowlishaw 1951) mitigate against the usefulness of this practice. Several equations (Linehan *et al*. 1947; Linehan 1952; Lowe 1959) have been evolved to allow for growth during the grazing period but are not satisfactory (Raymond 1963).

(ii) The cutting height does not match the grazing height. Cutting above grazing height will underestimate intake while cutting below grazing height will overestimate consumption.

Where pasture growth is uneven the problem of sampling the area adequately will be increased thereby accentuating the above imprecisions.

Essentially the method measures the disappearance rather than the consumption of pasture. This includes several sources of pasture loss (e.g. through death, trampling, dung patches, insects and rodents) over and above those due to consumption, so that even if measurement is made with acceptable precision, it will tend to overestimate intake by the grazing animal.

Intake will normally be measured on a group rather than individual basis by this method and even where tight control of both animal and pasture is possible the C.V. of dry matter consumption can easily exceed 20% (MacLusky 1955; Corbett and Greenhalgh 1960).

For the above reasons this method of intake measurement is not widely accepted for quantitative nutritional studies (Corbett and Greenhalgh 1960; Raymond 1963; Moule 1965).

II. Animal weighing

Although suggested over thirty-five years ago by Erizian (cited by Allden 1969) this technique for estimating intake has not been used until recently and then only in specialised situations. Thus it has been used to measure intake over periods of a few hours to allow the rate of eating (Whittaker 1965; Allden 1962) or digestibility of the pasture (Allden 1969) to be determined.

The technique utilises the formula:-

$$\begin{pmatrix}\text{herbage}\\ \text{consumed}\end{pmatrix} = \begin{pmatrix}\text{final body}\\ \text{weight}\end{pmatrix} + \begin{pmatrix}\text{weight of faeces}\\ \text{and urine excreted}\end{pmatrix} + \begin{pmatrix}\text{insensible}\\ \text{weight loss}\end{pmatrix} - \left(\begin{matrix}\text{initial}\\ \text{body weigh}\end{matrix}\right.$$

Details of the technique are given by Allden (1969).

The usefulness of the technique will depend on the relevance of the insensible weight losses estimated from muzzled sheep and on the accuracy with which the diet is sampled to allow moisture content determination.

B. Indirect Techniques

These methods depend on the separate estimations of faecal output (F) and the apparent digestibility of the herbage consumed (D). Intake can then be calculated from the expression:-

$$\text{Intake} = F \times \frac{100}{100 - D}$$

The expression within the bracket is known as the intake factor (Lancaster 1954).

Intake may be expressed in terms of dry matter, organic matter or digestible organic matter. The latter may be regarded as a measure of digestible energy (Corbett and Greenhalgh 1960) and is therefore of greater nutritional interest.

An important point to note about this method of deriving intake is that digestibility must be measured with a small standard error because the term (100 - D) is used rather than D itself thereby compounding the error term. For instance if a D value of 75% was estimated with an error term of ± 3% this would represent an error of ± 12% where (100 - D) was used to estimate intake.

It should also be appreciated that the coefficient of variation for a digestible organic matter intake factor is considerably higher than that for the corresponding organic matter digestibility.

I. Measurement of faecal output

Measurement of faecal output can be made either by total collection of faeces or by the use of external markers.

(i) Total collection. For total collection requirements include bags and harnesses, trained animals and apparatus to dry and weigh faeces. Advantages of such a method are the simple equipment required, low skilled labour requirement and a daily estimate of faecal output. However the technique is normally confined to entire or castrated males, although collection apparatus for females has been designed (Balch *et al*. 1951; Owen and Ingleton 1963). It also interferes with the normal return of faeces and parasite eggs to the pasture although this disadvantage is likely to be unimportant in the short term. Interference with animal behaviour is a potential source of bias and has been noted in cattle (Corbett 1960; Meyer *et al*. 1956) and sheep (Hutchinson 1956). It is for this reason that the training of animals and culling of the most nervous individuals is stressed (Anon. 1961; Moule 1965; Harris *et al*. 1967).

Errors in this method include bias which may occur due to incomplete collection of faeces and although their detection may be difficult, such errors should be eliminated by attention to fit and correct harnessing. Random errors due to defaecation around the time of changing the bag may occur although their importance will be minimised by collection over several days.

The method is normally confined to studies with sheep although apparatus for cattle has been designed (Lesperance and Bohman 1961). Restriction of the apparatus to one sex is perhaps the most important weakness of the method.

(ii) External markers. The use of external markers to measure faecal output is designed to overcome the problems of the total collection method but in doing so creates problems of its own.

In this method, a daily dose of marker is given to the animal and the concentration of this marker in the faeces is measured. Then daily faecal output is given by:-

$$\frac{\text{(Daily dose marker)}}{\text{(Faecal concentration of marker)}}$$

In other words, the method necessitates the use of a marker substance as well as the sampling of faeces and determination of faecal concentration of the marker.

The properties of the ideal marker substance have been listed by Raymond and Minson (1955). The marker should neither be absorbed or be abnormally retained in the digestive tract; it should be non-toxic, inexpensive and readily analysed, and finally, it should only be present in very small amounts in the original diet.

Several markers have been used (Raymond and Minson 1955) but of these Cr_2O_3 has approached the ideal most closely and has therefore received the most attention and refinement.

Sampling of faeces can be carried out by collection from the pasture or directly from the rectum (grab sampling).

Pasture sampling may be carried out on a group or individual basis. In the latter case, faeces may be identified by the use of coloured polystyrene chips. Random quadrats may be taken within a paddock, in which case "ring" sampling may be most suitable (Raymond and Minson 1955). This method of sampling will become slower as pasture length increases, while weather and insects may affect faecal composition.

Grab sampling, at the time of dosing, is less time consuming than pasture sampling and collection is automatically on an individual basis.

Both methods of sampling will be affected to a greater or lesser degree by fluctuations in Cr_2O_3 concentration during any one collection period. Several workers (Kane _et_ _al_. 1952; Lancaster _et_ _al_. 1953; Hardison and Reid 1953; Raymond and Minson 1955; Smith and Reid 1955; Corbett _et_ _al_. 1960a) have reported the tendency for faecal Cr_2O_3 concentrations to decrease during the morning and increase in the evening to a peak in the early hours.

Sampling at times at which samples would be representative for the 24 hour period is a theoretical possibility to avoid the effects of diurnal fluctuations. However the fact that such fluctuations may be inconsistent precludes such practices (Lambourne and Reardon 1963a), although they have been suggested by several authors (Kane _et_ _al_. 1952; Lancaster _et_ _al_. 1953; Hardison and Reid 1953; Smith and Reid 1955). Diurnal fluctuations will vary between animals and between days (Lambourne and Reardon 1963a), between grazing and pen-feeding conditions (Raymond and Minson 1955) and may be modified by pasture quality (Lambourne 1957a), climatic conditions and water consumption (Hardison and Reid 1953). That grab sampling is more liable to this source of bias than pasture sampling, is shown by the work of Raymond and Minson (1955) and Langlands _et_ _al_. (1963b).

Another approach to this problem is to try to minimise these fluctuations. This may be achieved either by dosing more frequently or by use of slow dissolving Cr_2O_3 preparations. Evidence for daily as opposed to every other day administration is given by Harris et al. (1967) while the benefit of twice daily as opposed to once daily administration has been indicated by Lambourne and Reardon (1963a).

The use of slow dissolving Cr_2O_3 preparations is based on the assumption that such a practice will result in more even passage of Cr_2O_3 from the rumen. Regurgitation losses may preclude any advantages to be gained from such preparations where Cr_2O_3 may be mixed with plaster of Paris (Pigden and Brisson 1957) or used to impregnate paper. However if the paper is shredded this problem is overcome and since compact pellets of shredded paper can be made so that they quickly revert to their original form in the rumen (Troelsen 1963), the method is practical. The use of impregnated paper has proved superior, as judged by reduced fluctuations, to capsule Cr_2O_3 in several studies (Corbett et al. 1960a; 1960b; Cowlishaw and Alder 1963) although this need not always occur (Langlands et al. 1963a). This may be especially so when a major portion of the day's ration is eaten immediately after dosing thereby allowing capsule Cr_2O_3 to be more thoroughly mixed with digesta than if feeding is spread throughout the day (Langlands et al. 1963a).

Analysis of Cr_2O_3 in faeces is normally carried out by one of several methods. These can be classified into two general categories - those that are rapid and accurate but require expensive equipment (Williams et al. 1962; Stevenson and Clare 1963) and those that require ordinary laboratory equipment but are only satisfactory if adequately standardised (Christian and Coup 1954; Stevenson and de Langen 1960).

Errors in the technique arise from several sources. Incomplete recovery can result from loss of all or part of the dose through regurgitation although this may be avoided. Further losses can occur at milling while incomplete chemical analyses may also contribute to less than 100% recovery. A temporarily low recovery may result from a drop in faecal output with its consequent increase in retention time. Recycling of Cr_2O_3 due to soil ingestion has been reported by Young and Corbett (1969) and would lead to underestimation of faecal production.

Errors may also occur from sampling techniques as discussed above while the bulking of faecal samples of equal weight but different marker concentration may also be important (Lambourne 1957b).

The advantages of an external marker method lie in the increased flexibility it allows as regards number and sex of individuals sampled. It is also thought to cause less interference with animal behaviour and may require less time in the field.

Apart from the errors involved, disadvantages of the technique include a requirement for skilled laboratory staff as well as laboratory equipment. More frequent handling of animals and longer collection periods for a given degree of precision may be required than for total collection (Grimes 1966).

Using this method, Corbett (1960) considered that it would be possible to estimate faecal output for an individual animal over a 7 day period with a coefficient of variation no greater than ± 5%. However such a low coefficient does not appear to have been achieved in practice, most of the published figures being close to a value of ± 12% (Lambourne and Reardon 1963a).

II. Measurement of diet digestibility

Before considering the techniques available for estimating diet digestibility it is important to realise that the digestibility of the ingested material depends not only on the intrinsic properties of that material but also on other factors which include:-

(i) Level of intake. An inverse relationship between digestibility and level of intake has often been demonstrated although Brown (1966), who reviewed this subject, concluded that the extent of decline in digestibility with increasing level of intake varied between diets, between experimental stations and between trials within experimental stations.

(ii) Animal variability. The extent of differences between cattle and sheep in their digestive efficiencies has been reviewed by Van Dyne (1968) who concluded that although cattle often digest the fibrous components of low quality roughages somewhat better than sheep, within species variation is often as high as between species variation.

Variation between sheep in digestibility of 1.1 (Forbes *et al.* 1946) and 1.3 (Raymond *et al.* 1953) units have been noted although the extent to which this variability is influenced by different conditions is not clear (Van Dyne 1968).

(iii) Age. Whether age affects the digestive efficiency of sheep is not clear. Digestibility was shown to increase up to 2 years of age by Raymond *et al.* (1954) but this may have been associated with increasing resistance to internal parasites (Minson and Raymond 1958).

(iv) Parasites. A depressing effect on digestibility by parasites has been reported (Spedding 1954) and may be especially important in young animals.

From the above it is clear that for digestibility measures to be relevant to the field situation they must be made not only using the diet of the grazing animal but also under conditions which reproduce those factors capable of affecting digestibility. Errors introduced by failure to observe these conditions have been termed "errors of application" by Minson and Raymond (1958).

Methods of estimating diet digestibility may be classified as to whether they require a sample of the herbage ingested by the grazing animal or not.

(i) Methods where sample of diet is not required

1. Faecal-index techniques

The use of this technique depends on the establishment, in pen trials, of regression equations predicting digestibility of feed from faecal components. Digestibility of herbage eaten by the grazing animal is then estimated from the concentration of the faecal components.

Of those faecal components which have been used crude fibre, normal acid fibre and the methoxyl fraction of lignin are negatively related to digestibility while chromogens and nitrogen show a positive relationship to digestibility.

Many regression equations of this type have been published and lists of these are available (e.g. Corbett and Greenhalgh 1960; Van Dyne 1968). Because their errors of application are greater than those of other indices, the use of fibre fractions has been largely unsuccessful (Raymond et al. 1956) while the methoxyl fraction of lignin has proved too insensitive to changes in digestibility (Reid and Kennedy 1956). When extracted from faeces, the chromogen fraction is very light labile (Lancaster and Bartrum 1954) and this may lead to the analytical errors (Corbett 1960) which prejudice this method. As a result faecal nitrogen is the most commonly used index.

The observation of Minson and Raymond (1958) that 90% of the total variation in faecal nitrogen - digestibility relationships resulted from variations in the pasture fed, led to the establishment of different regression equations for different pasture types and different seasons (e.g. Greenhalgh and Corbett 1960; Lambourne and Reardon 1962). Although these "local" regressions may lower prediction errors, errors of application, especially when selective grazing occurs will affect the validity with which these regressions are used.

It is not surprising therefore that Minson and Raymond (1958) consider that the faecal index technique is unlikely to allow differences in intake of less than 10% to be measured significantly, even when errors are minimised or allowed for. More recently Langlands (1969) has shown that the faecal nitrogen index technique is unsatisfactory when intake, digestibility or pasture availability vary to any extent. Information on the soil intake of ruminants (Healy 1967; 1968) and of the large biases in faecal index techniques due to soil ingestion (Lambourne pers. comm.) make these techniques even less attractive when ingestion of soil occurs to any extent.

(ii) Methods where sample of diet is required

The development of easily maintained oesophageal fistulae in sheep and to a lesser extent in cattle offers a potentially powerful means of studying the diet of the grazing animal.

However, the usefulness of any information derived from this method of diet sampling will depend on the validity of the procedures used. This question is discussed elsewhere in this review but it is pertinent to note that scant attention has been placed on this aspect of the use of oesophageal fistulated animals in much published work.

Assuming that the diet sampling procedure is adequate, then the samples collected can be used in two main ways for the evaluation of digestibility *in vivo*.

1. Microdigestion

The basis of these methods is the establishment of a regression equation between *in vivo* digestibility estimates of a feed and microdigestibility estimates of the same feed. The regression is then used to predict *in vivo* digestibility of a feed from a measure of its microdigestibility.

Microdigestion can be carried out either by *in vivo* or *in vitro* methods.

The use of *in vivo* methods has been largely confined in use to workers in U.S.A. and variables affecting estimates obtained by these methods have been reviewed by Van Dyne (1968). Interpretation of *in vivo* microdigestion estimates is difficult since their relationship to *in vivo* macrodigestion is seldom assessed (Van Dyne 1962; 1968). Although forages of known digestibility have been used to correct *in vivo* microdigestion estimates (Van Dyne and Weir 1964) this gives no indication of the precision of the estimates obtained. Thus until such relationships are assessed, digestibility estimates obtained by this method are of limited use.

A variety of *in vitro* microdigestion techniques have been evolved (Van Dyne 1962) but the two-stage technique of Tilley *et al*. (1960) forms the basis for the microdigestion technique used in many laboratories.

While several variables may affect estimates using this particular method (Drew 1966), the use of standard procedures and standard samples has resulted in standard errors of estimate as low as 1.06 (Drew 1966) although most lie between 2.0 - 3.0 (Tilley and Terry 1963; O'Shea and Wilson 1965; Oh *et al.* 1966; Alexander and McGowan 1966). The use of such regressions gives a more precise estimate of *in vivo* digestibility than does any other general relationship for the prediction of digestibility (Corbett 1966) although underestimation of *in vivo* digestibility may occur above 80% digestibility (Arnold and Dudzinski 1967c).

The use of *in vitro* digestibility estimates of diet samples therefore provides a method of measuring the digestibility of the diet of the grazing animal. Although selective grazing will not influence the precision of this method, some errors of application may still exist. These will occur when the regression equations used to predict *in vivo* digestibility have been derived from *in vivo* data collected under conditions which do not simulate those of the grazing animal. For example, sheep in pens often eat less than those in the field (Minson and Raymond 1958) so that a level of intake effect on digestibility may occur thereby giving rise to an application error. The extent to which such errors will be important will depend on the extent to which factors giving rise to them, have been incorporated in the prediction equation.

2. Ratio technique

In this technique a naturally occurring but indigestible indicator is required and its concentration in the feed and faeces is measured so that digestibility can be calculated from:-

$$100 - 100 \frac{\text{conc. indicator in feed}}{\text{conc. indicator in faeces}}$$

Several indicators have been used including fibre (Leroy 1952), silica (Van Dyne and Lofgreen 1964), chromogens (Reid *et al.* 1950) and lignin (Forbes and Garrigus 1948) while the use of indigestible cellulose merits consideration (Wilkins 1969).

Of these, lignin is the only one to have been used to any great extent up to the present time. However the ratio technique necessitates 100% recovery of indicator substance and since several workers (e.g. Lancaster 1944; McCullough 1959) have shown that "lignin" is not completely indigestible the method has not been popular. However recent refinements in determining the "lignin" fraction of herbage (Ulyatt *et al.* 1967) have allowed recoveries of lignin not differing significantly from 100%. Kellaway (pers. comm.) has obtained lignin recovery of 98.3 ± 1.2% and considers that probable reasons for this are the use of freeze-drying (which avoids artefact lignin produced during heat drying) and the use of Van Soest's (1964) method for isolating the lignin fraction which has a lower degree of nitrogen contamination than lignin isolated by other methods.

Lignin ratios have been used to measure digestibility along the digestive tract of the sheep (Ulyatt et al. 1967; Ulyatt 1969) and their use in association with oesophageal fistula and faecal samples would enable the digestibility of the grazing animal's diet to be estimated. However no report has yet been published on the relationship between % lignin in extrusa and % lignin in herbage ingested while between and within animal variance components for % lignin in extrusa and faecal OM need establishing. The possibility of diurnal fluctuations in the "lignin" fraction of extrusa needs investigation as does the repeatability of such fluctuations if they exist.

The main advantage of the ratio technique would be the elimination of application errors since digestibility would be determined directly from the grazing animal. However the tedious nature and imprecision of lignin analyses are serious drawbacks to the technique, while the effects of soil contamination have still to be determined.

Since different techniques of measuring digestibility can only be evaluated in terms of actual digestibility, comparisons of these are confined to pen feeding conditions. Under such conditions faecal nitrogen - digestibility regressions gave a more precise estimate of in vivo digestibility than did in vitro digestibility estimates (Arnold and Dudzinski 1967c). This is in agreement with an earlier suggestion of Langlands (1966) that the oesophageal fistula technique would give a less precise estimate of digestibility than "local" faecal nitrogen - digestibility relationships. However Kellaway (pers. comm.) has related digestible energy ratio (and hence digestibility) to several feed and faecal indices of digestibility in over twenty digestibility experiments. The best predictor of the digestible energy ratio was lignin ratio (C.V. 9.4%) followed by in vitro digestibility (C.V. 12.3%).

While this evidence is conflicting, it should be appreciated that a more meaningful comparison of the different techniques includes consideration of the magnitude of application errors involved in the use of each technique. From previous discussion it is clear that faecal index techniques are likely to be most affected by this source of bias and this fact is confirmed by data presented by Langlands (1967b).

The error in estimating herbage intake will depend on the errors associated with the estimation of both faecal output and digestibility or more appropriately the intake factor.

For example, the minimum C.V. which is likely to be achieved in practice can be calculated by combining the C.V.'s for the separate determinations of the intake factor and faecal output. Where total collection is used the minimum C.V. is likely to be ± 4 - 5% and this value may be increased to ± 7% where Cr_2O_3 is used to estimate faecal output (Grimes 1966). In practice values may approach these (Grimes 1966; Corbett 1969) but may rise above ± 20% (Lambourne and Reardon 1963a).

CHAPTER II

EXPERIMENTAL PROCEDURES

An experimental area was set up in 1966 by Professor B.R. Watkin to allow a study of the effects of different pasture types and stocking rates on animal and pasture production. The object of the present experiment was to study a small number of these treatments in more detail than is normally possible in an effort to provide information on some of the basic parameters of the grazing situation.

The materials and methods used in the experiment are described in this chapter.

MATERIALS

Experimental Site

The experiment was laid out on Massey University's "Tuapaka" farm (Lat. 40° 21'S), the actual site having a gently sloping NW aspect. The mean altitude of the site is approximately 200 feet above sea level.

The soil types of the area are complex and have been classified as Tokomaru silt loam, Ohakea silt loam and Kairanga fine sandy loam (Cowie pers. comm.). This is shown in Figure 1. Soil profiles taken on the experimental area have provided additional information (Pollock pers. comm.). The soil on the NW side of the creek is part of a high terrace of the Manawatu river (Tokomaru silt loam) while that on the SE side of the creek is derived from a fan overlying this high terrace (Ohakea silt loam). The fan has developed from the hills behind the experimental area.

An important feature is the apparent variation in drainage over the experimental site. There appears to be considerable horizontal water movement in the fan material which overlies the Tokomaru silt loam. In the latter drainage is impeded due to the presence of impermeable subsoil. This results in a relatively free draining area at the top of the fan, drainage becoming progressively worse towards the toe of the fan where the Tokomaru silt loam is closer to the surface. Thus on the NW side of the creek drainage is generally poor while on the SE side it varies from free draining through to poor.

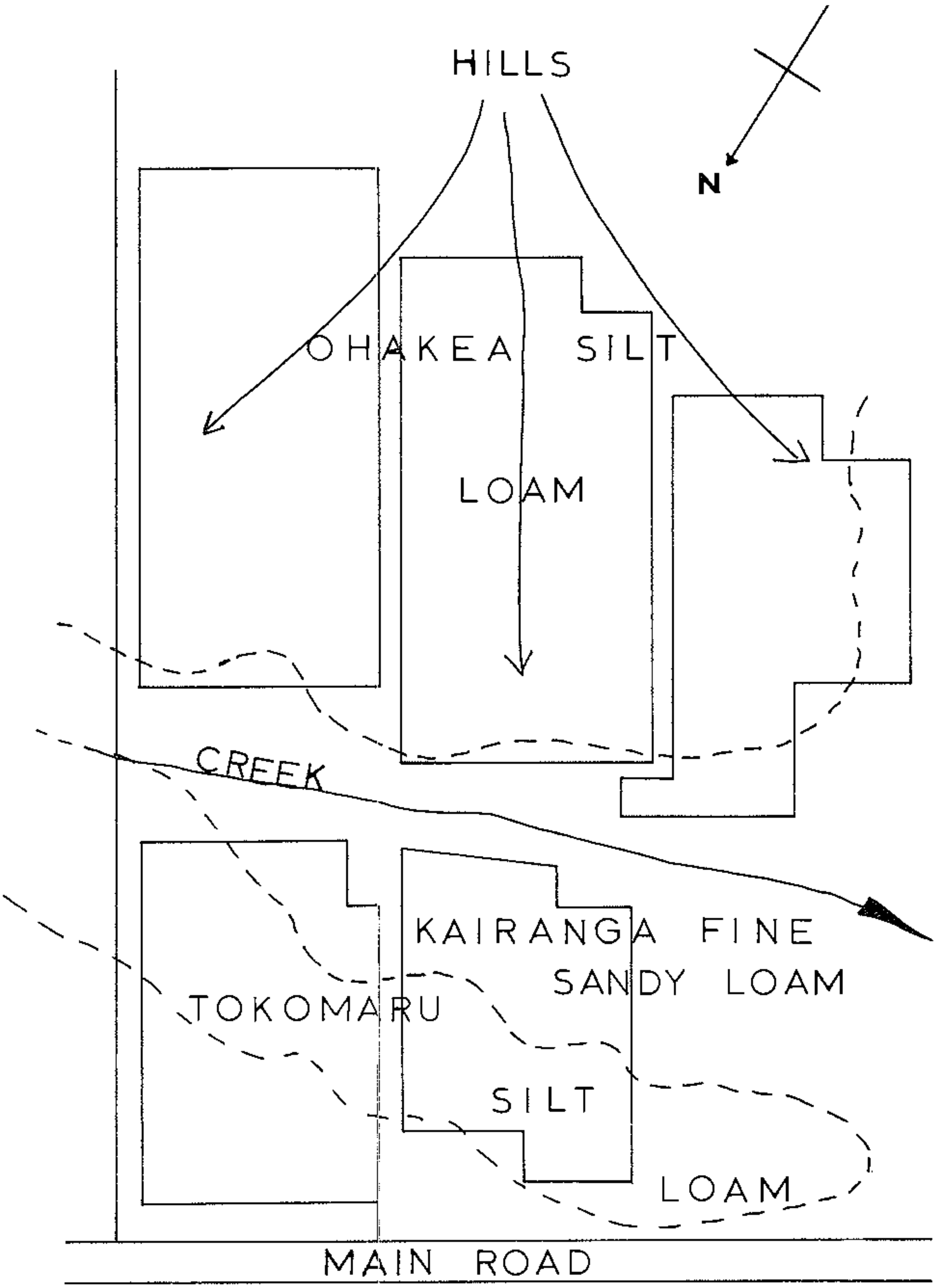
Temperature and rainfall records taken at the D.S.I.R. weather station 8 miles south-west of the experimental area are given in Appendix I.

Layout of experiment

The experimental area was laid out in the autumn of 1966 to allow a study of the effects of different pasture types and stocking rates on animal and pasture production. The design adopted was a randomised block design of 2/3 acre paddocks accommodating four replications of six different pasture types stocked at two different rates.

After the first year when pastures became well established, wethers grazed the area being set-stocked at either 6 or 13.5 sheep/acre. This phase of the experiment lasted from May 26th until December 14th 1967. Until May 10th 1968 when the experiment to be reported began, pasture management over the area was aimed at re-establishing or maintaining similarity between replicates of any particular pasture. Weed control

Figure 1


HILLS
N
OHAKEA SILT
LOAM
CREEK
KAIRANGA FINE
SANDY LOAM
TOKOMARU
SILT
LOAM
MAIN ROAD

measures were also taken in an attempt to re-establish the purity of several sward types, notably those of white clover.

The present work was planned to compare the production of N.Z. Grasslands "Huia" White Clover (Trifolium repens L.) grown alone and in association with N.Z. Grasslands "Apanui" Cocksfoot (Dactylis glomerata L.). In practice the percentage contribution of clover to total dry matter (DM) of the cocksfoot pastures remained low throughout the experiment while its contribution to the clover pastures although very high prior to the experiment dropped to below 10% in some cases. Thus the comparison is more meaningfully regarded as one between clover dominant and cocksfoot dominant pastures. These will be referred to as clover and cocksfoot pastures respectively throughout this thesis.

A high (9 sheep per paddock) and a low (4 sheep per paddock) stocking rate were used with three replications at the high stocking rate and two at the low stocking rate.

The layout of the paddocks used in the experiment is shown in Figure 2.

In the case of cocksfoot pastures the stocking rate applied to any particular paddock was the same as in the previous year. However in the case of the clover treatments all the high stocked paddocks had previously been stocked at a low rate while one of the low stocked paddocks (paddock 5) had previously been stocked at a high rate. Such allocation of treatments was necessary due to the poor persistence and recovery of clover paddocks after the 1967 experimental period. This resulted in only five clover paddocks being available at the start of the present experiment.

A small pen with an associated "wing" fence was set up on one corner of each paddock to facilitate animal handling.

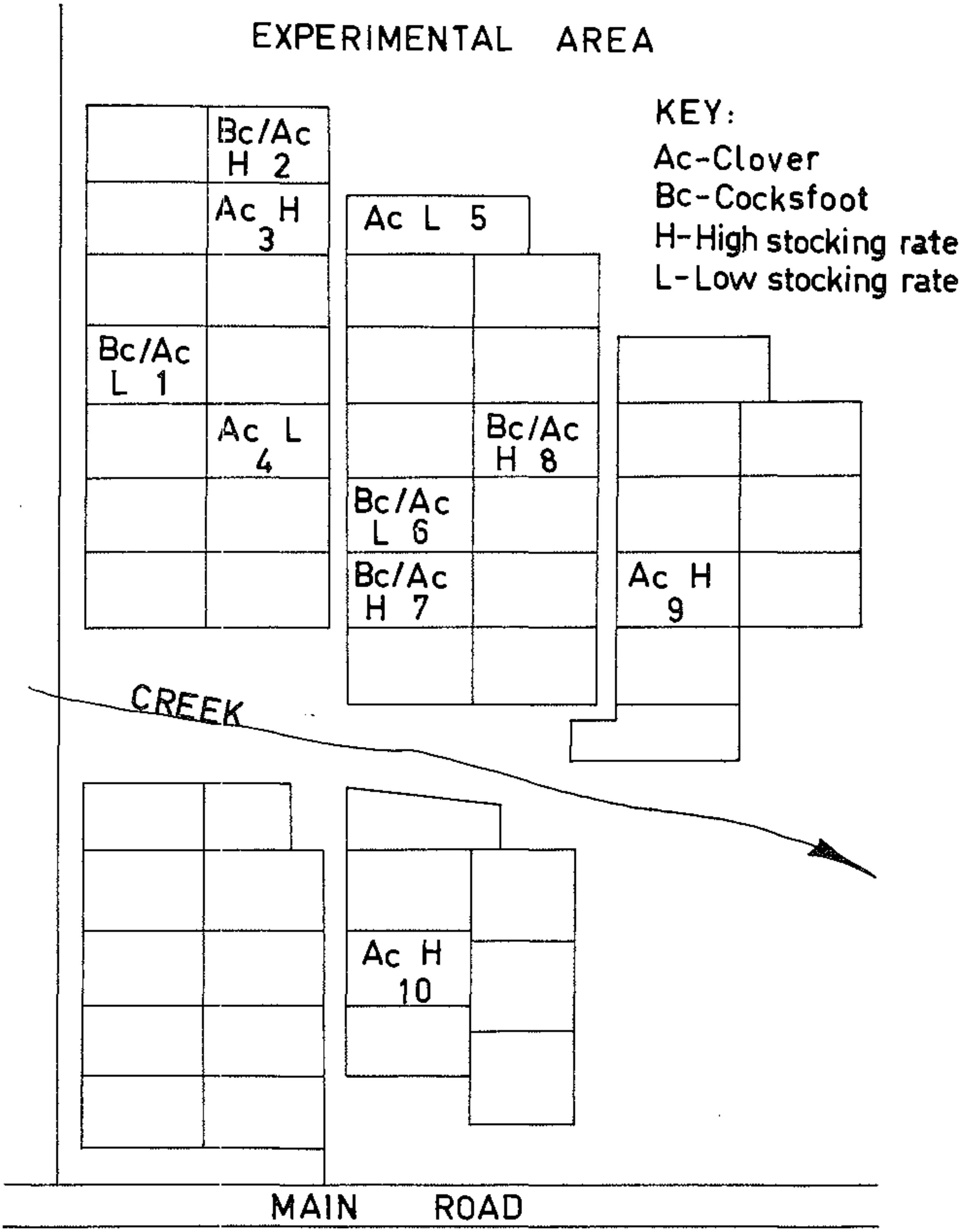
Experimental Animals

A line of sixty-five wether hoggets was purchased in early February. Oesophageal fistulae were established in twenty of these animals on February 19th and 20th. The fistulated sheep were shorn on May 6th while non-fistulated sheep were shorn on April 12th.

Unshorn ewe hoggets, from a large line also purchased in February, were also used in the experiment.

All sheep were grazed together from April 24th to May 10th when they were weighed. Allocation to groups was made on the basis of this weight.

Figure 2


EXPERIMENTAL AREA
KEY:
Ac-Clover
Bc-Cocksfoot
H-High stocking rate
L-Low stocking rate
Bc/Ac H 2
Ac H 3
Ac L 5
Bc/Ac L 1
Ac L 4
Bc/Ac H 8
Bc/Ac L 6
Bc/Ac H 7
Ac H 9
CREEK
Ac H 10
MAIN ROAD

Three non-fistulated wethers were allocated to the ten paddock groups, randomisation being restricted to give a similar liveweight mean and distribution for each group. Ten fistulated sheep, chosen on the basis of liveweight and the success of fistula establishment, were allocated at random, one to each group.

Thirty ewe hoggets were randomised into six groups of five sheep with randomisation again being restricted to give a similar liveweight mean and distribution for each group.

This allowed one group of four wethers to be allocated at random to each high and low stocked paddock while each high stocked paddock was also allotted one ewe hogget group chosen at random. This gave four and nine sheep per paddock at the high and low stocking rates, being equivalent to 13.5 and 6 sheep/acre respectively. Sheep were introduced to the paddocks on May 11th, 1968.

METHODS

Pasture management

Superphosphate, at the rate of 3 cwt. per acre, and muriate of potash, at 1 cwt. per acre, were applied to each paddock following sowing and during the subsequent springs and autumns up to and including the spring of 1968.

During the autumn of 1968 all paddocks were treated with "Fenitrothion" in an effort to reduce the incidence of Porina (*Wiseana* sp.).

Following the introduction of sheep in May no effort was made to maintain pastures in the pure state.

Animal management

Animals were set-stocked on the paddocks until the end of the experiment on 11th November 1968. They were given access to fresh water and salt licks at all times.

Prior to the experiment and at monthly intervals throughout the experiment all animals were drenched in an effort to reduce worm parasites.

During the middle of the experiment most of the ewe hoggets were affected by a skin dermatitis but this disappeared during the spring. One fistulated sheep (paddock 10) died in early October and was replaced by another fistulated animal.

Fistulated sheep only lost plugs twice throughout the experiment and then only for up to twelve hours.

Experimental methods

During the experiment, intake was estimated on seven occasions at approximately monthly intervals. At the same time animal liveweights and several pasture parameters were measured. The schedule of field work during these sampling periods is shown in Table I. Starting dates for each sampling period were:- 19th May, 16th June, 14th July, 11th August, 13th September, 10th October, 3rd November.

Wool samples were taken on 10th May prior to the start of the experiment and on 11th June, 9th July, 6th August, 3rd September, 1st October, 29th October and 13th November.

The time sequence of these samplings is shown in Table II and it will be noted that the wool growth data, corresponding to any particular period, were collected in such a way that a 2 - 2½ week time lag was allowed for response to changes in nutrition.

Animal liveweights

Animals were weighed at the end of each collection period being held in pens for a maximum period of two hours prior to weighing. Liveweight was measured to the nearest pound using a sling suspended from a spring balance supported by a tripod.

For any particular period, liveweight change was calculated from the difference in liveweight at the beginning and end of the period.

Wool production

Wool production was measured by means of sequential samples taken from the mid-side position of sheep as well as by fleece weights. Midside patches of approximately 100 cm^2 were established on all sheep at the start of the experiment and the wool growth on these patches was removed about every four weeks using "Oster" electric clippers (0000 blades). At the first sampling the four sides of each patch were measured to the nearest millimeter using calipers with elongated points. The patch area was then estimated from these dimensions assuming rectangular shape.

Wool samples were conditioned in a humidity room, weighed (to the nearest 0.001 g.), degreased with organic solvents and hot water, and

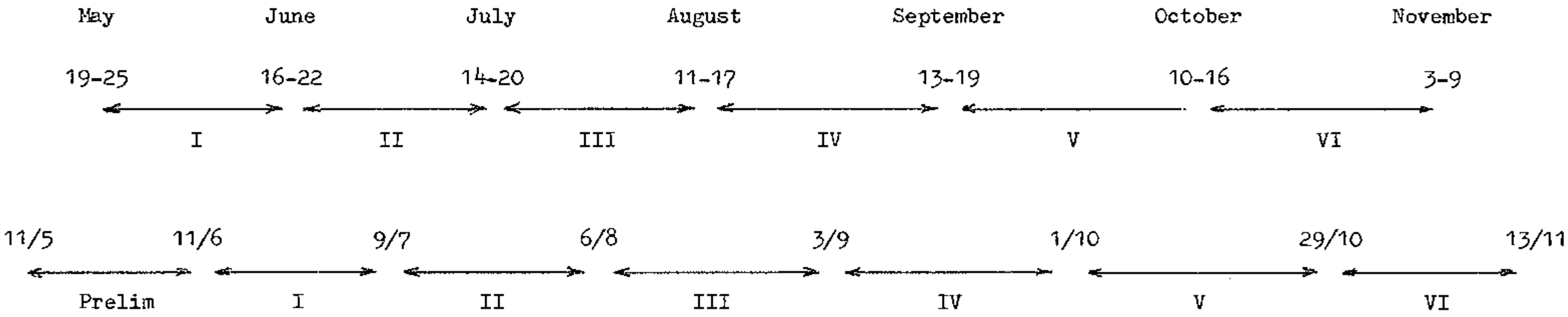
TABLE I

Schedule of field work

DAY	A.M.	P.M.
1	Harnesses and faecal collection bags on sheep	
2		1.00-2.30: Bags changed; faeces discarded. 3.00-4.45: O.F. samples.
3	Pastures sampled	As for day 2.
4	Pastures sampled.	1.00-2.30: Bags changed; faeces collected. 3.00-4.45: O.F. samples.
5		As for day 4.
6		1.00-2.30: Bags changed; faeces collected.
7		1.00-2.30: Bags removed; faeces collected. 2.30-3.30: Sheep weighed.

TABLE II

Time scale used in presentation of results



Dates: Top line = days during which intake, liveweight and pasture parameters were measured.

Bottom line = days on which wool samples were taken.

conditioned for forty-eight hours before clean weights were determined. Wool growth was expressed on the basis of the initial area of the patch.

All animals were shorn on 14th November, fleece weights being measured to the nearest 0.1 lb. on a "Kendall" fleece weighing table.

Pasture availability

To measure availability, pastures were cut at ground level using a "Sunbeam" electric shearing handpiece. Each subsample was placed in a plastic bag and subsequently washed in the laboratory. The entire subsample was then dried at 80° C in a "Unitherm" electric oven for about 24 hours when it was weighed.

At each sampling five subsamples were taken from each paddock using a rectangular quadrat having inside measurements of 4' 4½" and 1'. In all paddocks, with the exception of the low-stocked cocksfoot treatments, subsamples were taken at random over the entire area of the paddock although camping and previously sampled areas were avoided. In the low-stocked cocksfoot treatments where availability was very variable representative sites were chosen for subsampling.

The only exceptions to this routine were at the first sampling when subsamples were not washed and at the second and third sampling when subsamples were bulked for washing and drying.

Pasture growth

Whenever pasture availability was measured, two cages were placed on predetermined sites on each paddock, and growth was estimated from the difference between availability at one sampling and availability within the caged areas at the next sampling.

Two measures of growth were obtained for each paddock for each period. The cages used measured 7' x 3' and one 4' 4½" x 1' quadrat was cut from under each cage to give two estimates of availability after each growth period. Initial pasture availability was taken as the mean of the five subsamples taken in each paddock, except for the low stocked cocksfoot paddocks. In this case "paired" areas (Lynch 1960) were used.

At the beginning of the experiment two cages were placed diagonally opposite one another on each paddock. During the course of the experiment the cages were moved across the paddocks parallel to each other but in opposite directions. The sites were chosen by moving the cages five paces at each sampling except in the case of the low stocked cocksfoot paddocks. Here two sets of paired areas - one representative of high and another of low availability - were used.

Botanical composition

Botanical composition was estimated from pasture-availability samples. After washing, samples of approximately equal weight were taken from each availability subsample and bulked for each paddock. This sample was hand separated into clover components, grass components, weeds and dead matter, botanical composition being expressed on a dry weight basis. Approximately 10 g. dry weight was analysed for each paddock at each sampling.

One fifth of the dry weight of the bulked sample taken for botanical analysis was added to the weight of each pasture availability subsample in order to correct for the removal of wet material.

Soil contamination

The occurrence of large soil intakes became obvious as the experimental period progressed especially when pasture availability was low and ground conditions wet. For this reason it became necessary to assess the degree of soil contamination and its possible effects on the measurement of digestible organic matter intake.

The soil percentage in faeces and diet samples was estimated by the X-ray fluorescence technique outlined by Healy (1968). In this technique the titanium content of a faecal (or diet) sample is determined and compared with a standard curve relating the titanium content of known mixtures of dried soil and faeces (or diet samples) to their soil percentage.

In order to establish the standard curve soil samples were collected from the experimental area. Thirty 0 - 1" cores were taken from each paddock and dried at 100°C for one day when all plant material above the soil surface was removed. The soil was then ground to pass through a 1 mm. sieve and dried for a further two days. The sample for each paddock was then mixed thoroughly and a subsample of about 120 g. was removed. This was sieved to pass a 50 mesh sieve, less than 3% of the sample being rejected. Using soil prepared in this way equal weights from each paddock were combined to give a composite sample for the area. This composite sample was then used with soil free faeces and diet samples to provide mixtures having known soil percentages on a dry matter basis. The soil percentages of these mixtures ranged from 0% to 90%.

The titanium content of these standards was determined with a Philips P W 1010 X-ray Fluorescence Unit using a chromium target tube and a Lithium-fluoride analysing crystal. Counts were made for 15 seconds.

Curvilinear regressions were fitted to the data relating soil percentage of the standard mixtures to their titanium content. Separate regressions were established for faeces and diet standards.

Duplicate determinations of the titanium content of faeces and diet samples were made, these samples having been dried and ground prior to analysis. The titanium content of each sample was then used in association with the appropriate curvilinear regression to give an estimate of soil content.

Measurement of digestible organic matter (DOM) intake

DOM intake was estimated by combining measures of faecal output and digestibility predicted from the *in vitro* OM digestibility of diet samples collected *per* fistula.

(i) Output of faecal OM

Faecal output was measured by total collection. Prior to the first collection period wethers were fitted with the collection harnesses and bags for several days and any animal whose behaviour was markedly affected by the collection apparatus was not used for faecal collection during the experiment.

Faeces were collected from two wethers on each paddock over four days at each sampling, both the harnesses and bags being put on the sheep two days prior to the start of collection to allow time for adjustment of harnesses. If there was any reason to suspect that collection of faeces had been incomplete the sample for that day was discarded. Faeces were collected from each pair of sheep at the same time every day.

After the first collection period the same pair of sheep were used for faecal collections on each paddock for the remainder of the experiment with one exception. This was on paddock 10 where one sheep was changed at the September collection.

Samples collected on each day were weighed and a subsample of approximately 300 g. was then dried in a "Unitherm" oven at 80° C for about 24 hours to give an estimate of dry matter percentage and hence of daily faecal dry matter output. Dried samples for each sheep for each period were bulked on a proportionate dry matter basis, ground through a 2 mm. sieve and stored.

These samples were used in the determination of faecal soil percentages (c.f. previous section) and faecal OM percentages. Duplicate subsamples of approximately 2.0 g. of each of the bulked samples were redried for 48 hours at 100° C and ashed overnight at 600° C. The loss in weight during ashing gave an estimate of the apparent OM content of the faeces of each wether over each sampling period. This estimate combined with the estimate of daily faecal dry matter output gave an estimate of daily faecal OM output.

However if faeces are contaminated with soil, some of the apparent faecal organic matter will be due to the loss in weight of soil on ashing. It is therefore necessary to differentiate between that part of faecal OM which is due to loss in weight of undigested plant material and that part due to loss in weight of soil.

The way in which this separation was achieved is given in Appendix II (a) and by this means the output of faecal OM arising from ingestion of plant material was determined.

(ii) OM digestibility of diet samples

After faecal collections had been made on any particular paddock, all sheep except the fistulated wether were released from the pen. The fistulated animal remained in the pen until used for diet sampling, a maximum period of three and a half hours.

Diet samples were collected between 3 p.m. and 4.45 p.m. on four consecutive days as shown in Table I. The order in which paddocks were sampled was varied each day. Samples were collected into plastic bags fastened around the animals' neck for periods of 15 - 30 minutes depending on pasture conditions. Any sample in which the extrusa had separated into solid and liquid fractions was rejected as were samples contaminated with rumen contents. In such cases animals were re-penned until all other sampling was complete when they were used again for sample collection.

On collection, samples were immediately divided into two subsamples which were placed in waxed paper cups and put in crushed ice in an appropriate container. Once collection was completed, all samples were transferred to a freezer (26° F) at Massey University.

Subsequently one subsample was freeze-dried and ground to pass through a 1 mm. sieve. Subsamples prepared in this way were then bulked on an equal dry weight basis for each sheep over each collection period. These bulked samples were used for the determination of *in vitro* OM digestibility and the soil percentage of the diet. The remaining subsamples were used for botanical analysis of the diet.

A regression between *in vivo* and *in vitro* OM digestibility was established for four feed samples ranging in *in vivo* OM digestibility from 60% to 85% using the method described by Parks (1966). Rumen liquor was obtained from a rumen fistulated cow grazing a predominantly ryegrass/white clover pasture. This regression (given in Appendix III (a)) was then used as a basis for estimating *in vivo* OM digestibility of diet samples from their *in vitro* OM digestibility values.

Duplicate analyses within a run were made on each diet sample and if these differed by more than 2.5 digestibility units, the determination was repeated. Standards were included in each run. These did not differ by more than 2.5 digestibility units between runs and no corrections were made to estimates of digestibility for between run variance.

Since many of the diet samples were contaminated with soil it became necessary to ascertain to what extent this affected *in vitro* OM digestibility estimates. *In vitro* OM digestibility analyses were carried out on three standard feeds mixed with known amounts of soil. In all cases allowance for soil OM effects removed the difference between the digestibility of the feed with and without soil. The method of correction for soil contamination and detailed results are given in Appendix III (b) and III (c).

All *in vitro* OM digestibility values of diet samples were therefore corrected for soil contamination before being converted to the appropriate *in vivo* value. This value was then used to obtain a DOM intake factor for each paddock at each sampling. This was combined with the appropriate measure of faecal OM output to give an estimate of DOM intake for each of the wethers used for collection on each paddock.

Botanical composition of diet

The botanical composition of the diet was estimated for each paddock for each sampling period by the optical point quadrat method described by Grimes *et al*. (1965). This method was modified in two respects. Macerated material was not washed with ethanol and the gauze screen was pulled up through the floating plant material to give an even spread of herbage over the screen.

Subsamples of approximately 2 g. were taken from diet samples collected for a particular paddock in any one period and bulked, analysis being carried out on this composite sample. Plant material was identified as grass, clover component, weed or dead. Each sample was recorded with two replicates of 100 points.

Foraging time

Six "Kienzle" vibra-recorders became available in early August and these were used to measure foraging time (Allden 1962). Foraging times were measured with two vibra-recorders on each of paddocks 7 and 9 and with one vibra-recorder on each of paddocks 6 and 4 until the end of the experiment.

Data from charts produced by the vibra-recorders were recorded to give total hours foraging per day, percentage of total foraging time occurring between morning and evening twilight and number of foraging periods per day. Only periods of activity longer than five minutes were recorded from the charts.

Statistical analysis

Analysis of the data obtained in this experiment was complicated by two factors. In the first case replication of stocking-rate treatments was unequal while in the second case the third replication of the high-stocked treatments (paddocks 7 and 10) were not balanced with respect to blocks.

Data derived from the paddocks in blocks I (paddocks 1, 2, 3 and 5) and II (paddocks 4, 6, 8 and 9) were examined by analyses of variance corresponding to the following model (all classifications fixed):-

$$X_{ijkl} = m + P_i + B_j + S_k + (PB)_{ij} + (BS)_{jk} + (PS)_{ik} + (PBS)_{ijk} + e_{ijkl}$$

where m = general mean

P_i = pasture effect	i = 1 Clover, 2 Cocksfoot
B_j = block effect	j = 1 Block I, 2 Block II
S_k = stocking-rate effect	k = 1 High-stocked, 2 Low-stocked.

Data from the high stocking rate treatments were examined by analysis of variance assuming a hierarchal classification of samples within replications (paddocks 2, 3, 7, 8, 9, 10) within pasture types (cocksfoot and clover).

The significance of differences between means were tested using Duncan's New Multiple Range Test (Duncan 1955).

Liveweight changes, wool growth, pasture availability, pasture growth and DOM intake were analysed as described above. In addition, the effect of reducing variation in ewe wool growth by covariance with wool growth prior to the experiment was examined. The lack of correlation between sets of comparisons invalidated any adjustment of means. There were no data available on wether wool growth prior to the experiment.

Subclass variances in pasture availability for all samplings except the first were heterogeneous by Bartlett's test (Snedecor and Cochran 1967) but transformation of original data to base 10 logarithms removed this heterogeniety.

At the June and July samplings when pasture availability subsamples were bulked on a paddock basis, it was not possible to test the three way interaction in the analysis of variance as this was incorporated in the residual mean square. For the same reason, the analyses of data from high-stocked paddocks had to be modified such that only variation arising from differences between pasture types could be tested.

There was little difference between estimates of pasture growth on the low stocked cocksfoot paddocks obtained from "paired" areas or from the method used for all other paddocks. Estimates obtained by the latter method were used in statistical analysis. Bulking of samples in June and July necessitated changes, similar to those described for availability data, in the analyses of pasture growth data.

Presentation of Results

Results have generally been presented in three ways; in analysis of variance tables, tables of means and in diagrams.

In the analysis of variance tables the following levels of significance are indicated:-

$P < 0.10$ *

$P < 0.05$ **

$P < 0.01$ ***

Results of Duncan's New Multiple Range Test are presented in the tables of means so that within observations, means with the same letter do not differ significantly at the 5% level of significance.

In the diagrams the symbols Bc/Ac and Ac are used to describe cocksfoot clover and clover pastures respectively. A key to any other symbols used is provided in each diagram.

The time scale used throughout the presentation of results is shown in Table II.

CHAPTER III

RESULTS

RESULTS

(a) Animal Liveweights.

Figure 3 shows the changes in mean liveweight of the wether hogget groups on blocks I and II. The total liveweight change for these groups over the experimental period was examined by analysis of variance and this is summarised in Table III (a) while Table III (b) shows the means for each group tested by Duncan's New Multiple Range Test.

Over the entire experimental period sheep on the low stocking rate gained more weight than those on the high stocking rate (S effect) especially on clover pastures (P and PS effects). The large changes in liveweight of sheep on the clover paddocks of block I resulted in the significant B and PB effects while the significantly different liveweight changes of the two groups of high stocked clover sheep gave rise to a PB interaction at this stocking rate (PBS effect).

Figure 4 shows the liveweight changes occurring in the wether and ewe hogget groups on the high stocking rate paddocks. The analyses of variance of total liveweight change for both groups are given in Table IV (a).

Both analyses indicate that there were no differences in liveweight change due to pasture type although there were significant differences in the performance of sheep on different paddocks with those on cocksfoot paddocks having higher weight gains than all other sheep with the exception of those on paddock 3 (Table IV (b)).

In order to appreciate the development of these total effects more fully, liveweight changes occurring during each period were examined. A summary of the three way analyses of variance carried out on the wether hogget data from blocks I and II is given in Table V, the appropriate means being presented in Table VI.

(i) Preliminary period - During this period liveweight changes on all paddocks were similar. This period is not shown in Figure 3.

(ii) Period I - The high number of significant sources of variation contributing to liveweight change during this period prevents any unqualified generalisations about treatment effects. Thus although sheep at the low stocking rate gained more weight than those at the high stocking rate (S effect) this was more marked for clover than cocksfoot pastures (PS effect) and on block II than on block I (BS effect). Similarly although sheep on block I grew faster than those on block II (B effect) this occurred

Figure 3

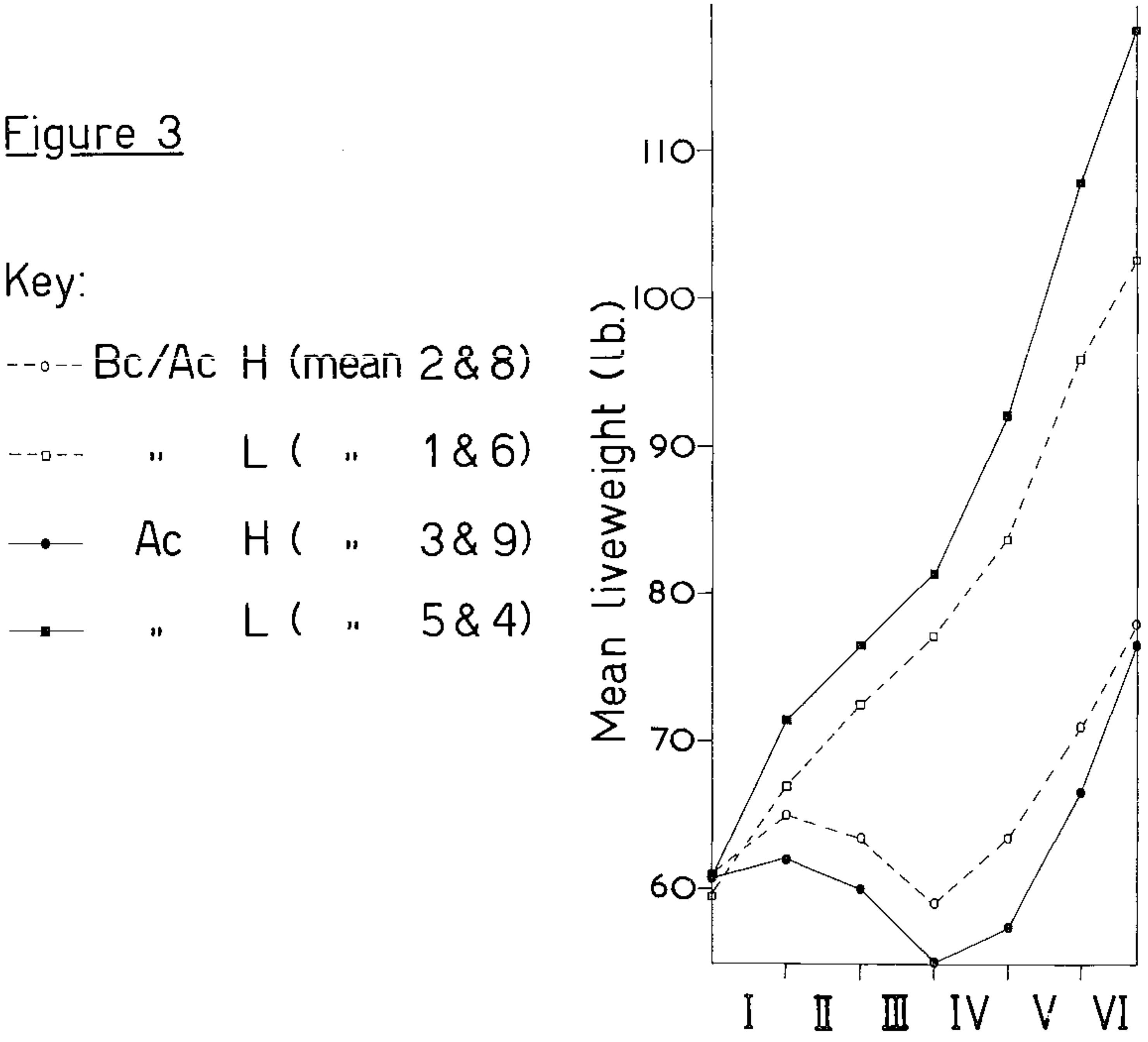

Key:
--o-- Bc/Ac H (mean 2 & 8)
--□-- " L (" 1 & 6)
—●— Ac H (" 3 & 9)
—■— " L (" 5 & 4)
Mean liveweight (lb.)
60
70
80
90
100
110
I
II
III
IV
V
VI

TABLE III

(a) Analysis of variance for total liveweight change on blocks I and II (lb./sheep).

Source of variation	D.F.	Mean Square
Stocking Rate (S)	1	6,800.1***
Pasture Type (P)	1	308.2***
Block (B)	1	253.5***
PS	1	434.1***
PB	1	170.7**
BS	1	8.8
PSB	1	149.4**
Residual	16	28.4
Total	23	

(b) Mean total liveweight change for wether hoggets on blocks I and II (lb./sheep).

Stocking Rate	Pasture Type	Block	Liveweight Change
High	Ac	I	35.7 c
		II	17.7 e
	Bc/Ac	I	26.7 de
		II	29.3 cd
Low	Ac	I	71.7 a
		II	66.0 a
	Bc/Ac	I	55.7 b
		II	50.7 b

Figure 4

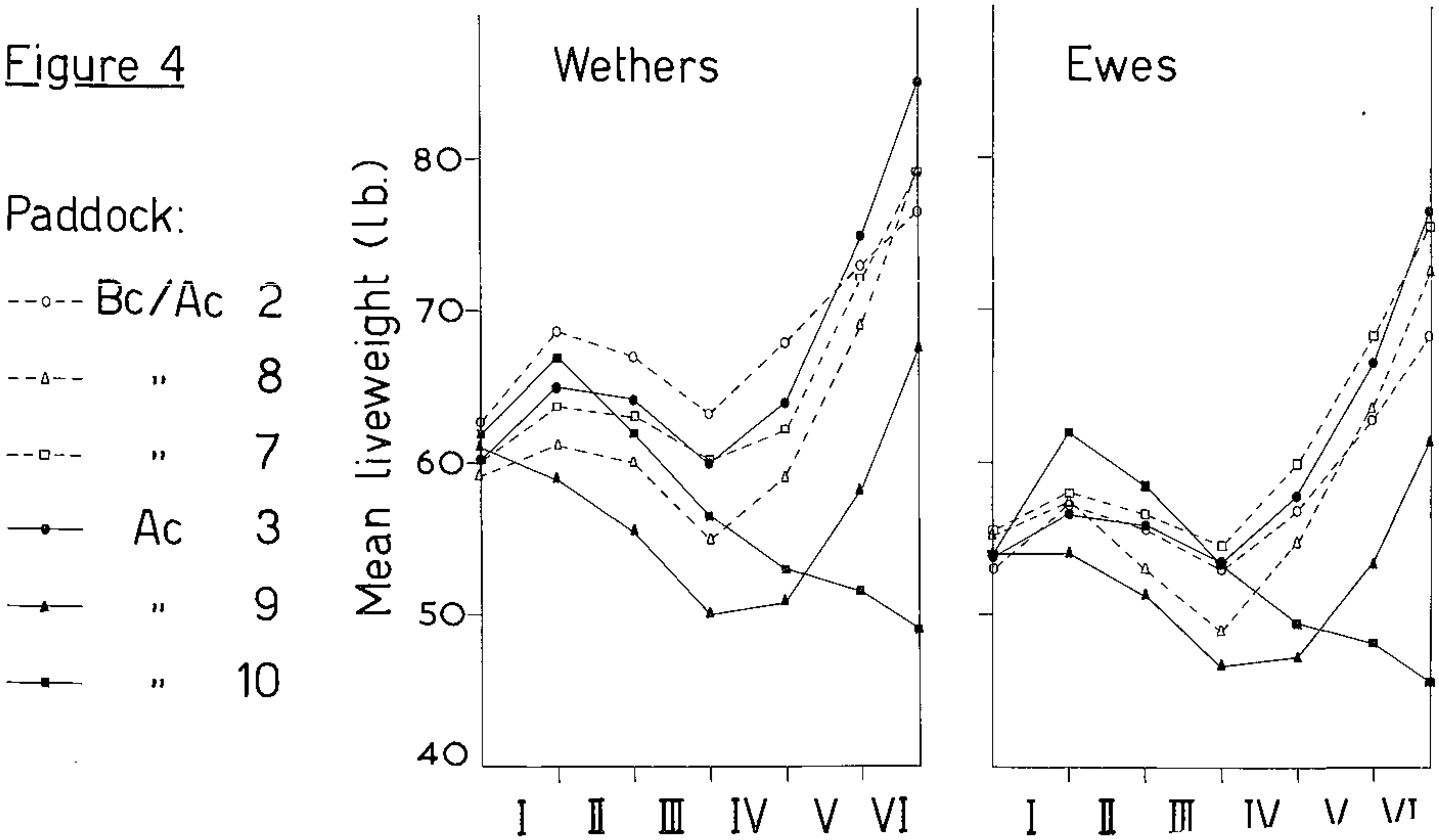

Paddock:
Bc/Ac 2
" 8
" 7
Ac 3
" 9
" 10
Wethers
Ewes
Mean liveweight (lb.)
80
70
60
50
40
I
II
III
IV
V
VI
I
II
III
IV
V
VI

TABLE IV

(a) Analysis of variance for total liveweight change on high stocked paddocks (lb./sheep).

(i) Wether hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	555.6
Among replicates within pastures	4	508.4***
Among sheep within replicates	12	36.9
Total	17	

(ii) Ewe hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	907.5
Among replicates within pastures	4	579.3***
Among sheep within replicates	24	17.5
Total	29	

(b) Mean total liveweight change for hoggets on high stocked paddocks (lb./sheep).

Pasture Type	Replicate	Wether hoggets	Ewe hoggets
Ac	3	35.7 a	32.0 a
	9	17.7 b	17.0 c
	10	- 1.0 c	1.2 d
Bc/Ac	2	26.7 ab	23.8 b
	8	29.3 a	28.0 ab
	7	29.7 a	31.4 a

TABLE V

Analyses of variance of liveweight changes on blocks I and II (lb./sheep)

			Mean Squares					
Source of variation	D.F.	Prelim	I	II	III	IV	V	VI
Stocking Rate (S)	1	1.04	253.50***	301.04***	522.67***	170.67***	192.67***	0.00
Pasture Type (P)	1	0.38	0.67	2.04	0.17	10.67	37.50**	54.00**
Block (B)	1	0.04	28.17***	7.04	10.67	37.50**	0.17	2.67
PS	1	7.04	54.67***	0.04	0.67	60.17***	6.00	0.17
PB	1	3.38	32.67***	1.04	2.67	17.67*	4.17	13.50
BS	1	3.38	60.17***	0.04	0.17	0.67	6.00	27.17*
PBS	1	1.05	5.33	22.04**	4.17	0.50	80.67***	33.17**
Residual	16	4.54	2.92	3.04	3.79	5.50	5.33	6.67
Total	23							

TABLE VI

Mean liveweight changes on blocks I and II. (lb./sheep)

			Period						
Stocking Rate	Pasture Type	Block	Prelim.	I	II	III	IV	V	VI
High	Ac	I	+ 10.66 a	+ 4.66 bc	- 0.66 c	- 4.33 b	+ 4.00 bc	+ 11.00 bc	+ 10.33 a
		II	+ 11.00 a	- 2.00 d	- 3.33 c	- 5.33 b	+ 0.66 c	+ 7.33 d	+ 9.33 a
	Bc/Ac	I	+ 12.66 a	+ 6.00 b	- 1.66 c	- 3.66 b	+ 4.66 bc	+ 5.00 d	+ 3.66 b
		II	+ 10.66 a	+ 2.00 c	- 1.33 c	- 5.00 b	+ 3.66 bc	+ 10.33 c	+ 10.33 a
Low	Ac	I	+ 11.00 a	+ 12.00 a	+ 4.33 ab	+ 6.66 a	+ 13.33 a	+ 15.00 ab	+ 10.33 a
		II	+ 12.00 a	+ 9.66 a	+ 5.66 ab	+ 3.33 a	+ 8.33 ab	+ 16.66 a	+ 9.66 a
	Bc/Ac	I	+ 10.00 a	+ 5.33 b	+ 7.33 a	+ 4.66 a	+ 6.66 b	+ 14.33 abc	+ 8.00 a
		II	+ 10.33 a	+ 9.66 a	+ 4.00 b	+ 4.66 a	+ 6.00 b	+ 10.33 c	+ 6.33 a

only at the high but not at the low stocking rate (BS effect) where the effect was reversed for cocksfoot pastures (PB effect).

(iii) Period II - Sheep at the high stocking rate lost weight while those on the low stocking rate gained weight (S effect) during this period. There was a significant BP interaction at the low stocking rate (PBS effect).

(iv) Period III - Sheep at the low stocking rate continued to gain weight while those at the high stocking rate continued to lose weight (S effect).

(v) Period IV - Sheep at the low stocking rate tended to gain more weight than those at the high stocking rate (S effect) while sheep on clover pastures tended to gain more weight than those on cocksfoot pastures at the low but not at the high stocking rate (PS effect). Sheep on block I gained more weight than those on block II (B effect) mainly due to the better performance of sheep on the clover pastures of block I. This gave rise to a PB interaction significant at the 10% - 5% level.

(vi) Period V - The significant second order interaction during this period complicates interpretation of the significant main effects which also occur. The second order interaction is due to PB interactions occurring within stocking rates and SB interactions occurring within pasture types. Therefore both the significant effects of stocking rate and pasture type on liveweight change must be considered in relation to block effects. Thus although liveweight change was generally greater at the low than at the high stocking rate (S effect) this did not occur always. Similarly the greater increase in liveweight on clover than on cocksfoot pastures (P effect) did not occur always.

(vii) Period VI - During this period the most notable feature was the small liveweight gain of sheep on one of the high stocked cocksfoot pastures. This was largely responsible for all the significant effects noted. Thus liveweight gain was similar for all treatments except on one particular paddock.

Stocking rate which was a major factor causing differences in total liveweight gain first had an influence on liveweight change during period I. This effect became most marked during periods II and III but from period IV onwards it diminished until in the final period only on one high stocked paddock was liveweight gain lower than on low stocked paddocks.

Pasture type initially influenced liveweight change in period I when a significant PS interaction occurred although this was mainly due to the relative performances of sheep on one high-stocked clover paddock and one low-stocked cocksfoot paddock. Pasture type was of little further consequence until period IV when, at the low stocking rate, liveweight gain was higher on clover than cocksfoot pastures. This effect was maintained into period V and to a lesser extent into period VI. At the high stocking rate there was some difference between the effects of pasture types during periods V and VI, mainly due to the lower liveweight gains of sheep on paddock 2.

At the low stocking rate there were only minor differences in the pattern of liveweight change between replicates of either pasture type. In contrast sheep on the high-stocked clover pastures had a poorer performance on block II than block I from period I to period IV while the poor performance of sheep on the high-stocked cocksfoot paddock of block II during the final part of the experiment has already been mentioned.

The analyses of variance for data from the high-stocked sheep groups are given in Table VII while the means are shown in Table VIII.

While there are some minor differences between the two analyses, both analyses indicate that there was no difference in effect on liveweight change between the two pasture types at the high stocking rate. This contrasts with interpretation of the three way analysis of variance which indicated some difference between pasture types during periods V and VI.

There were however differences between replicates within pasture types especially in the case of clover pastures. The liveweight changes of sheep on cocksfoot replicates were generally similar although the performance of sheep on paddock 2 fell towards the end of the experiment. In contrast the performance on clover paddocks was highly variable. Sheep on paddock 3 had similar weight changes to those on cocksfoot paddocks while sheep on paddock 9 started to lose weight earlier than any others and were slow to start gaining weight in spring. However the most striking pattern of liveweight change occurred on paddock 10 where sheep lost weight continuously from period II until the end of the experiment.

(b) Wool Growth.

Figure 5 shows the changes in mean wool-growth rate of the wether hogget groups of blocks I and II. The three way analysis of variance for total wool growth from mid-side patches over the experimental period is given in Table IX as are the means, tested for differences by Duncan's New Multiple

TABLE VII

Analyses of variance of liveweight changes on high stocked paddocks (lb./sheep)

(a) Wether hoggets

Source of variation	D.F.	Prelim	I	II	III	IV	V	VI
		Mean Squares						
Pasture Type (P)	1	0.00	8.00	14.22	6.72	40.50	37.56	8.00
Among replicates within pastures	4	3.11	29.44***	7.56	2.56	14.61	77.11***	70.17**
Among sheep within replicates	12	6.72	4.11	3.44	5.44	10.50	5.33	13.61
Total	17							

(b) Ewe hoggets

Source of variation	D.F.	Prelim	I	II	III	IV	V	VI
		Mean Squares						
Pasture Type (P)	1	8.53	0.13	3.33	9.63	187.50	73.60	43.20
Among replicates within pastures	4	8.17	25.70***	23.53***	8.73	46.37***	73.04***	123.67***
Among sheep within replicates	24	6.92	5.22	2.17	4.70	4.60	5.60	3.03
Total	29							

TABLE VIII

Mean liveweight changes on high stocked paddocks. (lb./sheep)

(a) Wether hoggets

					Period			
Pasture Type	Replicate	Prelim.	I	II	III	IV	V	VI
Ac	3	+ 10.66 a	+ 4.66 ab	- 0.66 a	- 4.33 a	+ 4.00 a	+ 11.00 a	+ 10.33 a
	9	+ 11.00 a	- 2.00 c	- 3.33 ab	- 5.33 a	+ 0.66 ab	+ 7.33 ab	+ 9.33 a
	10	+ 12.00 a	+ 5.00 ab	- 5.00 b	- 5.33 a	- 3.33 b	- 1.66 c	- 2.66 b
Bc/Ac	2	+ 12.66 a	+ 6.00 a	- 1.66 ab	- 3.66 a	+ 4.66 a	+ 5.00 b	+ 3.66 ab
	8	+ 10.66 a	+ 2.00 b	- 1.33 a	- 5.00 a	+ 3.66 a	+ 10.33 a	+ 10.33 a
	7	+ 10.33 a	+ 3.66 ab	- 0.66 a	- 2.66 a	+ 2.00 ab	+ 10.00 a	+ 7.00 a

(b) Ewe hoggets

					Period			
Pasture Type	Replicate	Prelim.	I	II	III	IV	V	VI
Ac	3	+ 8.0 a	+ 2.8 bc	- 0.8 a	- 2.2 a	+ 4.2 a	+ 8.8 a	+ 10.0 a
	9	+ 9.6 a	+ 0.2 c	- 2.8 ab	- 4.8 a	+ 0.6 b	+ 6.2 a	+ 8.0 ab
	10	+ 9.6 a	+ 6.2 a	- 1.8 a	- 5.0 a	- 4.0 c	- 1.1 b	- 2.6 c
Bc/Ac	2	+ 8.4 a	+ 4.2 ab	- 1.6 a	- 2.6 a	+ 3.8 a	+ 6.0 a	+ 5.6 b
	8	+ 10.6 a	+ 2.2 bc	- 4.4 b	- 4.0 a	+ 5.8 a	+ 8.8 a	+ 9.4 a
	7	+ 11.4 a	+ 2.4 bc	- 1.4 a	- 2.0 a	+ 6.2 a	+ 8.4 a	+ 7.6 ab

Range Test.

Sheep at the low stocking rate grew more wool than those at the high stocking rate (S effect) although mean wool growth on the high-stocked clover paddock of block I did not differ significantly from that on the low-stocked cocksfoot paddocks (Table IX (b)). At the low stocking rate mean wool growth tended to be higher on clover than cocksfoot paddocks (P effect).

At the high stocking rate (Figure 6, Table X) there was no difference in total wool growth due to pasture type. However significant differences in wool growth occurred between replicates within pasture types although these were more pronounced in the case of the ewe hoggets, perhaps due to the increased sensitivity of analysis resulting from the higher number of observations made.

As in the case of liveweight change, the changing pattern of wool growth was examined by analysis of variance of the wool grown in each period. The three way analyses of variance with the appropriate mean values are presented in Tables XI and XII respectively.

(i) Preliminary period - During this period there were no significant treatment effects on wool growth.

(ii) Period I - The high wool growth on the low-stocked clover paddocks during this period was largely responsible for the significant stocking rate and pasture effects noted. However there was no PS effect since overall, wool growth was higher on low than high-stocked cocksfoot paddocks.

(iii) Period II - Wool growth was greater at the low than at the high stocking rate (S effect). At the low stocking rate sheep on block II tended to grow more wool than those on block I while at the high rate this block effect was reversed (SB effect). Pasture type had little effect on wool growth at the high stocking rate but at the low stocking rate sheep on clover pastures tended to grow more wool than those on cocksfoot pastures (PS effect).

(iv) Period III - During this period the higher wool growth at the low stocking rate persisted (S effect) while pasture type continued to have some effect on wool growth at the low stocking rate (PS effect).

(v) Period IV - The stocking rate effect on wool growth continued into this period (S effect). Although the tendency for wool growth to be higher on clover than cocksfoot pastures at the low stocking rate continued, the PS effect did not reach significance.

Figure 5

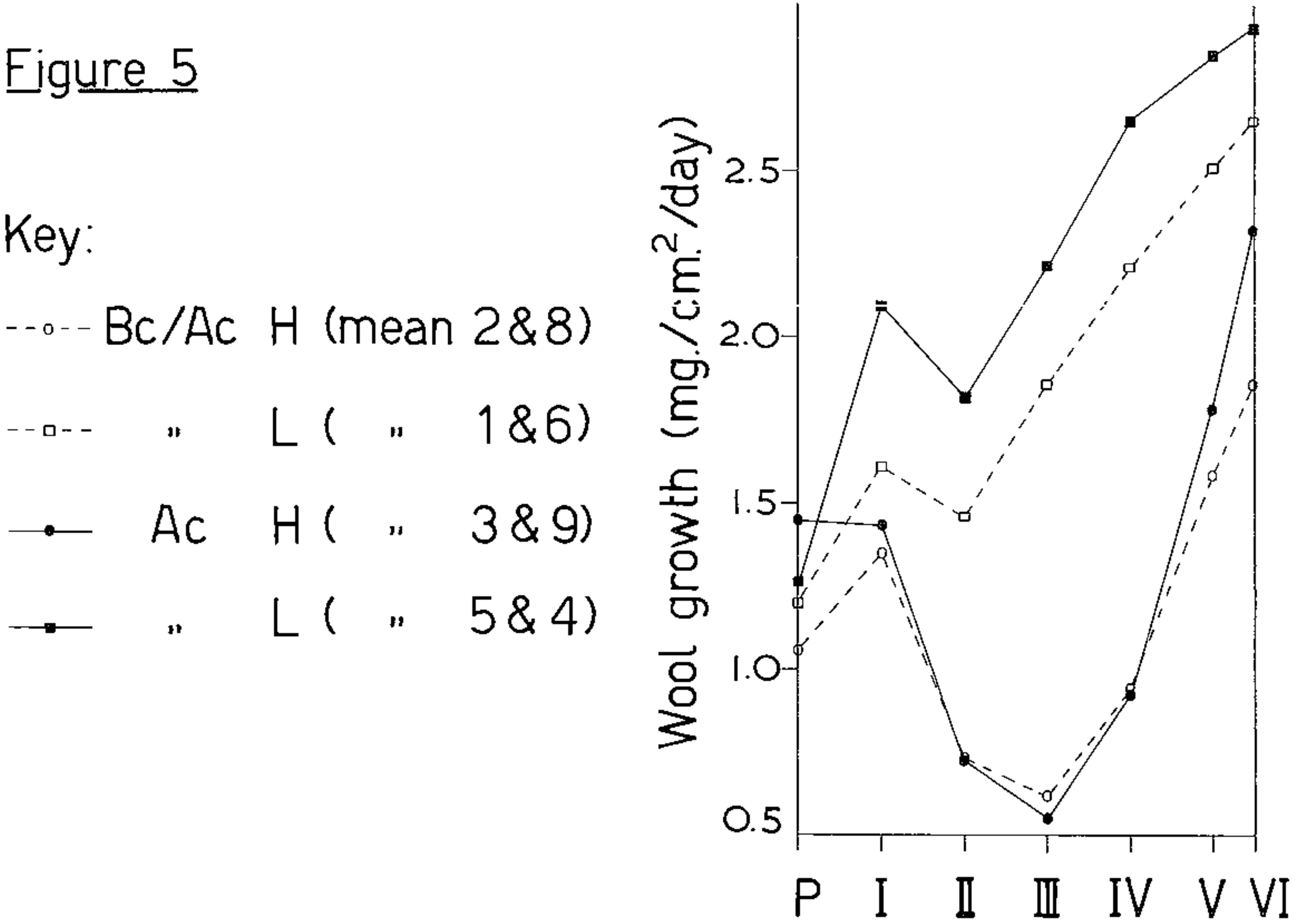

Key:
--○-- Bc/Ac H (mean 2&8)
--□-- " L (" 1&6)
—●— Ac H (" 3&9)
—■— " L (" 5&4)
Wool growth (mg./cm.^{2}/day)
2.5
2.0
1.5
1.0
0.5
P
I
II
III
IV
V
VI

TABLE IX

(a) Analysis of variance for total wool growth from mid-side samples on blocks I and II. (mg./cm.^{2})

Source of variation	D.F.	Mean Square
Stocking Rate (S)	1	151,114***
Pasture Type (P)	1	11,172*
Block (B)	1	983
PS	1	2,147
PB	1	8
BS	1	549
PSB	1	55
Residual	16	3,628
Total	23	

(b) Mean total wool growth from mid-side samples of wether hoggets on blocks I and II. (mg./cm.^{2})

Stocking Rate	Pasture Type	Block	Liveweight Change
High	Ac	I	245.6 bc
		II	219.1 c
	Bc/Ac	I	217.2 c
		II	199.0 c
Low	Ac	I	410.6 a
		II	409.3 a
	Bc/Ac	I	350.4 ab
		II	345.3 ab

Figure 6

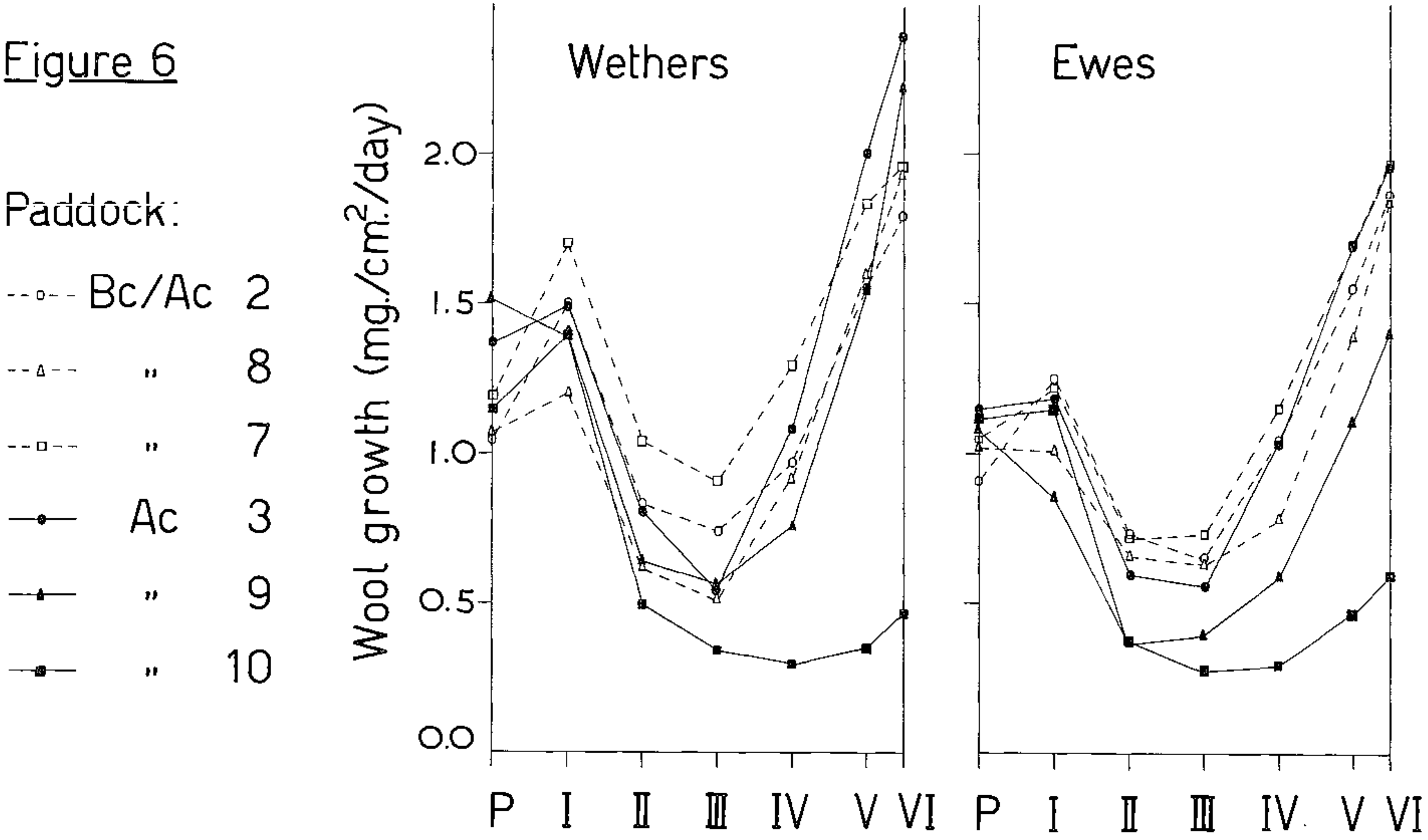

Paddock:
Bc/Ac 2
" 8
" 7
Ac 3
" 9
" 10
Wethers
Ewes
Wool growth (mg./cm.²/day)
2.0
1.5
1.0
0.5
0.0
P
I
II
III
IV
V
VI
P
I
II
III
IV
V
VI

TABLE X

(a) Analysis of variance for total wool growth from mid-side samples on high stocked paddocks (mg./cm.^{2})

(i) Wether hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	3,601
Among replicates within pastures	4	7,449
Among sheep within replicates	12	3,338
Total	17	

(ii) Ewe hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	12,760
Among replicates within pastures	4	6,518**
Among sheep within replicates	24	1,877
Total	29	

(b) Mean total wool growth from mid-side samples of hoggets on high stocked paddocks (mg./cm.^{2})

Pasture Type	Replicate	Wether hoggets	Ewe hoggets
Ac	3	245.6 a	207.4 ab
	9	219.1 ab	148.5 bc
	10	124.3 b	116.8 c
Bc/Ac	2	217.2 ab	204.1 ab
	8	199.0 ab	174.5 abc
	7	257.6 a	218.0 a

TABLE XI

Analyses of variance of wool growth on blocks I and II (10^{-4} g./cm^2)

Source of variation	D.F.	Mean Squares						
		Prelim.	I	II	III	IV	V	VI
Stocking Rate (S)	1	226.8	98202.9***	380757.4***	971258.3***	1053133.8***	466004.8***	66128.5***
Pasture Type (P)	1	30217.0	37756.3*	17813.6	12019.1	21094.0	34531.5	18283.8*
Block B	1	62.7	3730.7	108.0	0.4	7908.1	19794.4	2059.1
PS	1	15612.5	19192.9	18784.0*	26345.1*	24222.3	2172.8	976.1
PB	1	3495.2	163.8	275.0	8713.5	24.3	1507.8	2.7
BS	1	5239.2	5181.8	18904.2*	5195.4	1882.5	0.5	1516.9
PBS	1	9941.5	7083.2	1.3	23.3	6980.3	17737.3	3044.2
Residual	16	10726.9	10678.2	5875.5	7632.1	12596.6	13635.8	4539.9
Total	23							

TABLE XII

Mean wool growth on blocks I and II (mg./cm^2)

						Period			
Stocking Rate	Pasture Type	Block	Prelim.	I	II	III	IV	V	VI
High	Ac	I	43.93 a	41.39 abc	22.52 c	15.03 b	30.34 b	56.32 bc	36.05 ab
		II	48.22 a	38.87 bc	17.96 c	15.67 b	21.33 b	43.54 c	33.47 ab
	Bc/Ac	I	33.39 a	42.02 abc	23.29 c	20.79 b	27.16 b	43.61 c	26.94 b
		II	34.36 a	33.68 c	17.47 c	14.21 b	25.36 b	44.88 c	29.00 b
Low	Ac	I	45.24 a	60.33 a	47.64 ab	58.75 a	73.41 a	80.64 a	44.61 a
		II	35.48 a	56.82 ab	54.40 a	65.67 a	74.76 a	78.76 a	43.36 a
	Bc/Ac	I	36.76 a	42.79 abc	37.32 b	51.65 a	64.34 a	75.00 ab	42.56 a
		II	39.97 a	47.19 abc	42.64 ab	50.56 a	59.27 a	65.42 abc	36.93 ab

(vi) Period V - Sheep at the low stocking rate continued to grow more wool than those at the high stocking rate (S effect) although the difference between stocking rates decreased.

(vii) Period VI - Despite the fact that the difference in wool growth between the two stocking rates decreased further in this period, stocking rate still had a significant effect on wool growth (S effect). Wool growth tended to be higher on clover pastures at both stocking rates (P effect).

The stocking rate effect on wool growth developed from period I to remain very marked until period VI when wool growth on the high-stocked clover pastures approached that on the low-stocked cocksfoot pastures.

At the high stocking rate pasture type only had minor effects on the wool growth pattern while at the low stocking rate wool growth was generally greater on clover than cocksfoot pastures although this difference rarely reached significance at the 5% level.

There was no block effect on the wool growth pattern and few differences occurred between blocks within stocking rates and pasture types.

The analyses of variance for wool growth on high stocked paddocks are summarised in Table XIII and the means are shown in Table XIV.

Both analyses indicate that at the high stocking rate pasture type had little effect on the amount of wool grown in any one period although this effect was significant at the 10% - 5% level for the ewe hoggets during the preliminary period and approached significance at this level for the wether hoggets during this same period.

In both analyses differences between replications within pasture types were significant during period V and VI but whereas this effect was also significant at other periods for the ewes it was not so for the wethers. As in the analysis of total wool growth this may have been due to the higher number of observations in the case of the ewe hogget data.

The performance of sheep on cocksfoot paddocks was similar especially in the case of the ewes. In contrast large differences between the wool growth of sheep on the clover paddocks appeared from period II onwards so that only in some cases was the pattern of wool growth similar on cocksfoot and clover paddocks. Thus in the case of the wethers, performance on paddocks 3 and 9 was similar to that on the cocksfoot paddocks while on paddock 10 wool growth dropped, in period III, to a very low level from which it never really recovered. In the case of the ewes, the performance of sheep on paddock 3 was again similar to that of sheep on the cocksfoot paddocks

TABLE XIII

Analyses of variance of wool growth on high stocked paddocks. (10^{-4}g./cm.^{2})

(a) Wether hoggets

Source of variation	D.F.	Mean squares Prelim.	I	II	III	IV	V	VI
Pasture Type (P)	1	26530.1	759.7	12536.7	20751.4	42109.9	45552.2	3723.3
Among replicates within pastures	4	5938.5	7543.9	8115.3	6597.9	23776.2	88983.2***	38735.8***
Among sheep within replicates	12	13794.6	15583.3	5209.0	4477.6	10378.4	10125.7	3295.4
Total	17							

(b) Ewe hoggets

Source of variation	D.F.	Mean squares Prelim.	I	II	III	IV	V	VI
Pasture Type (P)	1	11339.0*	5316.4	22221.5	23234.8	73236.5	124981.6	56434.0
Among replicates within pastures	4	1507.0	9310.8	7603.5*	8519.3**	33714.1***	78205.5***	26720.5***
Among sheep within replicates	24	5615.2	7157.6	2837.6	2720.1	6498.0	8909.6	3281.7
Total	29							

TABLE XIV

Mean wool growth on high stocked paddocks. (mg./cm^2)

(a) Wether hoggets

		Period						
Pasture Type	Replicate	Prelim.	I	II	III	IV	V	VI
Ac	3	43.93 a	41.39 a	22.52 ab	15.03 ab	30.34 a	56.32 a	36.05 a
	9	48.22 a	38.87 a	17.96 ab	15.67 ab	21.33 ab	43.54 a	33.47 a
	10	36.81 a	39.03 a	13.73 b	9.45 b	8.27 b	9.88 b	7.11 b
Bc/Ac	2	33.39 a	42.02 a	23.29 ab	20.79 ab	27.16 ab	43.61 a	26.94 a
	8	34.36 a	33.68 a	17.47 ab	14.21 ab	25.36 ab	44.88 a	29.00 a
	7	38.17 a	47.48 a	29.26 a	25.52 a	36.44 a	51.43 a	29.33 a

(b) Ewe hoggets

Pasture Type	Replicate	Prelim.	I	II	III	IV	V	VI
Ac	3	36.64 a	33.11 a	16.52 ab	15.58 abc	28.79 a	47.41 a	29.37 a
	9	34.65 a	24.12 a	10.22 b	10.97 cd	16.58 bc	31.03 b	20.95 b
	10	35.71 a	32.24 a	10.59 b	7.80 d	8.42 c	13.16 c	8.91 c
Bc/Ac	2	29.25 a	35.00 a	20.49 a	18.57 ab	29.06 a	43.68 ab	28.00 ab
	8	32.56 a	28.41 a	13.00 ab	12.12 bcd	21.84 ab	38.92 ab	27.63 ab
	7	33.53 a	34.05 a	20.17 a	20.35 a	32.54 a	47.73 a	29.61 a

TABLE XV

(a) Analysis of variance for fleece weights on blocks I and II (lb. greasy/sheep).

Source of variation	D.F.	Mean Square
Stocking Rate (S)	1	38.5067***
Pasture Type (P)	1	5.2267**
Block (B)	1	7.0417***
PS	1	0.9600
PB	1	3.6817**
BS	1	0.4817
PBS	1	0.4817
Residual	16	0.7658
Total	23	

(b) Mean fleece weights of wether hoggets on blocks I and II (lb. greasy/sheep).

Stocking Rate	Pasture Type	Block	Fleece Weight
High	Ac	I	5.90 b
		II	3.47 c
	Bc/Ac	I	4.30 c
		II	4.00 c
Low	Ac	I	8.27 a
		II	6.97 ab
	Bc/Ac	I	6.43 b
		II	6.13 b

TABLE XVI

(a) Analysis of variance for fleece weights on high stocked paddocks (lb. greasy/sheep).

(i) Wether hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	0.0272
Among replicates within pastures	4	3.2822**
Among sheep within replicates	12	0.7917
Total	17	

(ii) Ewe hoggets

Source of variation	D.F.	Mean Square
Pasture Type (P)	1	1.3230
Among replicates within pastures	4	1.4960**
Among sheep within replicates	24	0.4765
Total	29	

(b) Mean fleece weights of hoggets on high stocked paddocks (lb. greasy/sheep).

Pasture Type	Replicate	Wether hoggets	Ewe hoggets
Ac	3	5.90 a	6.28 a
	9	3.47 b	5.16 b
	10	3.33 b	5.12 b
Bc/Ac	2	4.30 ab	5.50 ab
	8	4.00 b	6.02 ab
	7	4.60 ab	6.30 a

while the pattern of wool growth on paddock 10 was much the same as that of the wethers on this paddock. The performance on paddock 9 was intermediate between that of paddocks 3 and 10, contrasting with the situation in the case of the wethers.

The analyses of variance tables for fleece weight data are given in Table XV as are the appropriate means, tested by Duncan's New Multiple Range Test.

Fleece weights were generally higher on low than high-stocked paddocks (S effect) although the mean fleece weight on the high-stocked clover paddock of block I approached that of some of the low-stocked paddocks. Fleece weights also tended to be greater on block I than on block II (B effect), the greatest effect occurring on clover pastures (PB effect). These high fleece weights on the clover pastures of block I were mainly responsible for the significant pasture effect noted.

The analyses of variance of fleece-weight data from the high-stocked paddocks both indicate that there were significant differences in fleece weights between replicates although there were none between pasture types. Fleece weights were similar on all cocksfoot paddocks while on clover paddocks fleece weights were greater on paddock 3 than on paddocks 9 and 10, with those on paddock 3 being at least as heavy as those on the cocksfoot paddocks. Fleece weights on the other two clover paddocks tended to be lower than those on the cocksfoot replicates.

(c) Pasture Availability.

Changes which occurred in mean pasture availability on blocks I and II are given in Figure 7, the corresponding analysis of variance (Table XVII) and table of means (Table XVIII) following.

(i) May sampling - At this sampling, only two sources of variation (S and PB) did not contribute significantly to the total variation in pasture availability and this fact precludes any generalisations about the factors affecting availability. Availability on cocksfoot pastures was generally higher than on clover pastures (P effect) while within cocksfoot pastures availability was higher at the low stocking rate and within clover pastures at the high stocking rate (PS effect). At the low stocking rate availability was higher on block II than block I but this effect was reversed (BS effect) to such an extent at the high stocking rate that the block effect attained significance at the 10% - 5% level. While much of the total variation can be attributed to these effects, a significant portion of the variance is due

Figure 7

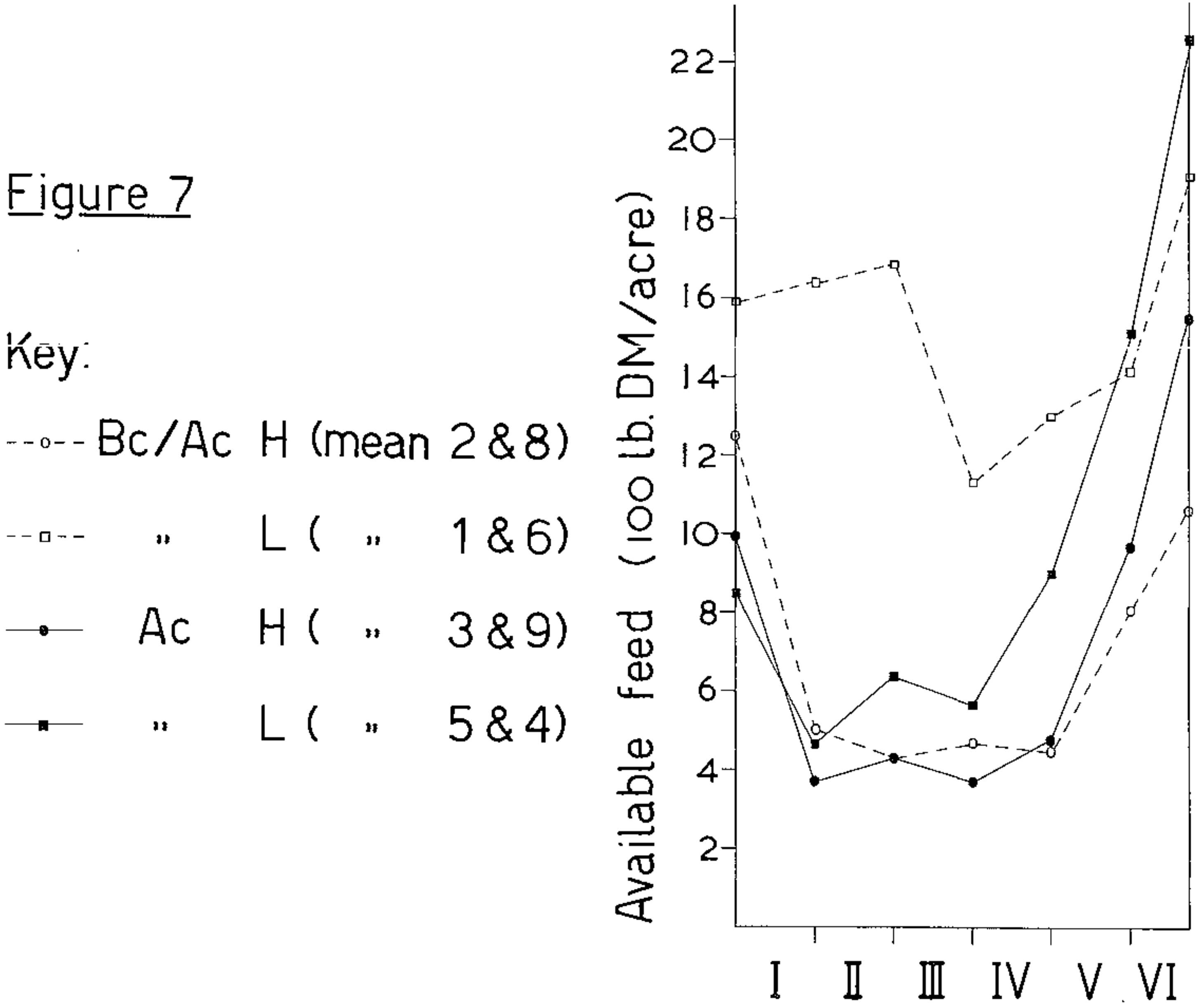

Key:
--○-- Bc/Ac H (mean 2 & 8)
--□-- " L (" 1 & 6)
—●— Ac H (" 3 & 9)
—■— " L (" 5 & 4)
Available feed (100 lb. DM/acre)
2
4
6
8
10
12
14
16
18
20
22
I
II
III
IV
V
VI

TABLE XVII

Analyses of variance of total pasture available on blocks I and II. (log. lb. DM/acre)

Source of variation	D.F.	Mean Squares May	August	September	October	November
Stocking Rate (S)	1	0.0069	0.7736***	1.3479***	0.4610***	0.3901***
Pasture Type (P)	1	0.4181***	0.3795***	0.0368**	0.0315**	0.1583***
Block (B)	1	0.0297*	0.0011	0.0000	0.0086	0.0725***
PS	1	0.0681***	0.0896***	0.0759**	0.0048	0.0146
PB	1	0.0005	0.0627***	0.0341**	0.0012	0.0039
BS	1	0.1740***	0.0012	0.0286**	0.0119	0.0200
PBS	1	0.1297***	0.0017	0.0002	0.0045	0.0023
Residual	32	0.0086	0.0081	0.0052	0.0047	0.0070
Total	39					

Source of variation	D.F.	Mean Squares June	July
S	1	0.1810**	0.2859**
P	1	0.2408**	0.0887*
B	1	0.0008	0.0008
PS	1	0.1004**	0.0884*
PB	1	0.0250**	0.0144
BS	1	0.0481**	0.0004
Residual	1	0.0001	0.0007
Total	7		

TABLE XVIII

Mean pasture availability on blocks I and II. (log. lb. DM/acre)

			Sampling Time						
Stocking Rate	Pasture Type	Block	May	June	July	August	September	October	November
High	Ac	I	3.1184 abc	2.5821 c	2.6180 c	2.5184 d	2.7320 c	2.9797 c	3.1690 c
		II	2.8110 d	2.5502 c	2.6500 c	2.6097 cd	2.6165 d	2.9854 c	3.2050 bc
	Bc/Ac	I	3.1194 abc	2.8048 b	2.6846 c	2.7104 bc	2.6427 cd	2.9125 c	3.0006 d
		II	3.0539 bc	2.5740 c	2.5840 c	2.6179 cd	2.6528 cd	2.8965 c	3.0454 d
Low	Ac	I	2.8164 d	2.4928 c	2.7533 bc	2.7036 bc	2.9540 b	3.1594 ab	3.2988 ab
		II	3.0006 c	2.7938 b	2.8504 abc	2.7914 b	2.9545 b	3.1913 a	3.3939 a
	Bc/Ac	I	3.2102 a	3.1869 a	3.2777 a	3.0597 a	3.0479 b	3.0932 b	3.1763 c
		II	3.1808 ab	3.2417 a	3.1676 ab	3.0143 a	3.1561 a	3.1890 a	3.3410 a

to the BS interaction occurring within clover pastures (PBS effect).

(ii) June sampling - As at the May sampling, most sources of variation made significant contributions to the total variation in pasture availability. The high availability of pasture on the low-stocked cocksfoot paddocks resulted in the significant P, S and PS effects, there being little difference between availability on the high-stocked paddocks and the low-stocked clover paddocks. Availability on block II continued to be higher than that of block I at the low stocking rate, the position being reversed at the high stocking rate (BS effect). The significant PB effect was mainly due to the high yields of the low-stocked clover pasture on block II and the high-stocked cocksfoot pasture on block I.

(iii) July sampling - The high availability of the low-stocked cocksfoot pastures continued to have a major influence on the analysis of variance for this sampling (S effect). However the smaller difference between availability on clover and cocksfoot pastures at this sampling resulted in the P and PS effects only reaching significance at the 10% - 5% level.

(iv) August sampling - Significant P, S and PS effects again occurred mainly as a result of the high level of availability of low-stocked cocksfoot pastures. Cocksfoot pastures tended to have a higher availability on block I than on block II in contrast to the clover pastures which had higher availabilities on block II than on block I (PB effect).

(v) September sampling - At this sampling differences in availability between high and low stocked pastures were well defined (S effect) while the high availability on the low stocked cocksfoot paddocks, especially that of block II, was mainly responsible for the significant P and PS effects. This high availability on block II in conjunction with the high availability of pasture on the high-stocked clover paddock of block I gave rise to the BS effect and was mainly responsible for the PB effect.

(vi) October sampling - At this sampling availability continued to be higher at low-stocking rates than at high ones (S effect) while within stocking rates clover pastures tended to have higher availabilities than cocksfoot pastures (P effect).

(vii) November sampling - The three main treatments all had significant effects on pasture availability at this sampling. Clover pastures generally had higher availabilities than cocksfoot pastures within stocking rates (P effect) while low-stocked pastures generally had greater availabilities than high-stocked pastures (S effect). Within pasture type and stocking rate, block II paddocks tended to have higher availabilities than those on block I (B effect).

Stocking rate had an important effect on pasture availability throughout the experiment. Thus the high initial availability on the low-stocked cocksfoot paddocks was largely maintained during the experimental period while availability increased earlier in the spring on low than on high stocked paddocks.

Pasture type also had important effects exhibiting a strong interaction with stocking rate up to the September sampling. Up to this time there were only small differences between the availabilities on high-stocked cocksfoot pastures and those on all clover pastures. However after this period availability on low-stocked clover paddocks increased rapidly while that on high-stocked clover paddocks increased to a greater extent than that on high-stocked cocksfoot pastures. This resulted in a significant difference between pasture types at the end of the experiment.

There were differences between blocks within stocking rates and pasture types at the May sampling but these had decreased by the July sampling. These were generally unimportant until the November sampling when paddocks on block II generally had higher availabilities than those on block I.

The pasture availability at each sampling for each high-stocked paddock is shown in Figure 8, the appropriate analyses of variance (Table XIX) and table of means (Table XX) also being presented.

The analysis of variance indicates that there was no persistent difference in availability due to pasture type although this effect did reach significance at the 10% - 5% level in August with availability being lower on clover than cocksfoot pastures. Reference to Table XX shows that availability on paddock 9 was comparable to that on paddocks 8 and 7 at this sampling.

However there were significant differences in availability between replications within pasture types although cocksfoot paddocks were remarkably similar throughout the experiment. In contrast to this, availability on clover pastures varied after period IV when the availability on paddock 10 continued to drop in contrast to that on the other two paddocks where it increased or was at least maintained. During periods V and VI availability on these two paddocks increased to a level above that on cocksfoot paddocks but the low availability on paddock 10 resulted in a non-significant difference between pasture types at the November sampling. This was in contrast to the significant difference between pasture types indicated for this sampling in

Figure 8

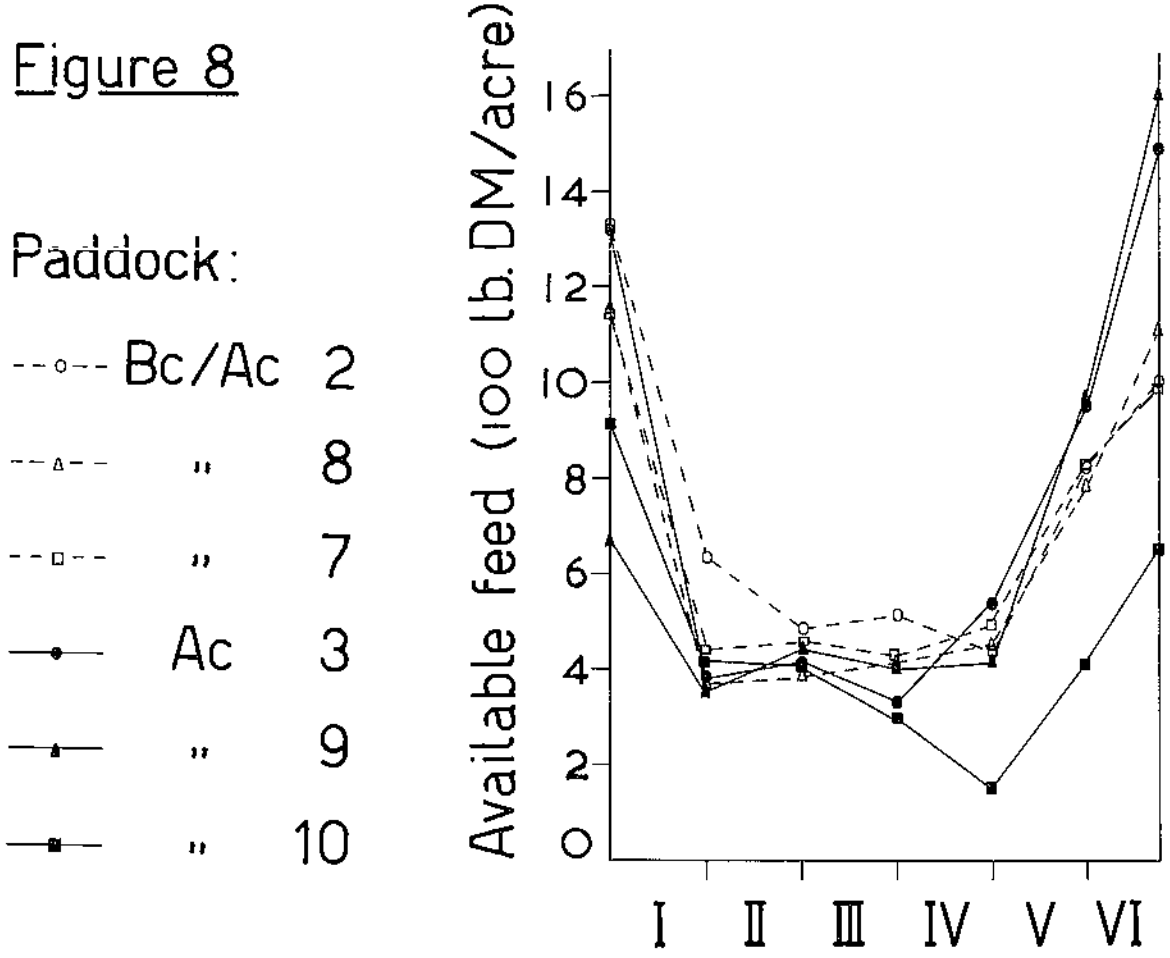

Paddock:
--○-- Bc/Ac 2
--△-- " 8
--□-- " 7
—●— Ac 3
—▲— " 9
—■— " 10
Available feed (100 lb. DM/acre)
0
2
4
6
8
10
12
14
16
I
II
III
IV
V
VI

TABLE XIX

Analyses of variance of total pasture available on high stocked paddocks. (log. lb. DM/acre)

Source of variation	D.F.	Mean Squares May	August	September	October	November
Pasture Type (P)	1	0.0967	0.1167*	0.1913	0.0136	0.0132
Among replicates within pastures	4	0.0629***	0.0223***	0.2300***	0.1243***	0.1288***
Among samples within replicates	24	0.0086	0.0033	0.0026	0.0050	0.0053
Total	29					

Source of variation	D.F.	June	July
Pasture Type (P)	1	0.0131	0.0050
Among replicates within pastures	4	0.0298	0.0016
Total	5		

TABLE XX

Mean pasture availability for high stocked paddocks. (log. lb. DM/acre)

		Sampling Time						
Pasture Type	Replicate	May	June	July	August	September	October	November
Ac	3	3.1183 a	2.5826 a	2.6183 a	2.5182 c	2.7320 a	2.9797 ab	3.1690 a
	9	2.8110 c	2.5509 a	2.6503 a	2.6097 b	2.6165 c	2.9854 a	3.2050 a
	10	2.9534 b	2.6145 a	2.6075 a	2.4517 c	2.1606 d	2.5973 c	2.7983 c
Bc/Ac	2	3.1193 a	2.8050 a	2.6848 a	2.7104 a	2.6427 bc	2.9125 ab	3.0006 b
	8	3.0540 ab	2.5736 a	2.5841 a	2.6179 b	2.6528 bc	2.8965 ab	3.0490 b
	7	3.0501 ab	2.6496 a	2.6545 a	2.6255 b	2.6926 ab	2.8812 b	2.9968 b

the three way analysis of variance.

(d) Botanical Composition.

Estimates of the percentage contribution of particular pasture components were combined with estimates of DM availability for each paddock at each sampling. This gave an estimate of the absolute availability of each component at each sampling for all paddocks as shown in Figures 9, 10, 11 and 12.

(i) Cocksfoot - Low stocked - Pasture available throughout the experiment consisted almost entirely of grass and dead matter, clover being present in negligible amounts. The amount of dead matter remained high at all times while there was only a limited presence of grass species (mainly *Lolium* spp.) other than cocksfoot, especially on paddock 6.

(ii) Cocksfoot - High stocked - Just as total availability was similar for the three paddocks so too was their botanical composition. After an initial increase, the amount of dead material tended to decrease up to September when it rose steadily for the rest of the experimental period. The quantity of clover present was never very high but tended to increase during the latter part of the experiment. The grass component followed the trend in total availability very closely and over the final period of the experiment it became clear that much of this component was comprised of species other than cocksfoot - notably *Poa* spp. The weed component was predominantly flat weeds in paddocks 8 and 7 while in paddock 2 penny royal (*Mentha pulegium* L.) accounted for the large increase in the weed component during the final period of the experiment.

(iii) Clover - Low stocked - The large amount of dead penny royal in paddock 4 is the only important difference between the two replicates of this treatment. This dead fraction decreased throughout the experiment until by the October sampling it had disappeared. The amount of dead matter was never very high although it increased during the latter part of the experiment. The weed component became large during periods II, III and IV. In paddock 4 the major component of this fraction was mouse-eared chickweed (*Cerastium* spp.) while in paddock 5 *Callitriche* spp. were most important initially, with thistles (*Cirsium lanceolatum* L.) appearing during period IV. The amount of clover remained more or less constant throughout, the greatest change occurring in the amount of grass present. This component, which comprised mainly *Poa* spp., was largely responsible for the changes which occurred in availability.

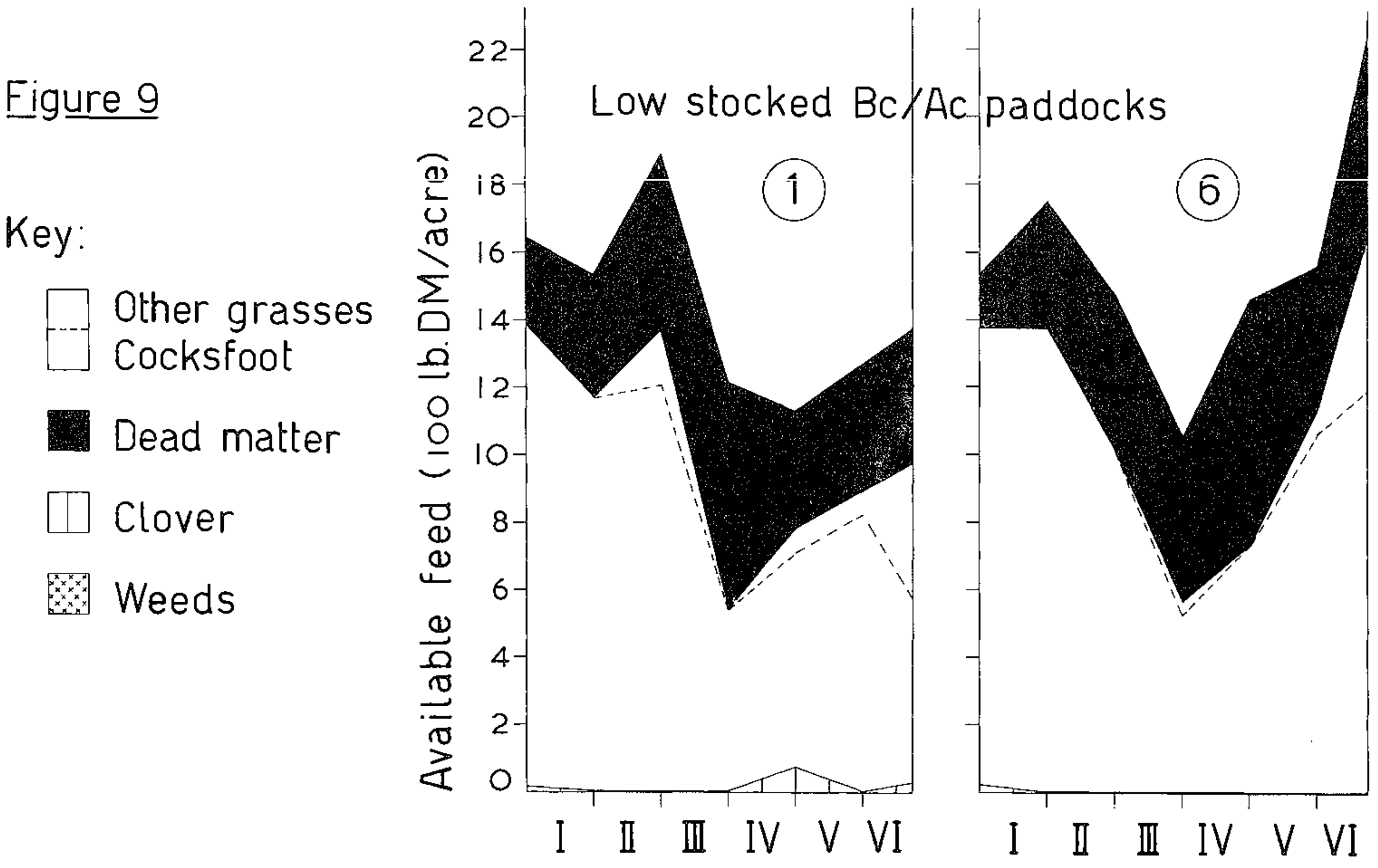


Figure 9
Key:
Other grasses
Cocksfoot
Dead matter
Clover
Weeds
Low stocked Bc/Ac paddocks
1
6
Available feed (100 lb.DM/acre)
22
20
18
16
14
12
10
8
6
4
2
0
I
II
III
IV
V
VI
I
II
III
IV
V
VI

Figure 10 High stocked Bc/Ac paddocks

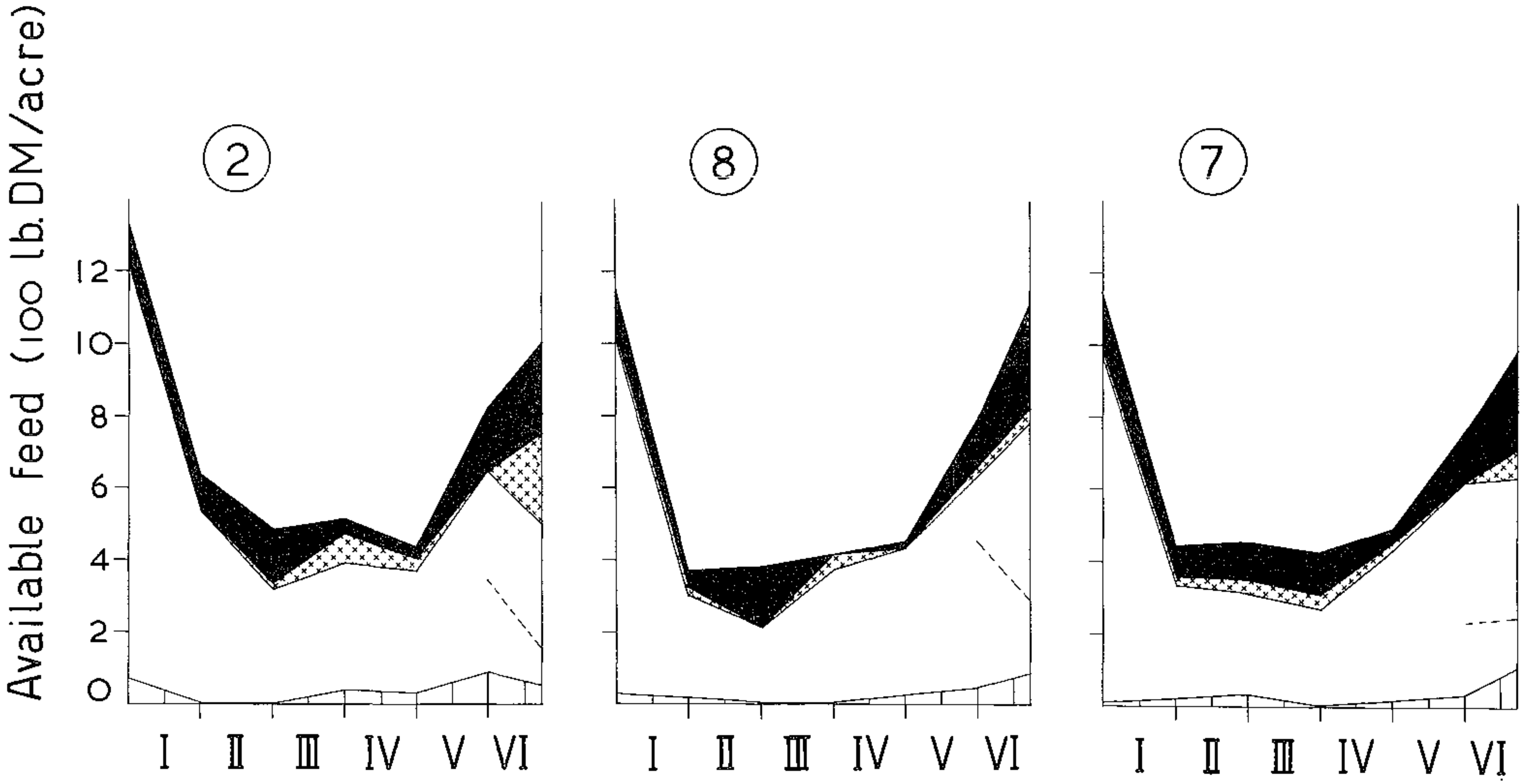


Figure 11

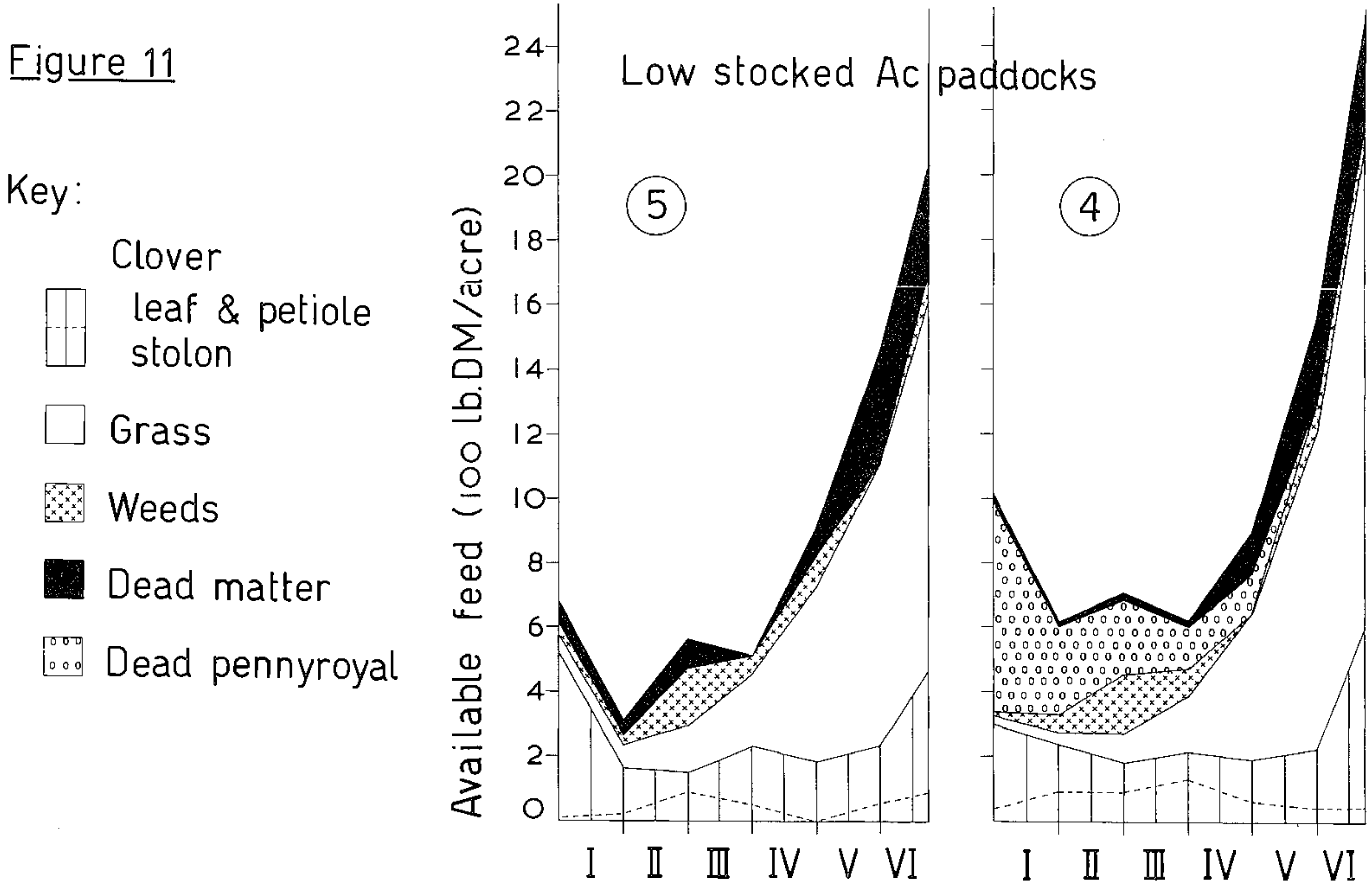
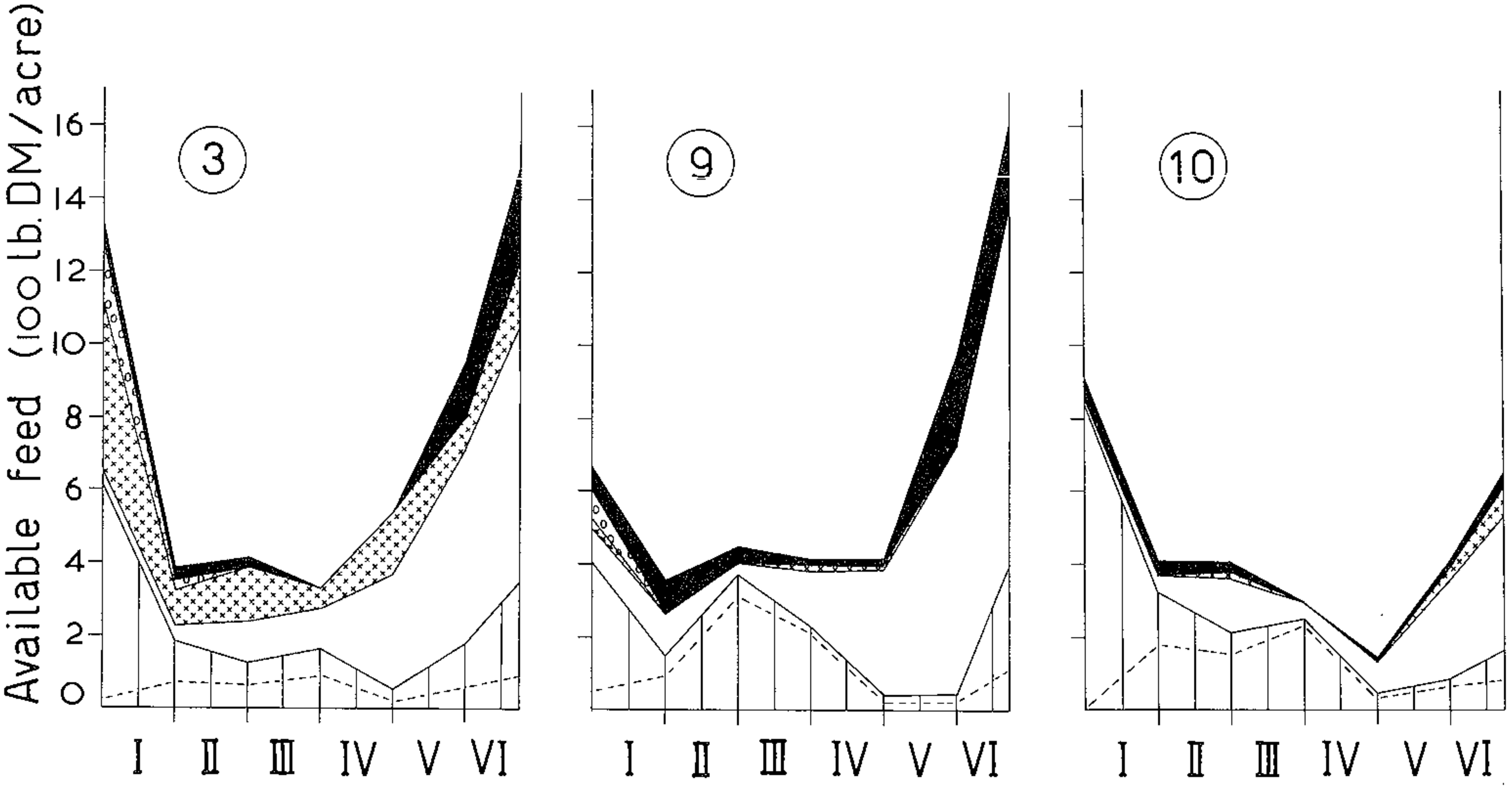

Key:
Clover
leaf & petiole
stolon
Grass
Weeds
Dead matter
Dead pennyroyal
Low stocked Ac paddocks
5
4
Available feed (100 lb.DM/acre)
0
2
4
6
8
10
12
14
16
18
20
22
24
I
II
III
IV
V
VI
I
II
III
IV
V
VI

Figure 12 High stocked Ac paddocks



(iv) Clover - High stocked - There were several differences in the availability of different components between the replicates of this treatment. The dead penny royal fractions in paddocks 3 and 9 soon disappeared while the availability of other dead matter was never very high although it increased during periods V and VI for paddocks 3 and 9. The weed component was negligible on paddocks 9 and 10 but was comparatively large on paddock 3, comprising mainly of penny royal. The amount of clover tended to drop to a minimum at the September sampling but thereafter increased to a greater or lesser degree. The amount of grass was mainly responsible for the change in total availability and once again was predominantly Poa spp.

Stocking rate had several effects on botanical composition within pasture types. In the case of cocksfoot pastures stocking rate had effects on the purity of the grass component as well as on the amount of clover and weeds present. There was also a difference in effect on the dead-matter component. Thus whereas this component remained virtually unchanged at the low stocking rate, at the high stocking rate it was reduced during periods III and IV and increased during the final part of the experiment.

In the case of clover pastures, differences due to stocking rate are not so readily recognised because of the variability between replicates. There appeared to be a difference in the pattern of clover availability between stocking rates. However apart from this the pattern of availability of different components seemed to be similar at both stocking rates although at a lower level for the high stocked paddocks.

(e) Pasture Growth.

The three way analyses of variance for pasture growth data are given in Table XXI, the means for each paddock following in Table XXII.

There were few significant differences in pasture growth. During period I low growth on the low-stocked cocksfoot paddock of block I and the high-stocked cocksfoot paddock of block II was largely responsible for the BS interaction.

During period V growth at the high stocking rate tended to be higher on cocksfoot than clover pastures whereas at the low stocking rate growth tended to be higher on clover than cocksfoot pastures (PS effect). Growth at the high stocking rate tended to be higher on block I while at the low stocking rate it tended to be higher on block II (BS effect).

The analyses of variance for pasture growth on the high stocked paddocks as well as the mean growth rates on these paddocks are shown in

TABLE XXI

Analyses of variance for pasture growth on blocks I and II. (lb. DM/acre/day)

		Mean Squares			
Source of variation	D.F.	III	IV	V	VI
Stocking Rate (S)	1	0.03	127.13	1.05	392.04
Pasture Type (P)	1	9.31	0.19	38.13	0.56
Block (B)	1	3.61	210.98	23.77	23.52
PS	1	133.39	11.38	868.78***	0.49
PB	1	32.49	4.24	0.91	226.50
BS	1	23.04	144.14	616.28**	57.39
PBS	1	3.61	112.33	2.49	313.55
Residual	8	83.89	118.31	66.69	182.02
Total	15				

		Mean Squares	
Source of variation	D.F.	I	II
S	1	3.13	2.88
P	1	51.00	39.61
B	1	1.13	6.48
PS	1	11.52	50.00
PB	1	2.00	0.98
BS	1	103.68*	10.13
Residual	1	1.99	29.65
Total	7		

TABLE XXII

Means of pasture growth on blocks I and II. (lb. DM/acre/day)

Stocking Rate	Pasture Type	Block	Periods I	II	III	IV	V	VI
High	Ac	I	+ 6.4 b	+ 10.8 a	+ 5.0 a	+ 26.7 a	+ 38.7 ab	+ 52.8 a
		II	+ 5.4 b	+ 11.3 a	+ 5.4 a	+ 10.5 a	+ 24.2 b	+ 35.4 a
	Bc/Ac	I	+ 9.2 ab	+ 24.8 a	+ 14.2 a	+ 24.1 a	+ 50.6 a	+ 36.6 a
		II	- 2.7 c	+ 16.2 a	+ 10.9 a	+ 10.1 a	+ 35.5 ab	+ 52.0 a
Low	Ac	I	+ 7.3 ab	+ 18.6 a	+ 7.5 a	+ 23.6 a	+ 41.3 ab	+ 50.8 a
		II	+ 11.8 a	+ 15.9 a	+ 14.6 a	+ 21.5 a	+ 50.0 a	+ 57.9 a
	Bc/Ac	I	- 3.6 c	+ 14.9 a	+ 7.0 a	+ 22.9 a	+ 22.2 b	+ 51.6 a
		II	+ 7.8 ab	+ 18.5 a	+ 6.6 a	+ 26.0 a	+ 33.5 ab	+ 55.6 a

TABLE XXIII

(a) Analyses of variance for pasture growth on high stocked paddocks (lb. DM/acre/day).

Source of variation	D.F.	Mean Squares I	II	III	IV	V	VI
Pasture Type (P)	1	17.00	101.68**	216.75***	18.26	1008.34*	66.74
Among replicates within pastures	4	18.21	12.11	12.83	165.63	181.31	314.56
Among samples within replicates	6			9.63	117.78	108.38	125.60
Total	11						

(b) Means of pasture growth on high stocked paddocks (lb. DM/acre/day).

Pasture Type	Paddock	Periods I	II	III	IV	V	VI
Ac	3	+ 6.4 a	+ 10.8 b	+ 5.0 bc	+ 26.7 a	+ 38.7 ab	+ 52.8 a
	9	+ 5.4 a	+ 11.3 b	+ 5.4 bc	+ 10.5 a	+ 24.2 ab	+ 35.4 ab
	10	+ 7.0 a	+ 10.6 b	+ 0.0 c	+ 6.8 a	+ 19.0 b	+ 22.3 b
Bc/Ac	2	+ 9.2 a	+ 24.8 a	+ 14.2 a	+ 24.1 a	+ 50.6 a	+ 36.6 ab
	8	- 2.7 a	+ 16.2 ab	+ 10.9 ab	+ 10.1 a	+ 35.5 ab	+ 52.0 a
	7	+ 2.2 a	+ 16.3 ab	+ 10.9 ab	+ 17.1 a	+ 50.6 a	+ 36.0 ab

Table XXIII.

During periods II, III and V the growth rate on cocksfoot paddocks tended to be higher than on clover paddocks although it should be noted that, on an individual paddock basis, significant differences between the two pasture types did not always occur during these periods. In the case of the clover paddocks there was a tendency for the growth rate to increase earlier in the spring on paddock 3 than on paddock 9 and earlier on paddock 9 than on paddock 10. However the only significant difference in mean growth rate noted was between paddocks 3 and 10 during period VI. There were no significant differences in growth rate between cocksfoot replicates.

(f) Soil Contamination.

The standard curve obtained relating the soil and titanium content of faeces was:-

$$y = 14.0 + 10.75x - 0.045x^2 \quad (S_{y.x} = 11.73)$$

where y = titanium content of faeces (counts per 15 secs.)
x = soil content of faeces (%)

The corresponding regression for diet samples was:-

$$y = 23.6 + 8.41x - 0.023x^2 \quad (S_{y.x} = 12.74)$$

where y = titanium content of diet (counts per 15 secs.)
x = soil content of diet (%)

Soil content of both faeces and diet samples collected throughout the experiment are given in Appendix II (b) and Appendix III (d) respectively.

(g) Digestible Organic Matter Intake

DOM intakes were estimated by combining measures of faecal OM output (Appendix II (b)) and predicted in vivo OM digestibility of diet samples (Appendix III (d)), both measures having been corrected for soil contamination.

The mean intake per sheep on the paddocks of blocks I and II are shown in Table XXV, the corresponding three-way analysis of variance being given in Table XXIV. Figure 13 shows the mean intake per sheep for pasture and stocking rate treatments.

Figure 13

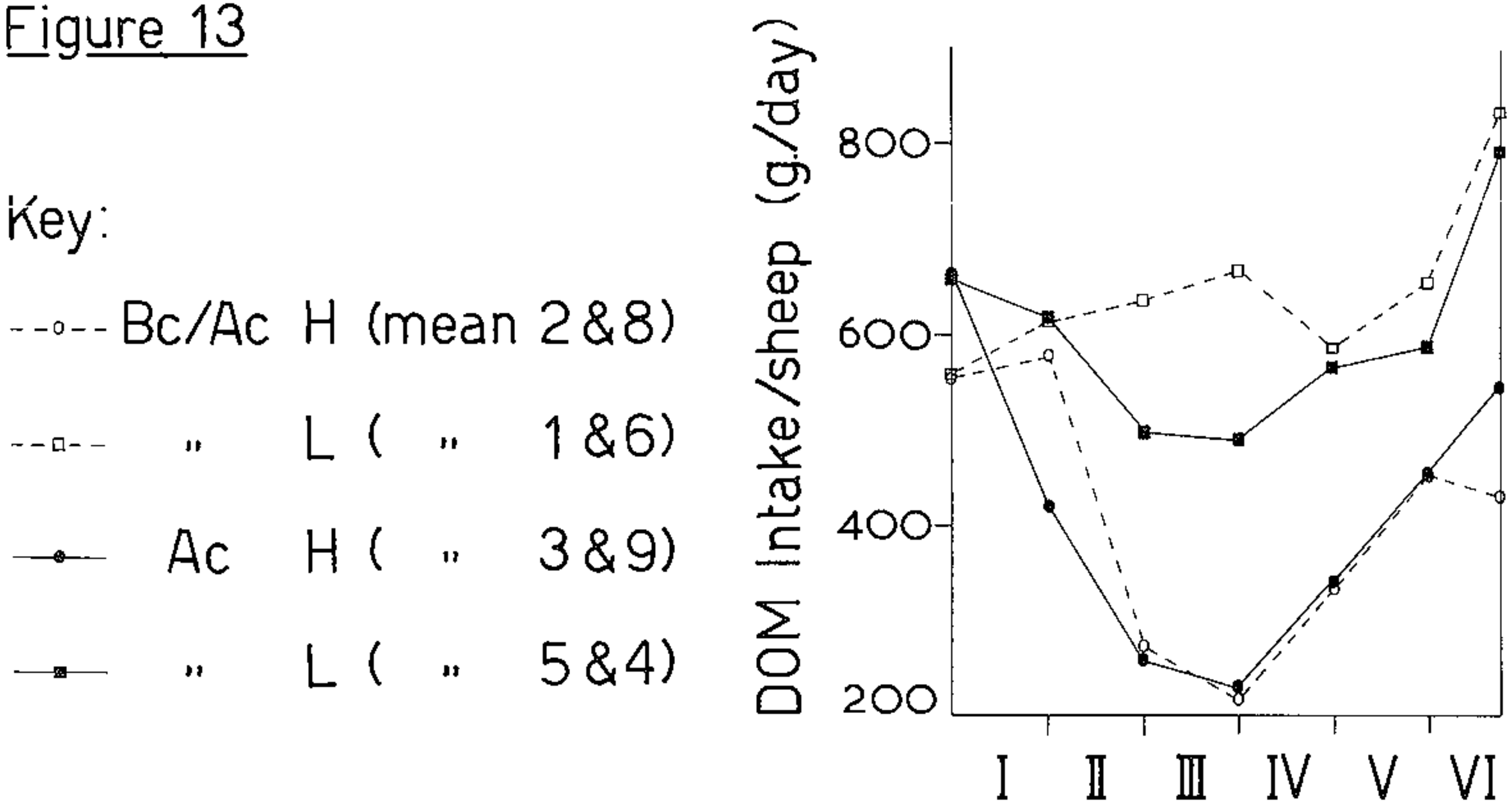

Key:
Bc/Ac H (mean 2&8)
" L (" 1&6)
Ac H (" 3&9)
" L (" 5&4)
DOM Intake/sheep (g./day)
800
600
400
200
I
II
III
IV
V
VI

TABLE XXIV

Analyses of variance of DOM intakes on blocks I and II. (g./sheep/day)

		Mean Squares						
Source of variation	D.F.	May	June	July	August	September	October	November
Stocking Rate (S)	1	10	53361***	363609***	504810***	229202***	113232***	419904***
Pasture Type (P)	1	43368***	25122**	22500***	26569***	176	4160	5041
Block (B)	1	495	6241	1892	6006	298	14042	11449
PS	1	68	26082**	15376**	35344***	1638	4830	24180
PB	1	58202***	2	210	69169***	431	10920	306
BS	1	495	26896***	2352	14280**	3511	8372	48420
PBS	1	18428**	2352	9702	1089	2627	61752***	93225*
Residual	8	3222	2672	1469	1346	7429	5117	19304
Total	15							

TABLE XXV

Mean DOM intake on blocks I and II. (g./sheep/day)

			Sampling Time						
Stocking Rate	Pasture Type	Block	May	June	July	August	September	October	November
High	Ac	I	646 abc	492 b	278 c	337 d	368 bcd	549 b	596 bc
		II	677 ab	347 c	238 c	123 f	311 d	359 d	491 bc
	Bc/Ac	I	591 bcd	628 a	249 c	209 e	326 d	370 cd	321 c
		II	516 cd	530 ab	293 c	226 e	342 cd	533 bc	539 bc
Low	Ac	I	565 bcd	582 ab	492 b	555 b	539 abc	604 ab	800 ab
		II	753 a	649 a	503 b	428 c	593 a	571 ab	780 ab
	Bc/Ac	I	653 abc	605 ab	686 a	582 b	574 ab	743 a	986 a
		II	465 d	623 a	583 b	751 a	597 a	566 ab	678 ab

(i) May sampling - Although intakes of sheep on block I were similar at this sampling, there were marked differences in intake on block II. Here intake on the cocksfoot paddocks was less than that on clover paddocks, especially at the low stocking rate, and this gave rise to the significant P, PB and PBS effects.

(ii) June sampling - Intakes of sheep on the high-stocked clover paddocks tended to be lower than that of sheep grazing on other paddocks. This was mainly responsible for the significant P, S and PS effects noted at this sampling. Irrespective of pasture type intake tended to be lower on block II at the high stocking rate while at the low stocking rate intake was, if anything, lower on block I (BS effect).

(iii) July sampling - At this sampling sheep on low stocking rates had higher intakes than those on high stocking rates (S effect). Intakes were similar at the high stocking rate irrespective of block and pasture type whereas at the low stocking rate sheep on cocksfoot pastures tended to have greater intakes than those on clover pastures (PS and P effects).

(iv) August sampling - Sheep at the low stocking rate continued to have higher intakes than those at the high stocking rate (S effect) and as at the previous sampling low-stocked sheep on cocksfoot paddocks (particularly on block II) tended to have higher intakes than those on the clover paddocks (PS effect). At the high stocking rate there was no overall difference in mean intake between sheep on the two different pasture types but whereas intake was similar on both blocks for cocksfoot pastures, intake was lower on block II than on block I for clover pastures. This was mainly responsible for the significant BS interaction which occurred and also contributed, with the high intake on the block II low-stocked cocksfoot paddock, to the significant PB interaction.

(v) September sampling - The stocking rate effect on intake persisted in this sampling period, there being no difference between intakes within stocking rates. However the high within-paddock variance at this sampling meant that even large differences in mean intake between paddocks were not significantly different at the 5% level.

(vi) October sampling - The most noticeable feature at this sampling was the low intake of high-stocked sheep on the clover paddock of block II and the cocksfoot paddock of block I. This gave rise to the significant stocking rate effect as well as to the PB interaction occurring at the high but not at the low stocking rate (PBS effect).

(vii) <u>November sampling</u> - Intakes tended to be higher at the low than at the high stocking rate (S effect) while intake remained low on the same two high-stocked paddocks as at the previous sampling. This again resulted in a PB interaction at the high stocking rate (PBS effect) although only significant at the 10% - 5% level.

Stocking rate had a large effect on DOM intake throughout the experiment except at the first sampling and towards the end of the experiment, when intakes between particular high and low-stocked paddocks were similar.

Pasture type had comparatively little effect on intake, a difference between pasture types only occurring at the first sampling. However there were several interactions between pasture type and stocking rate, the first occurring at the June sampling when intakes were similar on all paddocks except on the high stocked clover paddocks where it was noticeably lower. At the July and August samplings intakes were similar at the high stocking rate irrespective of pasture type but at the low stocking rate intakes were higher on cocksfoot than clover pastures.

There were several differences in intake between blocks within pasture types and stocking rates although there were no significant block effects. Thus intake on the high-stocked clover pasture of block II was generally lower than that on block I. In contrast intakes on the high-stocked cocksfoot paddocks was similar until September after which intake on the block I paddock failed to increase whereas that on block II increased markedly.

Intake on the low-stocked clover pastures was similar except at the May sampling when intake was greater on block II than on block I and in August when the position was reversed. A similar situation occurred in the case of cocksfoot paddocks with intake being higher on block I than block II at the May and July samplings and on block II than on block I at the August sampling.

The analysis of variance for DOM intakes of the high-stocked paddocks is given in Table XXVI as are the corresponding means. These are shown graphically in Figure 14.

The analysis of variance indicates that there was a difference in intake between pasture types on only one occasion. This was at the first sampling when intake on paddock 10 was very high.

However significant differences in intake occurred between replications at all except the September sampling. Intake on cocksfoot paddocks was similar at the first two samplings but over the next three samplings intake on paddock 7 tended to be higher than that on paddocks 2 and

Figure 14

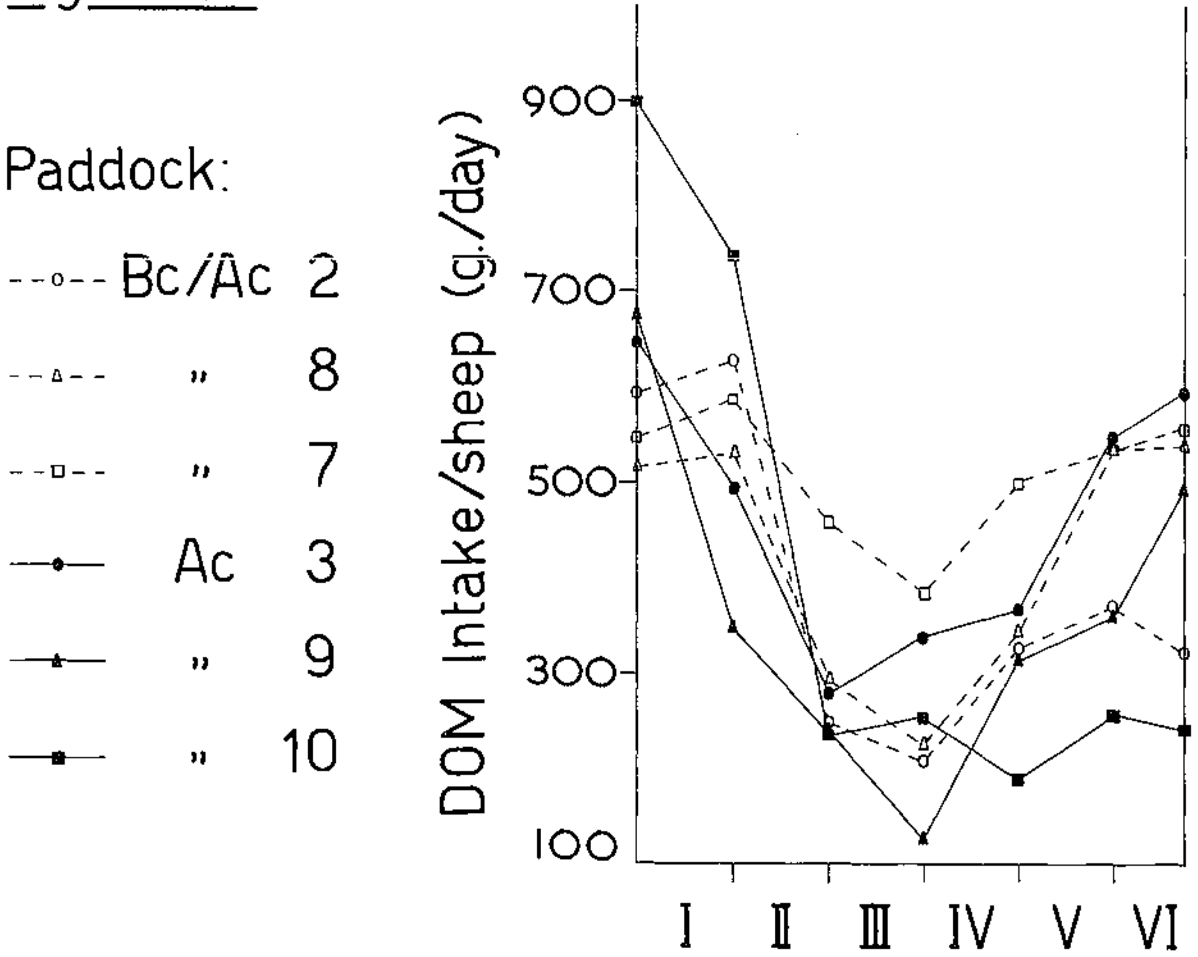

Paddock:
Bc/Ac 2
" 8
" 7
Ac 3
" 9
" 10
DOM Intake/sheep (g./day)
900
700
500
300
100
I
II
III
IV
V
VI

TABLE XXVI

(a) Analyses of variance of DOM intake on high stocked paddocks. (g./sheep/day)

		Mean Squares						
Source of variation	D.F.	May	June	July	August	September	October	November
Pasture Type (P)	1	108,490*	9,185	21,000	3,705	30,301	24,752	2,640
Among replicates within pastures	4	20,502*	41,694***	12,886**	20,994**	17,917	31,055**	50,397*
Among sheep within replicates	6	4,556	2,927	1,946	3,430	6,577	4,911	15,673
Total	11							

(b) Mean DOM intake on high stocked paddocks. (g./sheep/day)

		Sampling Time						
Pasture Type	Replicate	May	June	July	August	September	October	November
Ac	3	646 b	492 b	278 b	337 ab	368 ab	549 a	596 a
	9	677 b	347 c	238 b	123 c	311 ab	359 bc	491 ab
	10	899 a	739 a	234 b	251 abc	187 b	255 c	241 b
Bc/Ac	2	591 b	628 ab	249 b	209 bc	326 ab	370 abc	321 ab
	8	516 b	530 b	293 b	226 bc	342 ab	533 ab	539 ab
	7	545 b	585 b	459 a	385 a	500 a	532 ab	557 ab

8. Up to this time intake on these last two paddocks had been very similar but at the October and November samplings intake on paddock 8 increased to a level similar to that on paddock 7 while intake on paddock 2 remained low.

The intake on clover paddocks was variable over the first two samplings but at the July sampling intakes were similar on all three paddocks. At the following sampling intake on paddock 9 dropped to a very low level while that on paddocks 3 and 10 rose slightly. However from this point until the end of the experiment intakes on paddocks 3 and 9 rose with that on paddock 3 being somewhat higher than that on paddock 9 at any one sampling. In contrast intake on paddock 10 remained virtually unchanged for the rest of the experiment.

(h) Diet Selection.

The mean percentage botanical composition of the diet selected by fistulated sheep over the experimental period is given in Appendix IV. Also shown is the percentage botanical composition of the pasture available at each sampling.

In the case of cocksfoot paddocks, grass and dead matter contributed a minimum of 94% of the diet at any one sampling. The percentage contribution of each of these components to the diet on all cocksfoot paddocks at all samplings was plotted against their percentage availability as shown in Figure 15.

Any point below the dotted line represents selection against that particular component, any point above, selection for the particular component. The vertical distance between a particular point and the dotted line represents the degree of selectivity exerted.

Figure 15 indicates strong selection for grass and against dead matter. Selection against weeds is also apparent from the data in Appendix IV, the situation for clover being indeterminate.

Grass, clover and dead matter contributed a minimum of 95% to the diet on clover paddocks. In Figure 16 the percentage contribution of the grass and clover fraction and of the dead matter fraction to the diet on all paddocks have been plotted against their respective percentage availabilities for each sampling. Again strong selection for green matter and against dead matter is noted. Data in the appendix again indicate selection against weeds while no consistent pattern of clover selection is apparent.

Figure 15

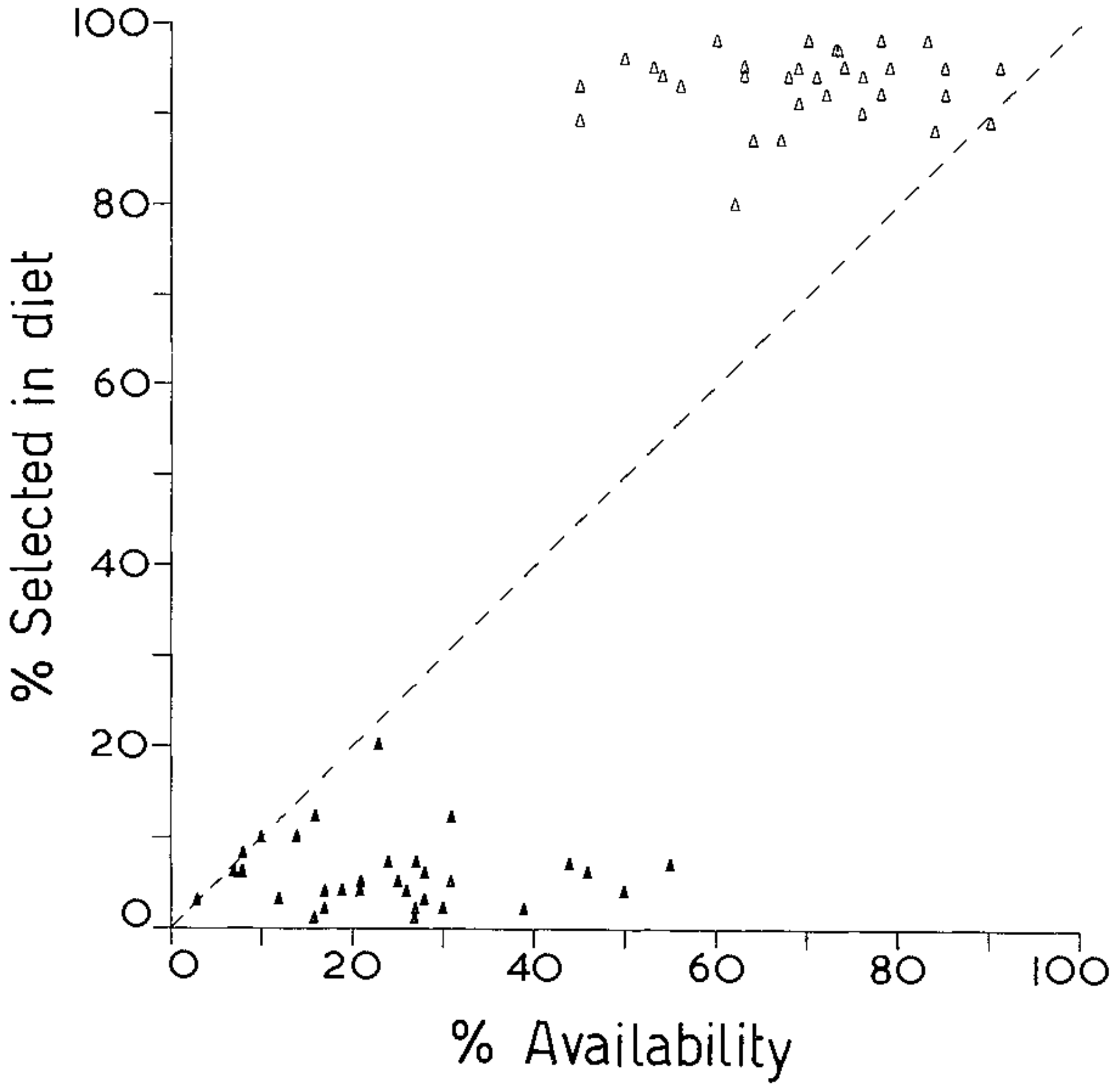
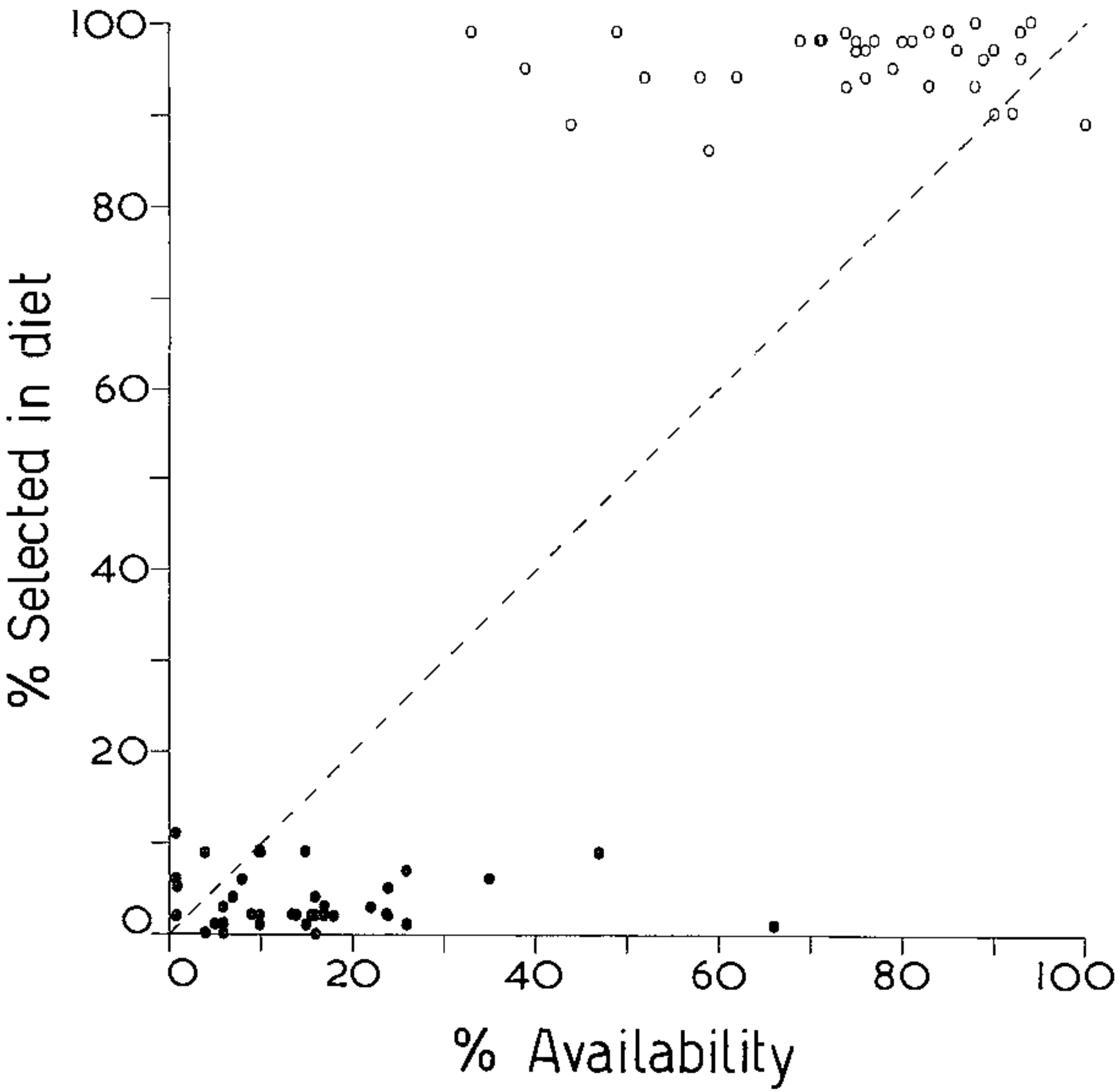

Key:
△ Grass
▲ Dead matter
% Selected in diet
0
20
40
60
80
100
% Availability
0
20
40
60
80
100

Figure 16


Key:
○ Clover & grass
● Dead matter
% Selected in diet
0
20
40
60
80
100
% Availability
0
20
40
60
80
100

(i) Foraging Behaviour.

Data collected with the vibra-recorders are summarised in Appendix V. Only records from periods lasting three days or more are given.

Several features are evident in this data despite the fact that attention to animal variability is limited.

(i) Cocksfoot - Low stocked. Total foraging time varied little over the recording period (range 9.0 - 6.6 hours), 70 - 85% of this foraging being carried out during daylight hours. The average length of all foraging periods was 0.7 hours.

(ii) Clover - Low stocked. Total foraging time decreased over the recording period from approximately 11.5 hours during early August to 7.0 hours in early November. As on the low stocked cocksfoot paddock, 70 - 85% of foraging took place in daylight hours while the average foraging period rarely exceeded one hour.

(iii) Cocksfoot - High stocked. There was no trend in total foraging time with season on this paddock, total foraging time varying from 9.1 to 13.7 hours/day. 72.5% to 96% of this activity was carried out in daylight hours while foraging periods rarely lasted less than one hour and were occasionally as long as three hours.

(iv) Clover - High stocked. Animal variability precludes any definite statement on trends in total foraging time on this paddock. These times varied from 8.3 to 13.1 hours, anywhere between 70% and 100% of this time being spent during daylight hours. Average length of a grazing period varied from 1.1 to 4.1 hours.

CHAPTER IV

DISCUSSION

DISCUSSION

(a) Methods

As a preliminary to discussion of these experimental results it is necessary to assess the validity of the methods used as well as any limitations to the way in which such results can be interpreted.

Animal production measures

In this study liveweight change has been used as a measure of the changing energy balance of the grazing animal. This assumes a constant relationship between a change in energy balance and a change in liveweight - an assumption which is unlikely to hold under all circumstances. For example it has already been noted in Chapter 1 (pp. 36-37) that the tissue composition of liveweight change may vary depending on several factors while in some cases changes in gut fill may be major factors contributing to changes in liveweight (Tayler 1954). In this study this may have been especially important during the period of rapid liveweight increase following the winter period.

Variation in wool growth over the experimental period was measured by means of samples taken from defined areas at the mid-side position of the sheep and expressed as wool growth/unit initial patch area. Cockrem (1968) has emphasised that interpretation of such measures of wool growth requires considerable caution. Thus inferences about changes in fleece production of an individual animal from changes in patch wool growth of the same individual can only be made if wool growth on the patch is representative of wool growth over the rest of the fleece area under all experimental conditions. Furthermore if estimates of actual changes in fleece weight are to be made then a knowledge of the relationship between patch unit area and total fleece area is required.

In this experiment neither the latter relationship nor the representative nature of patch wool growth were established and interpretation of wool growth/unit area should be limited to wool production from a unit of skin tissue. In addition the possibility that the midside technique enhances wool growth on the patch (McManus et al. 1964) must be borne in mind.

The time lag allowed for in the collection of wool growth data was based on evidence such as that of Ferguson (1962) and Doney and Eadie (1967) which showed the existence of such an effect. It was hoped that recognition of this effect would result in the establishment of more meaningful relationships between wool growth and other variables in the grazing situation.

In the case of the wethers fleece weights represent fleece production for the month prior to the experiment as well as for the experimental period. The ewe fleece weights represent fleece production from some time prior to the purchase of the animals up to the end of the experiment. In both cases differences in fleece weights are assumed to be mainly due to experimental treatments. Given the high proportion of fleece production which must have occurred during the experiment this assumption appears to be valid in the case of the wethers. In the case of the ewes such an assumption must be made with more care since differences in fleece weight may have existed prior to the start of the experiment. Although wool growth on the patch area prior to the experiment was known it was not possible to predict fleece production up to this time since the necessary relationships between patch wool growth and fleece production were not known.

Pasture production measures

Measures of pasture availability involve a subjective assessment of "ground level" and this may vary both within and between samplings as well as with ground conditions. A conscious effort was made to minimise this source of error after the May sampling by removing all plant material above "ground level" and washing samples. This difference in cutting height may have contributed, with sampling errors in the determination of botanical composition, to the increase in stolon weight on high stocked clover paddocks at the June sampling.

In interpreting measures of pasture availability it is important to recognise that this is a static measure of a dynamic situation. It represents the balance between the rate of dry matter accumulation and rate of dry matter disappearance - principally through decomposition and removal by the grazing animal - at a particular point in time.

Pasture growth for a particular period was estimated from the difference between availability at the beginning and end of that period. Such estimates will involve not only those errors inherent in taking availability estimates but also those due to inaccurate "pairing" of areas prior to the growth period. This may contribute to negative estimates of growth over a particular period especially if the growth rate is low. In addition to these sources of error, it is important to note that growth as assessed by this method may not be the same as growth under the grazing situation. The divergence between the two situations might be expected to increase the longer the period over which growth is measured and the greater the growth rate of the pasture. However this method remains the most practical for measuring pasture growth rate under continuous grazing and may be especially useful where differences in growth rate rather than absolute values are required.

Soil contamination

The method used to measure the soil content of diet and faecal samples has the advantages of speed and simplicity. The repeatability within a subsample was high giving estimates of soil content that differed by less than 1%. On the other hand duplicate subsamples gave estimates of soil content that differed by more than this and in a few extreme cases this difference was as great as 5%. However the importance of such discrepancies is reduced considerably where the loss in weight on ashing of the soil in a sample rather than the absolute amount of soil is required.

Potentially the most important source of bias in this method is that there may be a difference in the titanium content of ingested soil and the soil used to construct the basic regressions from which soil content estimates are derived. In order to measure the magnitude of any such difference in titanium content, samples of ingested soil free of plant material would be required. There would be considerable practical difficulties in obtaining such samples and no attempt was made to do so.

The soil samples used were taken from the 0-1" horizon and it was assumed either that the titanium content of soil was constant throughout this horizon or that the mean titanium content of the horizon was representative of that of ingested soil.

The former assumption has some basis on the grounds that the upper horizons of the soil are likely to have been well mixed by the action of earthworms, plant roots, hooves, etc. The second assumption is, at least in part, justified by the fact that sheep on pastures having low availabilities appeared to dig well into the top soil horizon to reach underground parts of plants especially when ground conditions were wet and soil contamination appeared to increase.

The bulking of soil samples from each paddock is justified on the basis that the titanium content was similar for samples from each paddock.

In the case of faecal samples the technique also assumes that the titanium containing fraction of ingested soil passes through the digestive tract at a rate representative of all soil. There appears to be no information on this point.

Digestible organic matter intake

(i) Faecal OM output - It was not possible to measure the standard error of mean faecal OM output for any particular sheep at any period since faeces were bulked prior to being analysed for soil and OM content.

There were no apparent trends in faecal output over any collection period indicating that behaviour was not unduly affected by the faecal collection apparatus. Observation of the harnessed sheep led to a similar conclusion.

The separation of faecal OM into that part due to loss in weight of the soil component and that part due to loss in weight of undigested plant material depends not only on the assessment of the soil content of the faeces (c.f. previous section) but also on the assumed value for loss on ignition of ingested soil. The validity of this latter value will depend on the similarity between ingested and sampled soil, a question that had already been discussed.

(ii) OM digestibility - Factors affecting the successful use of oesophageal fistulated sheep have been reviewed in Chapter 1 (pp. 43 - 47).

All the fistulated sheep used in this experiment, with the exception of the animal which died on paddock 10, appeared to act normally as judged by their patterns of production and total production. In all cases fistulated sheep ranked no lower than third in performance when compared with the other three wethers on the same paddock.

The extent to which diets collected by fistulated sheep were representative of the diets of other sheep is not known. However it was hoped that the continued presence of each fistulated sheep on one particular paddock, the low level of availability on many of the paddocks and the bulking of samples over four day periods would result in diet samples adequately representative for intake measurements. However such an approach masks between sheep and between day variations in diet characteristics.

The procedure used in sampling was evolved in an effort to minimise disturbance to the animal, reduce possible biases due to the time of sampling, remove problems of sampling collected extrusa and prevent chemical changes in the extrusa prior to analysis.

The regression established for the prediction of in vivo from in vitro OM digestibility estimates gave a low standard error of estimate but was based on only a small number of standard samples. These did however cover a range which included the digestibility of nearly all the collected samples.

It should be noted that this regression was based on feed rather than extrusa samples. In other words no allowance was made for salivary contamination of the feed. This may lead to an overestimate of digestibility of about two digestibility units (Landlands 1966; Drew pers. comm.). If it is assumed that all values of digestibility are two digestibility units too high then there will be a bias in DOM intake estimates which increases with increasing digestibility. In absolute terms the bias will depend not only on digestibility but on faecal OM output. When intakes were re-calculated assuming a constant drop of two digestibility units, it was noted that the absolute bias in intake increased by approximately 10 g. for every 100 g. intake.

The method of correction applied to *in vitro* digestibility values to allow for soil contamination effects appears to be valid. However interpretation of the digestibility figure so obtained must take into account the fact that *in vivo* processes may be affected by soil ingestion.

A preliminary trial to ascertain the possible existence of such an effect is reported in Appendix VI. Large between sheep differences in response to treatments precluded any consistent treatment effects although the digestive ability of some sheep appeared to be affected by the presence of soil in the digestive tract.

From this discussion it is apparent that there are several possible sources of bias in the digestibility estimates obtained in this experiment. However, in the absence of concrete evidence for such biases, digestibility estimates have been left unaltered.

A further point to note when considering intake estimates is that, at any particular sampling time, intake estimates of sheep on the same paddock are derived using a common estimate of digestibility.

(b) Experimental Results

In the following sections the levels of animal and pasture production realised are discussed as are relationships between animal and pasture production variables which may contribute to such levels of production.

The data used in investigating such relationships covered periods I to VI and included measurements of liveweight change, wool growth, pasture availability, intake and grazing times. For any one period mean pasture availability and mean daily DOM intake per sheep were taken as the mean of the appropriate measurements made at the beginning and end of that period. Mean daily rate of liveweight change was calculated from the difference in liveweight at the beginning and end of each period. Wool growth data, corresponding to any particular period, were collected in such a way that a 2 - $2\frac{1}{2}$ week time lag was allowed for response to changes in nutrition (c.f. Table II).

Animal Production Variables

One of the features of the high stocking rate treatments was the similarity of animal production on cocksfoot paddocks. Thus there was little difference between paddocks in terms of wool production and total liveweight gain although the rate of liveweight increase tended to be lower on paddock 2 over the final part of the experiment (especially in the case of wethers) resulting in a slightly lower total liveweight gain on that paddock.

In contrast to this overall similarity in production, animal production on the high-stocked clover paddocks was very variable with production being highest on paddock 3 and lowest on paddock 10 with that on paddock 9 lying intermediate. Thus in the case of total liveweight change there was no gain on paddock 10 while the gain on paddock 9 was about half of that on paddock 3. These differences largely reflect the difference in time when liveweight began to increase in the spring although the loss in weight of sheep on paddock 9 during the early part of the experiment was also a contributing factor. In the case of total wool growth the differences in performance were less marked, such differences arising in the spring. In contrast to this, there was little difference in fleece weights of sheep on paddocks 9 and 10, these being significantly lower than those of sheep on paddock 3.

Any comparison of the effects of pasture type on animal production at the high stocking rate is complicated by the wide range of production on the clover paddocks. Production on paddock 3 was similar to or greater than that on cocksfoot paddocks while that on the other two clover paddocks was generally less than that on cocksfoot paddocks.

At the low stocking rate there were not many differences in animal production within pasture types, one of the few being the difference in mean weight of fleeces produced on paddocks 4 and 5. Production per animal was generally higher on clover than cocksfoot paddocks at this stocking level although the effect was more pronounced for liveweight gain than for wool growth.

Animal performance over the whole experimental period was generally higher at the low than the high stocking rate although there was some evidence that the effect of stocking rate on liveweight change and wool growth was decreasing towards the end of the experimental period.

Although there were some minor differences, these patterns of liveweight and wool production were similar to those found in the previous year for the same treatments at the same experimental site (Bublath 1969).

The greater number of significant differences occurring in the case of total liveweight changes (Tables III (b) and IV (b)) than in the case of total wool growth/unit area (Tables IX (b) and X (b)) indicates the differing sensitivities of these two productive processes to the treatments imposed. Such a difference in sensitivity has been noted in many experiments (Arnold 1968) and may be explained, at least in part, by the extent to which each process is affected by changes in energy balance.

Thus liveweight change is largely a function of changes in net energy balance (Blaxter 1962) on these pastures where crude protein content is unlikely to have been a major limiting factor to growth (Corbett 1969). The relationship between wool growth and energy balance is less direct because wool, unlike body tissue, cannot be catabolised once elaborated (Lambourne 1968). Furthermore, the supply of precursor materials for wool growth may be enhanced when body tissue is catabolised, so that wool growth can be inversely related to net energy storage where losses in body tissue occur (Ferguson 1962). Both these latter mechanisms may serve to buffer the effects of negative energy balance on wool growth and may therefore have been important in reducing differences in wool production between the two rates of stocking over the experimental period.

In addition it should be recognised that wool growth depends on factors, other than energy balance, which give rise to an annual rhythm of wool growth (Chapter 1, pp. 40 - 42). In effect this rhythm sets a wool growth potential and since it reaches a minimum in the late winter - early spring period in N.Z. Romney sheep (Storey and Ross 1960) it seems probable that this factor may have been important in determining wool growth under the particular conditions of this experiment. Thus any potential differences in wool growth due to differences in net energy balance may not have been fully expressed especially when the wool growth potential was at a minimum.

Linear regressions relating mean daily rate of liveweight change to mean daily rate of wool growth for each period were calculated for each paddock. These were initially combined on a within pasture type within stocking rate basis and subsequently on a within stocking rate basis. This gave rise to the two regressions having similar slopes but significantly ($P < 0.01$) different elevations which are shown in Figure 17. The correlation coefficients for each stocking rate ($r = 0.654$*** at low and $r = 0.910$*** at high stocking rate) were significantly different ($P < 0.01$).

This result may be compared with the work of McManus *et al.* (1964) and Leigh *et al.* (1968) who obtained similar relationships. However these workers do not appear to have found a difference in relationship between stocking rates - perhaps due to the longer periods over which their data were combined and/or the lack of a time lag allowance in the collection of their data. On the other hand Doney and Smith (1961) noted that liveweight changes and wool growth rates did not coincide in their work.

Such statistical relationships, when they exist, do not necessarily imply that both productive processes are affected by common factors - they may merely imply that the separate factors affecting wool growth and liveweight change act simultaneously to cause the different productive processes to alter in a similar fashion. Conversely, the lack of such relationships does not necessarily imply that there are no major factors affecting both productive processes - it may imply that there is a different time lag between the effect of such factors on each productive process.

Since intake may be expected to have some influence on both liveweight change and wool growth the relationships between these two variables and mean daily DOM intake/sheep for each period were investigated.

It appeared that these intake - production relationships were time dependant at the high stocking rate. This is shown in Figure 18 where the values for each period are marked. Initially regressions were calculated on a within pasture type basis for the first (periods I, II and III) and second (periods IV, V and VI) half of the experiment. Since the within pasture type regressions were not significantly different from one another these were combined to give the following regressions which are also shown in Figure 18.

Liveweight change (y) and intake (x)

Periods I - III $y = 0.00071x - 0.345$ $r = 0.842$***

Periods IV - VI $y = 0.00132x - 0.300$ $r = 0.847$***

Figure 17

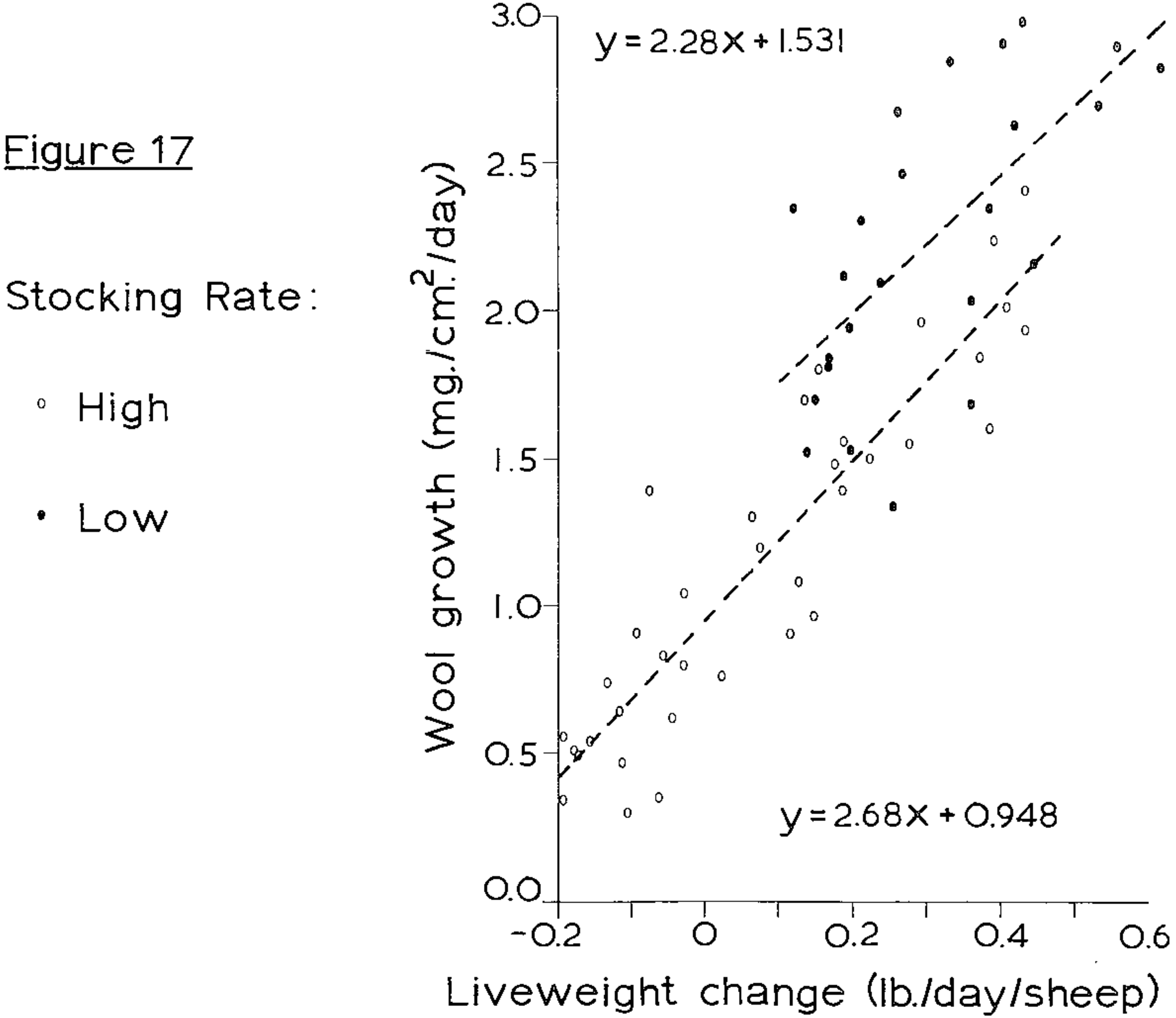
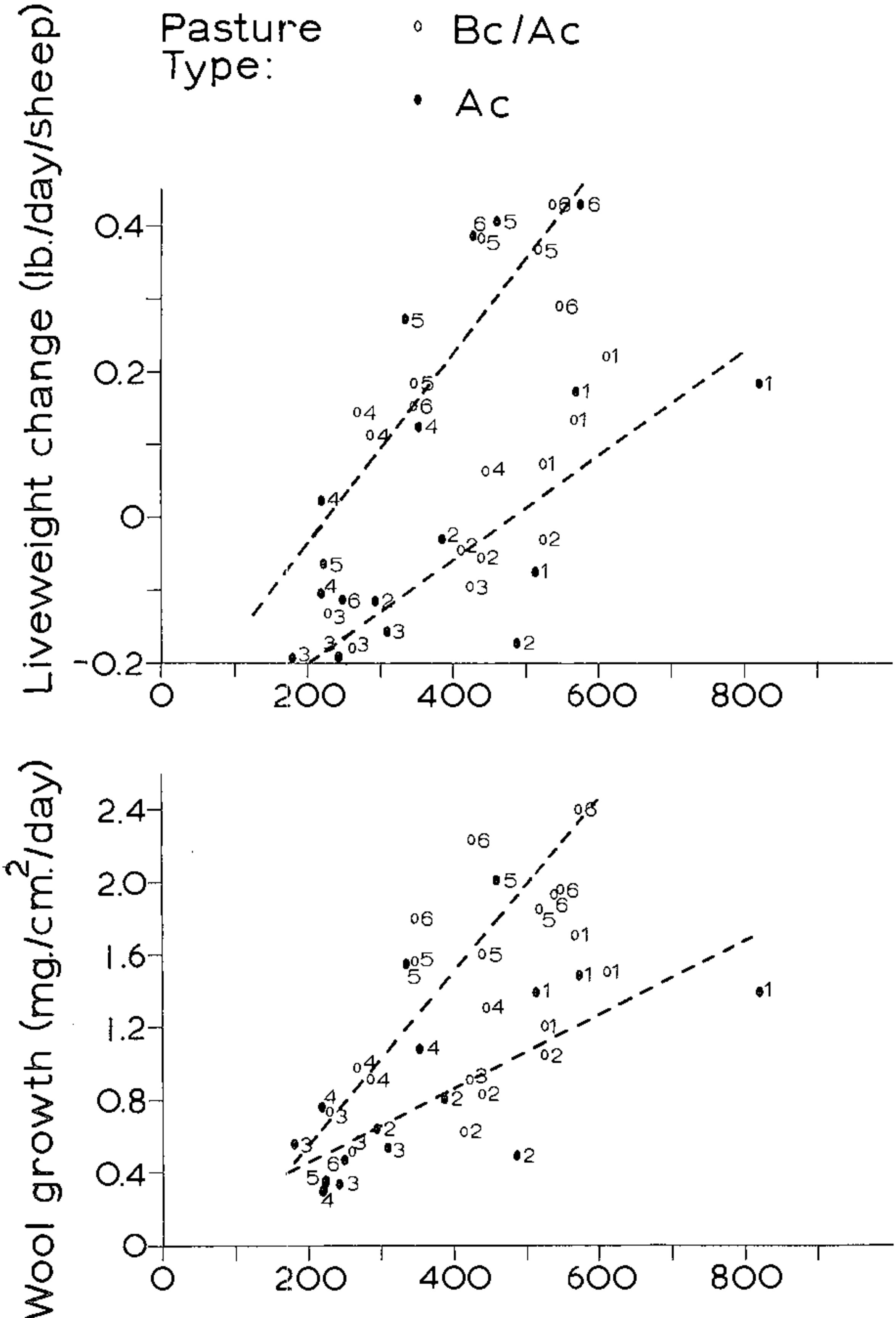

Stocking Rate:
○ High
• Low
y = 2.28X + 1.531
y = 2.68X + 0.948
Wool growth (mg./cm.^{2}/day)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.2
0
0.2
0.4
0.6
Liveweight change (lb./day/sheep)

Figure 18



Pasture Type:
○ Bc/Ac
● Ac
Liveweight change (lb./day/sheep)
0.4
0.2
0
-0.2
0
200
400
600
800
Wool growth (mg./cm.^{2}/day)
2.4
2.0
1.6
1.2
0.8
0.4
0
0
200
400
600
800
Mid-period intake (g.DOM/day/sheep)

Wool growth (y) and intake (x)

Periods I - III $y = 0.00204x + 0.046$ $r = 0.794^{***}$

Periods IV - VI $y = 0.00478x - 0.407$ $r = 0.879^{***}$

In both the case of liveweight change and wool growth, the two regressions were significantly ($P < 0.01$) different from one another. It should be appreciated that although this approach demonstrates a different relationship between intake and production for the first and second halves of the experiment it may, in fact, simplify the true situation in which the relationship may change from period to period.

The changing relationship between intake and production which is demonstrated by this approach indicates that, at the high stocking rate, a unit of DOM intake was associated with a greater amount of production during the second half of the experiment (most notably during periods V and VI) than during the first half.

At the low stocking rate intake remained relatively constant throughout the experiment (Figure 13) and since animal production varied to a considerable degree (Figures 3 and 5) it is not surprising that there was no statistically significant relationship between intake and animal production at this stocking rate. However since the data were combined over time the lack of any such relationship may indicate a changing relationship between intake and production with time rather than a total lack of relationship.

Compensatory growth following weight loss during the winter took place on most high-stocked paddocks during the second half of the experiment. It is therefore reasonable to suggest that one of the main factors giving rise to the changing relationship between intake and liveweight change at this stocking level was compensatory growth with its possible associations with increased efficiency of feed utilisation (Meyer and Clawson 1964) and changes in gut fill (Wilson and Osbourn 1960). Complete elucidation of the relationship would include consideration of changes in maintenance requirements with changing body weight and condition, with changes in pasture conditions and with weather conditions. It would also include a knowledge of the tissue composition of liveweight change and of changes in nutritive value of ingested herbage. Such changes in nutritive value may have arisen from changes in the maturity of diet components (Corbett 1969), in diet composition (Appendix IV) and in the physiological condition of the sheep (Blaxter 1962). It is considered that bias in intake measurements is unlikely to have been important since it would affect both regressions to about the same extent.

At the low stocking rate the lack of relationship between intake and liveweight change is not easy to explain. Compensatory growth only appeared to take place during one period (period V) but recalculation of the regression between intake and liveweight change omitting this data did not enhance the significance of the relationship. An explanation would perhaps involve an assessment of changing maintenance requirements and changes in nutritive value of the diet. With respect to maintenance requirements there was no obvious relationship between liveweight change and body weight to suggest a changing maintenance requirement with changes in body weight. Again it is considered unlikely that bias in intake measurements would provide an explanation since any bias would tend to minimise differences between intake estimates.

In considering wool growth responses to intake it is important to recognise that seasonal changes in the wool growth potential of the sheep is likely to have been of some importance as a limiting factor during the experimental period and may have overridden any nutritional effects on wool growth. Such a relationship between wool growth potential and nutrition has been demonstrated by Doney (1966) and by Doney and Eadie (1967).

At the low stocking rate wool growth appeared to have a definite time dependence, falling to a minimum in period II, and then increasing irrespective of changes in intake. It is suggested that at this stocking rate the changing wool growth potential was a major factor influencing wool growth although some effect of nutritive value is seen in the higher wool growth on clover than cocksfoot paddocks. At the high stocking rate the changing wool growth potential may have contributed to the changing relationship between intake and wool growth but other factors such as changes in the nutritive value of the diet and the effects of rapidly changing liveweight on wool growth (Ferguson 1962) would also have to be taken into account.

Since intake, at the low stocking rate, was no higher on clover than cocksfoot pastures and animal production tended to be higher on clover pastures there is some indication that pasture type had some effect (other than by its effect on intake) on animal production at this stocking level. Such enhanced production from clover dominant pastures is in line with many other studies (Chapter 1 pp. 18 - 19) although the factors giving rise to the higher production are not yet fully defined. Ulyatt (1969) has recently shown that there is an effect other than that on intake and this may involve differences in carbohydrate composition and associated differences in fermentation rates and volatile fatty acid (VFA) production and utilisation (Corbett *et al.* 1966; Butler *et al.* 1968). It is of interest to note that cocksfoot has a lower nutritive value than ryegrass (Castle *et al.* 1962; Milford and Minson 1966).

This appears to reflect differences other than those due to intake and digestibility (Corbett 1969) and may include the tendency for cocksfoot to yield a higher proportion of acetic acid in total VFA production than do other temperate grass species (Bath and Rook 1965).

At the high stocking rate there did not appear to be any effect of pasture type on animal production. The mechanisms involved may have included those operating in the work of Joyce and Newth (1967) which showed that differences in energy retention between white clover and perennial ryegrass disappeared as feeding levels approached maintenance. This result may also have been due to the greater similarity in botanical composition between diets on high than on low-stocked paddocks (Appendix IV).

Pasture production variables

As in the case of animal production, pasture production on the high-stocked cocksfoot paddocks was very similar while on the clover paddocks there were, once again, considerable variations in productivity.

Total availability on cocksfoot pastures never dropped any lower than that on clover paddocks during the winter period although availability on two of the clover paddocks subsequently increased to levels above those on the cocksfoot paddocks. Availability on paddock 10 remained low in the spring.

Although the generally low growth rate on clover paddocks during periods II and III probably contributed to their availability being lower than that on cocksfoot paddocks at the August sampling a good relationship between pasture growth and availability is not to be expected. This is because availability reflects not only the rate of DM accumulation but also the rate of DM removal. A further complication to a simple relationship may be the rapid changes which can occur in availability as a result of changes in grazing pressure (Campbell 1966b). However this does not mean that growth rate may not have a close relationship to availability and this appears to occur for paddock 10 in the spring period when the low availability reflects the low growth rate at this time.

At the low stocking rate there were few differences in availability on clover paddocks once the initial differences in availability had been reduced, nor were any differences in growth rate detected. In contrast an availability difference developed on the cocksfoot paddocks from September onwards so that the availability on paddock 6 was greater than that on paddock 1 by the end of the experiment. Since growth rates were similar on these paddocks such differences in availability are likely to have arisen from an increased rate of DM loss through death and decay. A crown rust infection was seen to occur in paddock 1 from August onwards and since such an infection may be associated with an increase in the rate of leaf senescence (Lancashire and Latch 1966) it seems likely that this may have been associated with the difference in availability which developed over the latter part of the experiment.

Up until September availability on low stocked clover paddocks remained much lower than that on cocksfoot paddocks but after this sampling it rose very rapidly to be equal to that on cocksfoot paddocks by November. This rapid increase in availability was probably, at least in part, due to the higher growth rate on clover paddocks during period V.

There were few differences in growth rate due to stocking rate although the pattern of growth rate falling to a winter minimum and rising in the spring was consistent with the pattern of changing climatic factors in this area (Brougham 1968). Within pasture types, availability was generally lower on high than low-stocked pastures presumably due to the higher grazing pressure on high-stocked pastures. Such results have been obtained on several occasions (Arnold et al. 1964a; Anon. 1967). As well as affecting the level of availability, stocking rate affects the pattern of availability changes. Thus availability was more or less maintained at its initial level at the low stocking rate until the September/October period when it began to increase especially in the case of clover pastures. In contrast availability on the high-stocked paddocks was reduced to a winter minimum and did not begin to increase until about a month later than on low-stocked paddocks. Given the absence of growth rate differences between stocking rates, such differences in the pattern of availability changes reflect the difference in the pattern of changing animal demands and DM decay at the two stocking rates.

These results for pasture growth and availability exhibit a general similarity to those obtained in the previous year (Bublath 1969) although there are some minor differences. For example, availability on clover pastures tended to increase to a higher level (relative to that on cocksfoot pastures) during the spring in this experimental period. This difference probably arose from the between year difference in grass content which presumably resulted from the application of herbicides in 1967. There were also a larger number of significant differences in growth rate during 1967 - perhaps due to the more favourable conditions for growth during this year.

Within cocksfoot pastures, the most notable differences in botanical composition between stocking rates were the purity of the grass component, and the size of the clover and dead matter contents. At the high stocking rate the contribution of cocksfoot to the grass component was very much reduced - this low persistence of cocksfoot under frequent, hard defoliations has been noted in a similar environment (Brougham 1960) while the relatively high susceptibility of cocksfoot to treading has also been noted (Edmond 1964). The increase in Poa spp. - P. trivialis and P. pratensis - is also consistent with previous experience on high-fertility sites in this area (Edmond 1964; Brougham 1968) and in Britain (Charles 1968). The increased clover content on high-stocked pastures may be attributed to increased light intensity at the base of the sward under these conditions (Chapter 1, pp. 15-16) as well as to the opening up to the sward through death of cocksfoot plants. This change in micro-environment may also contribute to the increased weed content found on high stocked pastures.

The amount of dead matter present at any one time represents the balance between the rates of senescence and decomposition of plant material at that time. The rate of senescence appears to be related to a decrease in light intensity while the rate of decay will depend on factors which include the moisture conditions and type of micro-organisms present in the dead plant material (Hunt 1965). Thus the rate of senescence may be expected to increase with availability since high availability is likely to be associated with a lower light intensity at the base of the sward. The rate of decay may also be expected to increase under such conditions but in this case does not appear to have risen to the extent that it compensates for the higher death rate at high levels of availability. Thus at the low stocking rate where availability was always high the amount of dead matter remained high throughout the experiment while the amount of dead matter at any one time at the high stocking rate was largely dependant on the level of availability. This result is comparable to that of Campbell (1964) who noted that the amount of dead matter available increased with decreasing utilisation. Bublath (1969) noted a similar difference between high and low-stocked cocksfoot paddocks at the end of the previous year's experiment. His data also indicate that pasture type may be an important factor governing the amount of dead matter accumulation.

In the case of clover paddocks, there were few obvious differences in botanical composition due to stocking rate. The amount of dead matter present again seemed to be largely related to the level of availability while the high amount of bare ground on all paddocks during the winter encouraged invasion by other species, notably Poa spp., as it had done in the previous year (Bublath 1969). Changes in the amounts of different components in the spring largely reflected changes in total availability.

Pasture availability and animal production

Relationships between sheep production and pasture availability have been reported by several Australian workers (Willoughby 1959; Williams 1964; Sharkey and Hedding 1964; Arnold 1964a; Bishop et al. 1966) but none appear to have been reported for New Zealand conditions.

Several general associations between animal production and pasture availability are apparent in this experiment. For example, the performance of sheep on low-stocked paddocks, where pasture availability was highest, was greater than that of high-stocked sheep. Similarly, the low performance of sheep on paddock 10 during the spring was associated with both low pasture availability and low DOM intake/sheep. It was therefore decided to examine the relationship between availability and animal production more closely.

The diet of all sheep on all paddocks invariably consisted of over 90% green matter (Appendix IV). This high proportion of green matter in the diet was not surprising given the generally small proportion of dead matter at low levels of availability and the inaccessibility of dead matter when availability was high. Since the green component of the diet was so predominant the dead component of pasture has been ignored in the consideration of the relationship between pasture availability and animal production. Furthermore availability has been expressed on a per head basis in an attempt to equate the relationships at high and low stocking rates.

The relationship between pasture availability and intake for cocksfoot and clover pastures is shown in Figure 19. In both cases the data suggest asymptotic relationships such that intake increases with increasing pasture availability up to a certain level when it remains more or less constant despite further increases in availability. The asymptote appears to lie close to 100 lb. green matter available/acre/sheep for both pasture types.

Taken in conjunction with the relationships between intake and animal production this asymptotic availability-intake relationship may be expected to result in asymptotic relationships between pasture availability and animal production. These latter relationships are shown in Figures 20 and 21 for wool growth and liveweight change respectively.

The values corresponding to each period have been marked for wool growth data from the low-stocked paddocks. It will be noted that in the case of cocksfoot pastures wool growth is a function of time rather than

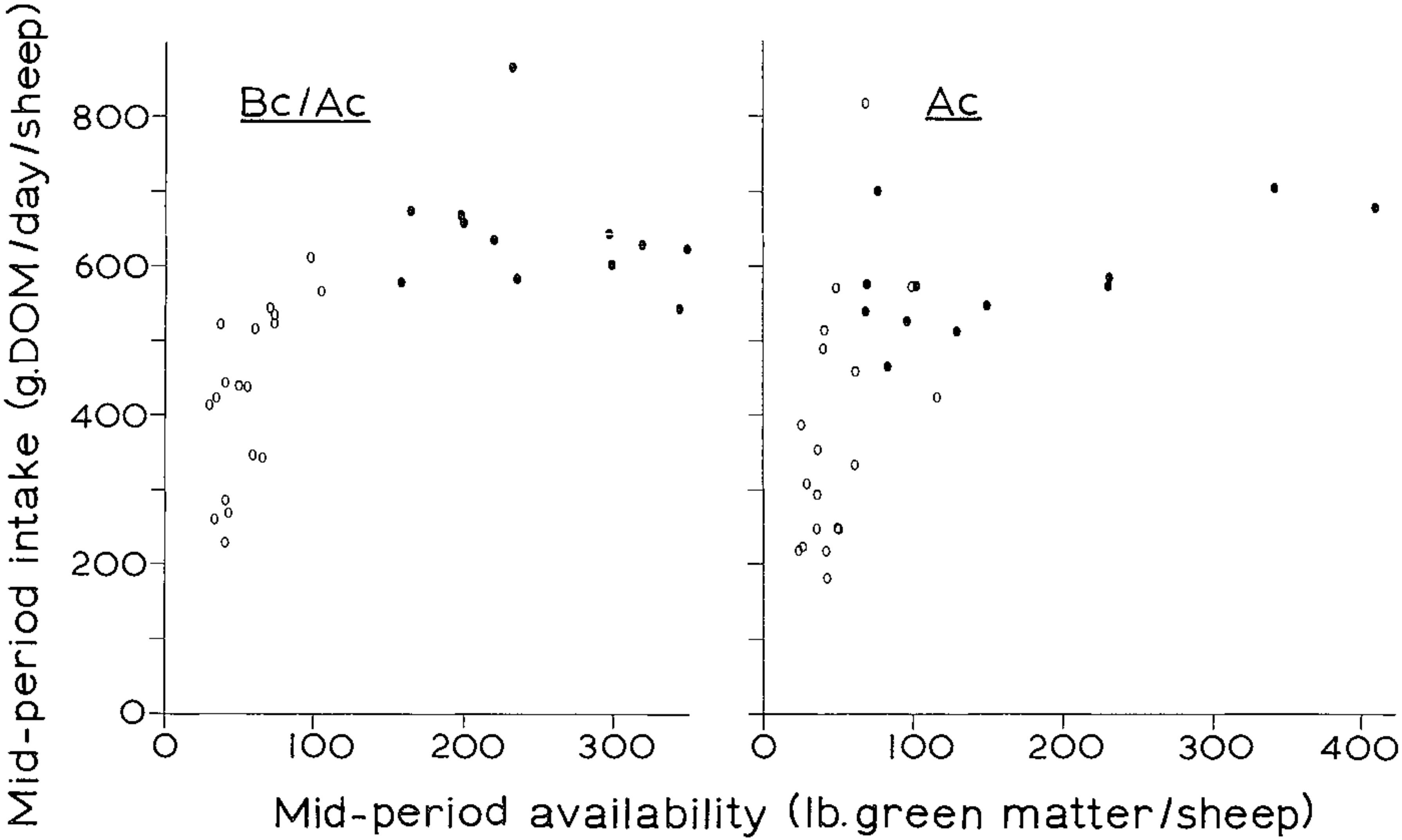
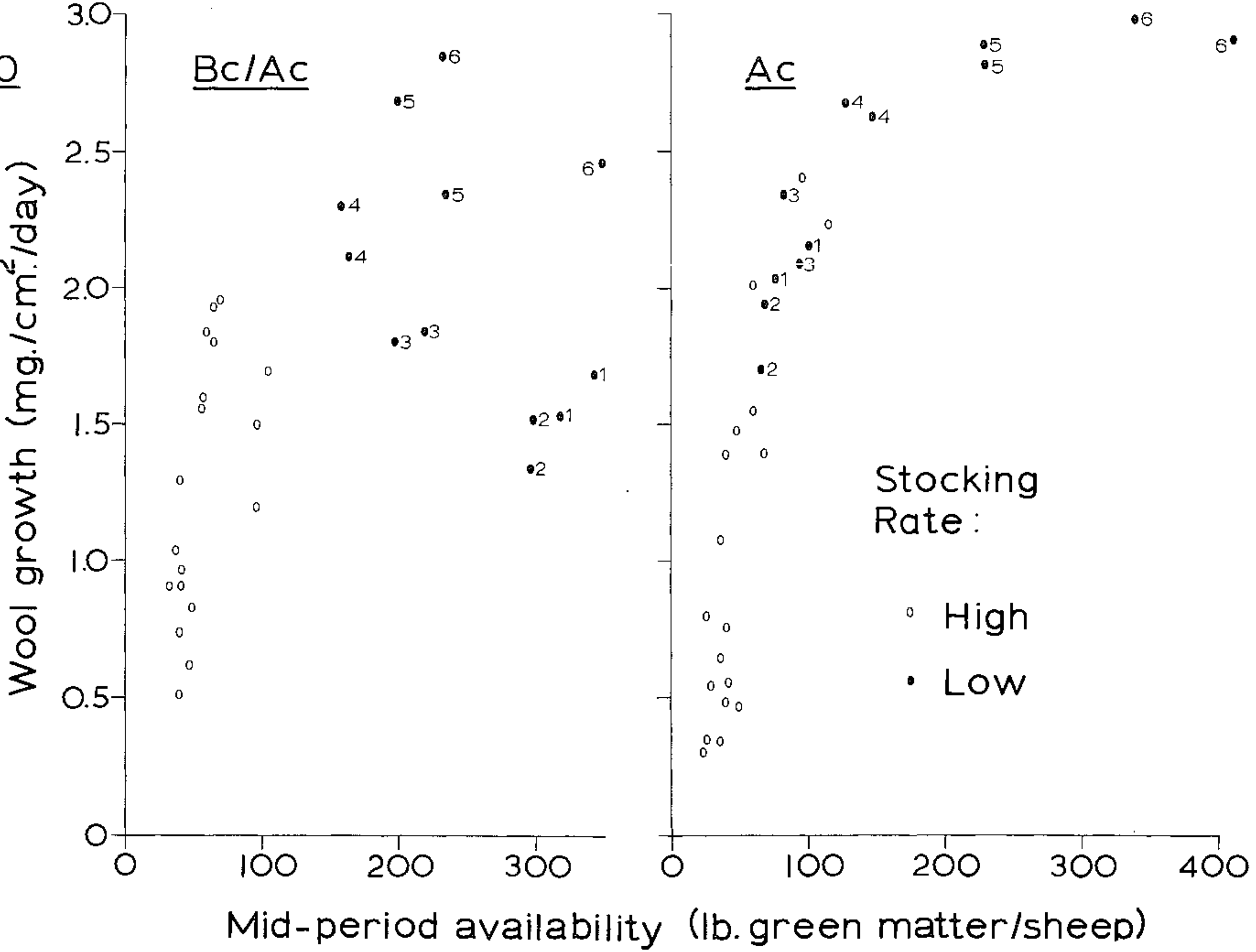


Figure 19 ○ = High stocked, ● = Low stocked

Figure 20


Bc/Ac
Ac
Wool growth (mg./cm.^{2}/day)
0
0.5
1.0
1.5
2.0
2.5
3.0
0
100
200
300
400
Mid-period availability (lb. green matter/sheep)
Stocking Rate:
○ High
● Low
1
2
3
4
5
6

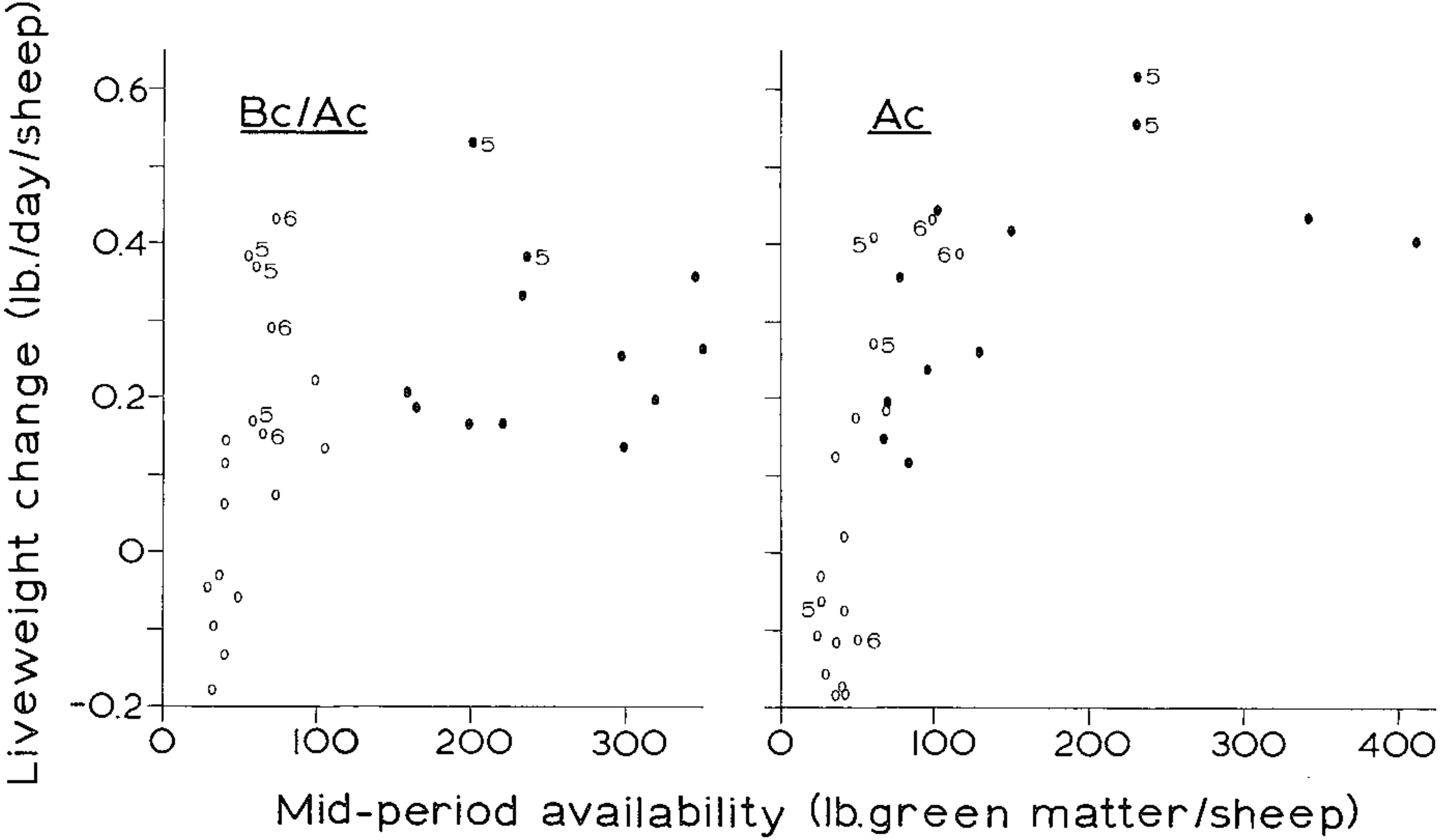
availability. It is suggested that this is associated with varying wool growth potential. If this is the case then it appears likely that the same situation occurs on clover paddocks but that the coincidence of changing availability with changing wool growth results in the asymptotic relationship noted. At the high stocking rate pasture availability is closely associated with wool growth, through the common relationship of both these variables to intake.

The nature of the relationship between pasture availability and liveweight change is not readily apparent. The values for periods when compensatory growth occurred - periods V and VI at the high stocking rate and period V at the low stocking rate - have been marked on Figure 21. If these values are considered to represent a special situation in which liveweight changes are unusually high then the relationship between availability and animal production again tends to be asymptotic.

The basic relationship relating pasture availability and animal production is that between intake and pasture availability. The acceptance of the asymptotic nature of this relationship depends on the acceptance of several factors.

In the first instance, the relationship depends on the combination of measurements taken over a period of time. The digestibility of the diet rarely dropped below 70% on the low-stocked paddocks so that it seems likely that intake regulation was primarily physiological in type (Corbett 1969) over the experimental period on these paddocks. Thus it should be clear that intake remains relatively constant despite changes in age, physiological condition and weight of the sheep - all factors which might be expected to affect intake (Corbett 1969) - especially when there is no evidence that pasture characteristics limited intake. In the case of availability the combination of within stocking rate data taken over the experimental period assumes that the gross measure of availability adequately describes the structure of the pastures over that period of time in terms of the influence on size of bite and hence intake (Chapter 1 pp. 28 - 29). Such an assumption is inevitably made even when data from pastures having different availabilities are combined and its validity will depend on the extent to which "availability" is the limiting component to intake. Thus in some cases green matter may be a more valid measure of availability than total dry matter while in others leaf length, leaf density, digestibility or protein content may be the most valid measure (Spedding et al. 1966; Arnold and Dudzinski 1967b). Since the digestibility of the diet had no apparent

Figure 21 ○ = High stocked, ● = Low stocked



relationship either to total or green dry matter availability and since the diet consisted almost exclusively of green matter and all pasture types appeared to have similar structures at a given level of availability it is considered that the measure of availability used in this study is valid for these particular experimental conditions.

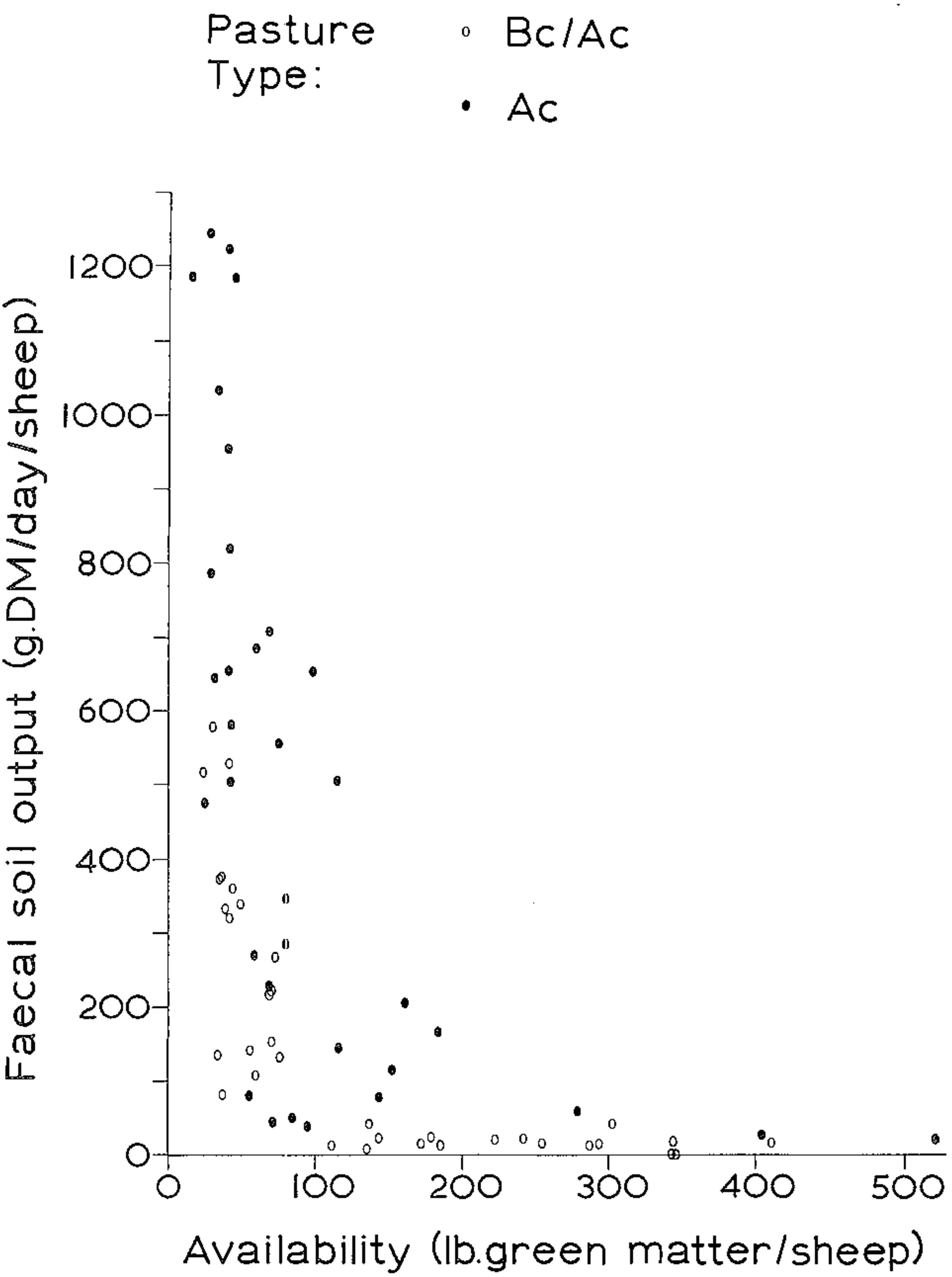
The combination of data from two stocking rates assumes that availability per head is an adequate means of describing the structure of pastures having different levels of availability per acre but similar levels of availability per head (because they support different numbers of sheep). Unfortunately there was not enough overlap between data from the two stocking rates to indicate the validity or otherwise of this assumption. However even if the data are combined on an availability per acre basis an asymptotic relationship will occur although the asymptote will not be in the same position as that found when availability is expressed on a per head basis.

If this asymptotic relationship between intake and availability is accepted then there are important implications for designing grazing management systems over a wide range of stocking rates in such a way that intake is not limited by availability. In addition availability has been expressed so that it provides a measure of grazing pressure (the number of animals per unit of available forage - Mott 1960) thereby giving an indication of the relationship between grazing pressure and intake. This type of information might complement that of Campbell (1966b), which describes the relationship between grazing pressure and stocking rate, to give an indication of optimum stocking rate under given conditions of pasture production and management.

This asymptotic relationship showing that pasture availability is non-limiting to intake above 100 lb. green matter/acre/head is further emphasised by data on foraging times and faecal soil outputs.

Data for foraging behaviour were limited and only on paddock 4 did availability change to any extent during the recording period. Taken overall the data indicated that total foraging times increased when availability dropped below 150 - 200 lb. green matter/acre/sheep. Above this level of availability total daily foraging time varied between seven and eight hours while below this level it increased up to thirteen hours. There was considerable variation at low levels of availability no doubt due to increased variation between sheep and perhaps associated with the large variation in faecal soil output at these levels of availability (Figure 22). These data indicate that one of the behavioural responses of sheep to falling availability during this experiment was an increase in foraging time. This response

Figure 22


Pasture Type:
○ Bc/Ac
● Ac
Faecal soil output (g.DM/day/sheep)
0
200
400
600
800
1000
1200
0
100
200
300
400
500
Availability (lb.green matter/sheep)

occurred when availability dropped below about 150 - 200 lb. and apparently allowed intake to be maintained down to availabilities of 100 lb. The range of grazing times recorded were similar to those found by Arnold under his experimental conditions (1964a).

If it is assumed that soil passed unchanged through the grazing animal then the faecal soil outputs shown in Figure 22 represent soil intakes. These results indicate that soil intake is generally small until availability drops below 200 lb. green matter/acre/sheep and that below this point soil intake is very variable probably depending on several factors such as dentition, selectivity, soil type, ground conditions and appetite drive. In addition these results confirm the changing relationship between intake and availability which occurs between 100 - 200 lb. available green matter/acre/sheep.

This level of availability necessary for maintaining intake may be compared with other values published for Phalaris tuberosa - Trifolium subterraneum pastures (Arnold 1966c; Arnold and Dudzinski 1967a; 1967b). In these studies availability was expressed as lb. total dry matter/acre and the asymptote values varied from about 700 to about 2000 lb./acre. The main reason suggested for these differences was the difference in physiological condition of the sheep - as their appetite levels increased so their ability to adjust to decreasing pasture availability dropped (Arnold and Dudzinski 1967b) - although in one case (Arnold 1966c) marked selection for green material indicates that total dry matter was an inadequate measure of availability. Data presented by Wheeler et al. (1963) indicate that intakes will increase markedly following shearing irrespective of pasture availability.

Pasture structure may also affect grazing times and intake (Arnold 1963; Arnold and Dudzinski 1967b) and it has been suggested that this has an important effect on the level of pasture necessary to maintain intake (Leigh et al. 1968).

The asymptote value in this study is much lower than those found by Australian workers. It is suggested that the main reason for this is the difference in the way in which availability has been expressed while differences in physiological condition and breed of the sheep used and in pasture structure may also be contributing factors.

This discussion has shown that a start to the explanation of the levels of animal production obtained in this experiment can be made on the basis of the relationships between availability and intake and between intake and animal production.

The effect of stocking rate on animal production can be largely explained in terms of the effect of stocking rate on the amount of green matter available/acre/sheep. Thus whenever this quantity dropped below 100 lb. intake tended to drop while above this level intake remained more or less constant. However it should be stressed that this figure depends on the validity with which data from different stocking rates have been combined. Regardless of the exact asymptote value, the data do indicate an asymptotic relationship between intake and pasture availability and it is suggested that some research effort, designed specifically to investigate this relationship more fully, would be worthwhile. In particular such research should explore the possibilities of the relationship between grazing pressure and intake as a guide to defining optimum stocking rates.

Animal production not only depends on the level of intake but on the efficiency with which such intake is converted to production. At the high stocking rate the relationship between intake and animal production appeared to change with time but there did not seem to be any difference between pastures types. At the low stocking rate the form of the relationship between intake and liveweight change was not clear while wool growth appeared to be more a function of wool growth potential than of intake. In this case pasture type did appear to have some effect on animal production over and above the effect on intake. Although the available data on animal production and intake were adequate for indicating the general relationship between these two variables, it is clear that a greater understanding of their relationship requires much more basic knowledge of such aspects as the factors influencing maintenance requirements and nutritive value of ingested herbage. In addition the definition of the composition of liveweight change and the relationship between intake and wool growth cycles in Romney sheep would lead to an increased understanding of the levels of production in grazing Romney sheep.

Variability of animal production within stocking rate and pasture type differed considerably between treatments. The similarity of animal production within pasture types at the low stocking rate was probably due to the fact that production was limited by animal rather than plant factors. At the high stocking rate, where the interaction between ecosystem components was greater, there was considerable variability between clover replicates.

Although the reasons for this increased variability are not known there are several possible contributing factors. Thus the difference in drainage between paddock 10 and the other two paddocks is most likely to have contributed to the failure, on paddock 10, of pasture production (and hence animal production) to increase in the spring, especially when the above average rainfall in October (Appendix I) and the generally late spring of this year are taken into account. Similarly the different weed control treatments applied to the different paddocks prior to the experiment, and the initial differences in availability and botanical composition may have contributed to variability of response. The contrasting similarity of production on cocksfoot paddocks may have resulted, at least in part, from the similarity of drainage on all paddocks as well as from the fact that they had all received very similar treatments for a much longer period of time than the clover paddocks.

An increase in replication at high stocking rates has been advocated by Morley (1966b) on the grounds that understanding of the biology of grazing systems will be increased by such a practice. The value of this approach has been confirmed in this study where the failure of paddock 10 in the spring has highlighted the lack of knowledge of the factors and relationships involved in giving rise to pasture "crashes". Such knowledge is important if "crashes" are to be anticipated.

Conclusions

This study has indicated some ways in which different pasture types and different stocking rates interact within one climatic environment to give rise to varying levels of pasture and animal production. The study has also indicated possible mechanisms underlying such interactions as well as emphasising the potential importance of factors, such as differences in site productivity and soil intakes, which have received little attention up to the present time. However, the most valuable aspect of this work has been the provision of a guide to potentially worthwhile lines of research for the future.

SUMMARY

In an experiment designed to study some of the interactions occurring in grazing ecosystems animal and pasture production variables were measured on two pasture types (cocksfoot/clover and clover) at two stocking rates (6 hoggets/acre at the low and 13.5 hoggets/acre at the high rate). Pasture treatments were replicated twice at the low and three times at the high stocking rate. Animal production was measured in terms of liveweight changes, wool growth on midside patches and fleece weights while pasture production was measured in terms of growth, availability and botanical composition. In addition DOM intake/sheep, the botanical composition of the diet and foraging behaviour were studied.

Liveweight increases were greater at the low than the high stocking rate mainly due to differences in liveweight change over the winter period. At the low stocking rate sheep on clover pastures gained more weight than those on cocksfoot pastures whereas at the high stocking rate sheep on cocksfoot pastures gained as much, if not more, weight than those on clover pastures. Wool production showed a similar pattern of response to these treatments although not as many significant ($P < 0.05$) differences between treatments were established.

There were few differences in pasture growth between treatments while pasture availability on low stocked cocksfoot pastures was higher than on all high stocked pastures throughout the experiment. Availability on low stocked clover pastures was low at the start of the experiment and remained so until the spring when it increased rapidly to equal that on low stocked cocksfoot pastures. Availability was generally similar on all high stocked pastures. The grass content of clover pastures increased throughout the experimental period but, on these pastures, there were few differences in botanical composition due to stocking rate. In contrast, there were large differences in the botanical composition of cocksfoot pastures with the grass component consisting almost exclusively of Dactylis glomerata at the low stocking rate but having a high percentage of other grass species at the high stocking rate. In addition there were differences in the weed and clover contents as well as in the amount of dead matter present.

Throughout the experiment DOM intake/sheep remained relatively constant on low stocked paddocks with that on clover paddocks tending to be slightly lower than that on cocksfoot paddocks. These intakes were greater than those on the high stocked paddocks which dropped to a winter minimum to increase to a greater or lesser degree in the spring. There were no

differences due to pasture type at this stocking rate although there were differences between replicates.

Measurements of the botanical composition of the diet indicated selection for green matter and against dead matter and weeds.

There was little variability in response within stocking rate and pasture type except in the case of high stocked clover paddocks. In this case productivity ranged from equality with high stocked cocksfoot paddocks to an almost complete failure of production to increase in the spring.

Investigation of the relationships between animal and pasture production variables showed that the levels of production achieved in this experiment could be largely explained in terms of the relationship between pasture availability and intake and between intake and animal production. The validity and implications of these findings are discussed.

REFERENCES

Alberda, T. (1966) Proc. 10th int. Grassld Congr., Helsinki p.140.

Alder, F.E. (1968) J. Br. Grassld Soc., 23, 310.

——— and Cooper, E.M. (1967) J. agric. Sci., Camb. 68, 331.

Alexander, R.H. and McGowan, M. (1966) J. Br. Grassld Soc. 21, 140.

Allden, W.G. (1962) Proc. Aust. Soc. Anim. Prod. 4, 163.

——— (1968) Proc. Aust. Grassld Conf. 2, 213.

——— (1968a) Aust. J. agric. Res. 19, 621.

——— (1968b) Aust. J. agric. Res. 19, 639.

——— (1968c) Aust. J. agric. Res. 19, 981.

——— (1968d) Aust. J. agric. Res. 19, 997.

——— (1969) Aust. J. agric. Res. 20, 499.

Anon. (1961) "Research Techniques in use at the Grassland Research Institute" C.A.B. Bull. No. 45.

——— (1967) "Stocking Rate Experiments" Dept. Agric., Victoria.

Anslow, R.C. (1965) J. Br. Grassld Soc. 20, 19.

——— and Green, J.O. (1967) J. agric. Sci., Camb. 68, 109.

Appadurai, R.R. and Holmes, W.J. (1964) J. agric. Sci., Camb. 62, 327.

Arnold, G.W. (1960a) Aust. J. agric. Res. 11, 1026.

——— (1960b) Aust. J. agric. Res. 11, 1034.

——— (1962) Aust. J. agric. Res. 13, 702.

——— (1963) Wool Technol. Sheep Breed. 10, 17.

——— (1963a) Proc. Prime Lamb Prod. Symp. p.42.

——— (1964a) "Grazing in Terrestrial and Marine Environments" Ed. D.J. Crisp, Proc. 4th Symp. Br. ecol. Soc. p.133.

——— (1964b) Proc. Aust. Soc. Anim. Prod. 5, 258.

——— (1964c) Proc. Aust. Soc. Anim. Prod. 5, 275.

——— (1964d) Aust. C.S.I.R.O. Field Sta. Rec. 3 (1), 29.

——— (1966a) Aust. J. agric. Res. 17, 521.

——— (1966b) Aust. J. agric. Res. 17, 531.

——— (1966c) Proc. Aust. Soc. Anim. Prod. 6, 213.

——— (1968) Proc. Aust. Grassld Conf. 2, 189.

——— and McManus, W.R. (1960) Proc. Aust. Soc. Anim. Prod. 3, 63.

——— and Dudzinski, M.L. (1966) Proc. 10th int. Grassld Congr., Helsinki p.367.

——— and ——— (1967a) Aust. J. agric. Res. 18, 349.

——— and ——— (1967b) Aust. J. agric. Res. 18, 657.

——— and ——— (1967c) J. agric. Sci., Camb. 68, 213.

———, McManus, W.R. and Bush, I.G. (1964a) Aust. J. exp. Agric. Anim. Husb. 4, 392.

———, ———, ——— and Ball, J. (1964b) Aust. J. exp. Agric. Anim. Husb. 4, 71.

———, Ball, J., McManus, W.R. and Bush, I.G. (1966) Aust. J. agric. Res. 17, 543.

Auda, H., Blaser, R.E. and Brown, R.H. (1966) Crop Sci. 6, 139.

Balch, C.C., Bartlett, S. and Johnson, V.W. (1951) J. agric. Sci., Camb. 41, 98.

——— and Campling, R.C. (1962) Nutr. Abstr. Rev. 32, 669.

Barrow, N.J. (1967) J. Aust. Inst. agric. Sci. 33, 254.

——— and Lambourne, L.J. (1962) Aust. J. agric. Res. 13, 461.

Bath, I.H. and Rook J.A.F. (1965) J. agric. Sci., Camb. 64, 67.

Bernardon, A.E., Huss, D.L. and McCully, W.G. (1967) J. Range Mgmt. 29, 69.

Bishop, A.H., Birrell, H.A. and Tew, A. (1966) Proc. Aust. Soc. Anim. Prod. 6, 161.

Black, J.N. (1963) Aust. J. agric. Res. 14, 20.

Bland, B.F. and Dent, J.W. (1964) J. Br. Grassld Soc. 19, 306.

Blaxter, K.L. (1962) "The Energy Metabolism of Ruminants" Hutchinson, Lond.

——— and Wilson, R.S. (1963) Anim. Prod. 5, 27.

———, Wainman, F.W. and Wilson, R.S. (1961) Anim. Prod. 3, 51.

Bohman, V.R. (1955) J. Anim. Sci. 14, 249.

Booysen, P. de V., Tainton, N.M. and Scott, J.D. (1963) Herb. Abstr. 33, 209.

Bornemissza, G.F. (1960) J. Aust. Inst. agric. Sci. 26, 54.

Bowman, J.C. (1967) Proc. 14th Easter School agric. Sci., Nottingham Univ. p.291.

Bradford, G.E., Weir, W.C. and Torell, D.T. (1961) J. Anim. Sci. 20, 281.

Bradfield, P.G.E. (1967) Proc. 14th Easter School agric. Sci., Nottingham Univ. p.92.

Brockman, J.S. and Wolton, K.M. (1963) J. Br. Grassld Soc. 18, 7.

Bromfield, S.M. (1961) Aust. J. agric. Res. 12, 111.

Brougham, R.W. (1955) Aust. J. agric. Res. 6, 804.

——— (1956a) Aust. J. agric. Res. 7, 377.

——— (1956b) N.Z. Jl. Sci. Technol. A 38, 78.

——— (1959) N.Z. Jl agric. Res. 2, 1232.

——— (1960) N.Z. Jl agric. Res. 3, 125.

——— (1966) Proc. N.Z. ecol. Soc. 13, 58.

——— (1968) Proc. Aust. Grassld Conf. 2, 225.

——— and Harris, W. (1967) N.Z. Jl agric. Res. 10, 56.

———, Glenday, A.C. and Fejer, S.O. (1960) N.Z. Jl agric. Res. 3, 442.

Brown, K.R. (1968) N.Z. Jl agric. Res. 11, 131.

Brown, L.D. (1966) J. Dairy Sci. 49, 223.

Brown, R.H. and Blaser, R.E. (1968) Herb. Abstr. 38, 1.

Bryan, W.W. and Sharpe, J.P. (1965) Aust. J. exp. Agric. Anim. Husb. 5, 433.

Bublath, A.G. (1969) M.Agr.Sc. Thesis, Massey Univ.

Burger, A.W., Jackobs, J.A. and Hittle, C.N. (1958) Agron. J. 50, 629.

Burns, J.C., Noller, C.H. and Rhykerd, C.L. (1964) Agron. J. 56, 364.

Burton, G.W., Jackson, J.E. and Hart, R.H. (1963) Agron. J. 55, 500.

Butler, G.W., Rae, A.L. and Bailey, R.W. (1968) N.Z. agric. Sci. 3, 8.

Butterfield, R.M. (1966) Res. vet. Sci. 7, 168.

———, Pryor, W.J. and Berg, R.T. (1966) Res. vet. Sci. 7, 417.

Byrne, P.F. (1968) Wool Economic Res. Rep. 13, Bur. Agric. Econ. (Aust.).

Campbell, A.G. (1961) Proc. N.Z. Soc. Anim. Prod. 21, 18.

——— (1964) Proc. N.Z. Soc. Anim. Prod. 24, 17.

——— (1966a) N.Z. Jl agric. Res. 9, 1009.

——— (1966b) Proc. 10th int. Grassld Congr., Helsinki p.458.

——— (1966c) J. agric. Sci., Camb. 67, 199.

——— (1966d) J. agric. Sci., Camb. 67, 211.

——— (1966e) J. agric. Sci., Camb. 67, 217.

——— (1967) Proc. N.Z. Soc. Anim. Prod. 27, 126.

——— (1969) N.Z. Jl agric. Res. 12, 67.

Campling, R.C. (1964) Proc. Nutr. Soc. 23, 80.

——— (1966) Outl. Agric. 5, 74.

Carter, E.D. (1968) Proc. Aust. Grassld Conf. 2, 173.

Castle, M.E., Drysdale, A.D. and Watson, J.N. (1962) J. Dairy Res. 29, 199.

Charles, A.H. (1968) Proc. 9th Br. Weed Control Conf. 3, 1223.

Chisholm, A.H. (1965) Rev. Mktg. agric. Econ., Sydney 33 (1), 5.

Christian, C.S. and Shaw, N.H. (1952) Aust. J. agric. Res. 3, 277.

Christian, K.R. and Coup, M.R. (1954) N.Z. Jl Sci. Technol. A 36, 328.

Clapp, J.G., Chamblee, D.S. and Gross, H.D. (1965) Crop Sci. 5, 468.

Clarke, E.A. (1959) Proc. N.Z. Soc. Anim. Prod. 19, 91.

Claxton, J.H. (1963) Aust. J. biol. Sci. 16, 695.

Cockrem, F.R.M. (1968) Lecture notes. Massey University.

Conrad, H.R., Pratt, A.D. and Hibbs, J.W. (1964) J. Dairy Sci. 47, 54.

Conway, A. (1963) Ir. J. agric. Res. 2, 243.

Cook, C.W. (1959) J. Range Mgmt. 12, 289.

———, Mattox, J.E. and Harris, L.E. (1961) J. Anim. Sci. 20, 866.

———, Blake, J.T. and McCall, J.W. (1963) J. Anim. Sci. 22, 579.

Coop, I.E. (1953) J. agric. Sci., Camb. 43, 456.

——— (1967) Proc. N.Z. Soc. Anim. Prod. 27, 154.

——— and Clark, V.R. (1955) N.Z. Jl Sci. Technol. A 37, 214.

——— and Drew, K.R. (1963) Proc. N.Z. Soc. Anim. Prod. 23, 53.

Corbett, J.L. (1960) Proc. 8th int. Grassld Congr., Reading p.438.

——— (1964) Proc. Aust. Soc. Anim. Prod. 5, 138.

——— (1969) "International Encyclopedia of Food and Nutrition", Pergamon Press 17, 593.

——— and Greenhalgh, J.F.D. (1960) "Production and use of grass" Monogr. No. 9, Soc. Chem. Ind., London.

———, ———, McDonald, I. and Florence, E. (1960a) Br. J. Nutr. 14, 289.

———, Reid, G.W., Langlands, J.P. and Florence, E. (1960b) Proc. Nutr. Soc. 19, xx.

———, Langlands, J.P. and Reid, G.W. (1963) Anim. Prod. 5, 119.

———, ———, McDonald, I. and Pullar, J.D. (1966) Anim. Prod. 8, 13.

Costin, A.B. (1964) "Grasses and Grasslands" Ed. C. Barnard, MacMillan.

Cowlishaw, S.J. (1951) J. Br. Grassld Soc. 6, 179.

——— (1962) J. Br. Grassld Soc. 17, 52.

——— (1969) J. Br. Grassld Soc. 24, 207.

——— and Alder, F.E. (1963) J. Br. Grassld Soc. 18, 328.

Davidson, J.L. (1968) Proc. Aust. Grassld Conf. 2, 125.

——— and Donald, C.M. (1958) Aust. J. agric. Res. 9, 53.

——— and Milthorpe, F.L. (1966a) Ann. Bot. 30, 173.

——— and ——— (1966b) Ann. Bot. 30, 185.

Davidson, R.L. (1964) J. Br. Grassld Soc. 19, 273.

Davies, E.B., Hogg, D.E. and Hopewell, H.G. (1962) Int. Soc. Soil Sci. p.715.

Davies, H. Lloyd (1962) Proc. Aust. Soc. Anim. Prod. 4, 167.

——— (1968) Proc. Aust. Grassld Conf. 2, 181.

Dickinson, A.G. (1960) J. agric. Sci., Camb. 54, 378.

Doak, B.W. (1952) J. agric. Sci., Camb. 42, 162.

Donald, C.M. (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.80.

——— and Black, J.N. (1958) Herb. Abstr. 28, 1.

——— and Allden, W.G. (1959) Aust. J. agric. Res. 10, 199.

Doney, J.M. (1964) J. agric. Sci., Camb. 62, 59.

——— (1966) J. agric. Sci., Camb. 67, 25.

——— and Smith, W.F. (1961) J. agric. Sci., Camb. 56, 365.

——— and ——— (1964) Anim. Prod. 6, 153.

——— and Eadie, J. (1967) J. agric. Sci., Camb. 69, 411.

Doyle, J.J. (1967) Aust. J. exp. Agric. Anim. Husb. 7, 318.

Drew, K.R. (1966) Proc. N.Z. Soc. Anim. Prod. 26, 52.

Duncan, D.B. (1955) Biometrics 11, 1.

Edmond, D.B. (1958) N.Z. Jl agric. Res. 1, 319.

—— (1962) N.Z. Jl agric. Res. 5, 389.

—— (1963) N.Z. Jl agric. Res. 6, 265.

—— (1964) N.Z. Jl agric. Res. 7, 1.

—— (1965) Proc. N.Z. Grassld Ass. p.112.

—— (1966) Proc. 10th int. Grassld Congr., Helsinki p.453.

Elliott, R.C., Fokkema, K. and French, C.H. (1961) Rhodesia agric. J. 58, 124.

Elsley, F.W.H., McDonald, I. and Fowler, V.R. (1964) Anim. Prod. 6, 141.

Evans, L.T., Wardlaw, I.F. and Williams, C.N. (1964) "Grasses and Grasslands" Ed. C. Barnard, MacMillan.

Everitt, G.C. (1967a) Proc. N.Z. Soc. Anim. Prod. 27, 52.

—— (1967b) Proc. 14th Easter School agric. Sci., Nottingham Univ. p.131.

Fels, H.E., Moir, R.J. and Rossiter, R.C. (1959) Aust. J. agric. Res. 10, 237.

Ferguson, K.A. (1962) Aust. J. biol. Sci. 15, 720.

——, Wallace, A.L.C. and Lindner, H.R. (1965) "Biology of the Skin and Hair Growth" Angus and Robertson p.655.

Fernando, G.W.E. (1961) Trop. Agriculturist 117, 167.

Fontenot, J.P. and Blaser, R.E. (1965) J. Anim. Sci. 24, 1202.

Foot, A.S. (1963) 1st Symp. Eur. Grassld Fed. p.40.

Forbes, E.B., Elliott, R.F., Swift, R.W., James, W.H. and Smith, V.F. (1946) J. Anim. Sci. 5, 298.

Forbes, R.M. and Garrigus, W.P. (1948) J. Anim. Sci. 7, 373.

Fowler, V.R. (1967) Proc. 14th Easter School agric. Sci., Nottingham Univ. p.195.

Fraser, A.S. and Short, B.F. (1960) "The Biology of the Fleece" Tech. Pap. Anim. Res. Labs. C.S.I.R.O., Aust. No. 3.

Gallagher, J.R., Watkin, B.R. and Grimes, R.C. (1966) J. agric. Sci., Camb. 66, 107.

Galpin, N. (1947) J. agric. Sci., Camb. 37, 275.

Giles, J.R. (1968) Aust. J. exp. Agric. Anim. Husb. 8, 149.

Gillard, P. (1967) J. Aust. Inst. agric. Sci. 33, 30.

Grimes, R.C. (1966) Ph.D. Thesis, University of New England.

———, Watkin, B.R. and May, P.F. (1965) J. Br. Grassld Soc. 20, 168.

———, ——— and Gallagher, J.R. (1966) J. agric. Sci., Camb. 66, 113.

Gordon, H. McL. (1958) Proc. Aust. Soc. Anim. Prod. 2, 59.

Greenhalgh, J.F.D. (1966) Proc. 10th int. Grassld Congr., Helsinki p.351.

——— and Corbett, J.L. (1960) J. agric. Sci., Camb. 55, 371.

——— and Reid, G.W. (1967) Nature, Lond. 214, 744.

——— and ——— (1969) J. agric. Sci., Camb. 72, 223.

Gunn, R.G. (1964a) J. agric. Sci., Camb. 62, 99.

——— (1964b) J. agric. Sci., Camb. 62, 123.

——— (1965) J. agric. Sci., Camb. 64, 311.

——— (1967a) J. agric. Sci., Camb. 69, 341.

——— (1967b) J. agric. Sci., Camb. 69, 345.

——— (1968) J. agric. Sci., Camb. 71, 161.

Halley, R.J. (1955) J. Br. Grassld Soc. 10, 229.

Hardison, W.A. and Reid, J.T. (1953) J. Nutr. 51, 35.

Harkess, R.D. (1963) J. Br. Grassld Soc. 18, 62.

Harris, L.E., Lofgreen, G.P., Kercher, C.J., Raleigh, R.J. and Bohman, V.R. (1967) Bull. 471. Utah State Univ.

Heady, H.F. (1964) J. Range Mgmt. 17, 76.

Healy, W.B. (1967) Proc. N.Z. Soc. Anim Prod. 27, 109.

——— (1968) N.Z. Jl agric. Res. 11, 487.

Henderson, A.E. (1953) J. agric. Sci., Camb. 43, 12.

Herriott, J.B.D. and Wells, D.A. (1963) J. agric. Sci., Camb. 61, 89.

Hight, G.K. and Barton, R.A. (1965) J. agric. Sci., Camb. 64, 413.

——— and Sinclair, D.P. (1965) N.Z. Jl agric. Res. 8, 1079.

——— and ——— (1967) N.Z. Jl agric. Res. 10, 323.

Hilder, E.J. (1966) Proc. 10th int. Grassld Congr., Helsinki p.977.

Hodgson, J. (1966) J. Br. Grassld Soc. 21, 258.

——— and Wilkinson, J.M. (1968) J. Br. Grassld Soc. 23, 75.

——— and Ollerenshaw, J.H. (1969) J. Br. Grassld Soc. 24, 226.

Hogan, J.P. (1965) Aust. J. agric. Res. 16, 855.

Holder, J.M. (1962) Proc. Aust. Soc. Anim. Prod. 4, 154.

Holt, E.C. and McDaniel, J.C. (1963) Agron. J. 55, 561.

Hugo, W.J. (1958) S. Afr. J. agric. Sci. 1, 203.

Hull, J.L., Meyer, J.H. and Kromann, R. (1961) J. Anim. Sci. 20, 46.

Humphreys, L.R. and Robinson, A.R. (1966) Proc. 10th int. Grassld Congr., Helsinki p.113.

Hunt, L.A. (1965) J. Br. Grassld Soc. 20, 27.

——— and Brougham, R.W. (1967) N.Z. Jl agric. Res. 10, 397.

Hunt, W.F. (1968) M.Agr.Sc. Thesis, Massey Univ.

Hunter, G.C. (1952) Nutr. Abstr. Rev. 23, 705.

Hutchinson, J.C.D. (1965) "Biology of the Skin and Hair Growth" Angus and Robertson p.565.

——— and Wodzicka-Tomaszewska, M. (1961) Anim. Breed. Abstr. 29, 1.

Hutchinson, K.J. (1956) Proc. Aust. Soc. Anim. Prod. 1, 52.

——— and Porter, R.B. (1958) Proc. Aust. Soc. Anim. Prod. 2, 33.

Hutton, J.B. (1962) N.Z. Jl agric. Res. 5, 409.

——— (1963) Proc. N.Z. Soc. Anim. Prod. 23, 39.

Ivins, J.D. (1960) Proc. 8th int. Grassld Congr., Reading p.459.

——— and Drake, K.G. (1964) Rep. Sch. Agric. Univ. Nott. p.62.

Jacques, W.A. and Edmond, D.B. (1952) N.Z. Jl Sci. Technol. A 34, 231.

Jantii, A. and Kramer, P.J. (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.33.

Johns, A.T. (1963) Proc. N.Z. Grassld Ass. p.59.

Johnstone-Wallace, D.B. and Kennedy, K. (1944) J. agric. Sci., Camb. 34, 190.

Jones, D.I.H. (1962) J. Sci. Fd. Agric. 13, 83.

Jones, Ll. I. (1932) Welsh Pl. Breed. Stn. Bull Series H. No. 13, p.95.

——— (1952) Proc. 6th int. Grassld Congr., Pennsylvania p.1348.

——— (1959) Proc. 7th Easter School agric. Sci., Nottingham Univ. p.34.

——— (1967) Welsh Pl. Breed. Stn. Tech. Bull. No. 2.

Jones, M.G. (1933) Jl R. agric. Soc. 94, 21.

Joyce, J.P. and Newth, R.P. (1967) Proc. N.Z. Soc. Anim. Prod. 27, 166.

Kane, E.A., Jacobson, W.C. and Moore, L.A. (1952) J. Nutr. 47, 263.

Keenan, D.M., McManus, W.R. and Freer, M. (1969) J. agric. Sci., Camb. 72, 139.

Kirton, A.H. and Barton, R.A. (1958) J. agric. Sci., Camb. 51, 265.

Kydd, D.D. (1966a) J. Br. Grassld Soc. 21, 284.

——— (1966b) J. Br. Grassld Soc. 21, 289.

Lambourne, L.J. (1957a) J. agric. Sci., Camb. 48, 273.

——— (1957b) J. agric. Sci., Camb. 48, 415.

——— (1968) Proc. Aust. Grassld Conf. 2, 33.

——— and Reardon, T.F. (1962) Nature, Lond. 196, 961.

——— and ——— (1963a) Aust. J. agric. Res. 14, 239.

——— and ——— (1963b) Aust. J. agric. Res. 14, 272.

Lancaster, R.J. (1944) N.Z. Jl Sci. Technol. A 25, 137.

——— (1954) N.Z. Jl Sci. Technol. A 36, 15.

——— and Bartrum, M.P. (1954) N.Z. Jl Sci. Technol. A 35, 489.

———, Coup, M.R. and Percival, J.C. (1953) N.Z. Jl Sci. Technol. A 35, 117.

Langer, R.H.M. (1963) Herb. Abstr. 33, 141.

——— and Steinke, T.D. (1965) J. agric. Sci., Camb. 64, 291.

Langlands, J.P. (1965) Nature, Lond. 207, 666.

——— (1966) Anim. Prod. 8, 253.

——— (1967a) Anim. Prod. 9, 167.

——— (1967b) Anim. Prod. 9, 325.

——— (1969) Anim. Prod. 11, 369.

———, Corbett, J.L., McDonald, I. and Reid, G.W. (1963a) Br. J. Nutr. 17, 211.

———, ———, ———, and ——— (1963b) Br. J. Nutr. 17, 219.

Leigh, J.H. and Mulham, W.E. (1966a) Aust. J. exp. Agric. Anim. Husb. 6, 460.

——— and ——— (1966b) Aust. J. exp. Agric. Anim. Husb. 6, 468.

——— and ——— (1967) Aust. J. exp. Agric. Anim. Husb. 7, 421.

Leroy, A.M. (1952) Proc. 6th int. Grassld Congr., Pennsylvania p.1354.

Lesperance, A.L. and Bohman, V.R. (1961) J. Anim. Sci. 20, 503.

———, ——— and Marble, D.W. (1960) J. Dairy Sci. 43, 682.

Linehan, P.A. (1952) Proc. 6th int. Grassld Congr., Pennsylvania p.175.

———, Lowe, J. and Stewart, R.H. (1947) J. Br. Grassld Soc. 2, 145.

Lombard, P.E. and Van Schalkwyk, A. (1963) S. Afr. J. agric. Sci. 6, 205.

Lowe, J. (1959) Proc. 7th Easter School agric. Sci., Nottingham Univ. p.88.

Ludwig, T.G., Healy, W.B. and Cutress, T.W. (1966) N.Z. Jl agric. Res. 9, 157.

Lynch, P.B. (1960) N.Z. Dept. Agric. Bull. No. 399.

——— (1966) N.Z. Jl Agric. 113 (4), 55.

McBride, G., Arnold, G.W., Alexander, G. and Lynch, J.J. (1967) Proc. ecol. Soc. Aust. 2, 133.

McClymont, G.L. (1967) "Handbook of Physiology - Section 6. Alimentary Canal" 1, 129.

McCullough, M.E. (1959) Agron. J. 51, 219.

McDonald, I.W. (1968) Nutr. Abstr. Rev. 38, 381.

McDougall, E.I. (1948) Biochem. J. 43, 99.

Macfadyen, A. (1961) Ann. appl. Biol 49, 215.

McFarlane, J.D. (1965) Aust. J. exp. Agric. Anim. Husb. 5, 252.

McLachlan, K.D. (1968) Aust. J. exp. Agric. Anim. Husb. 8, 33.

——— and Norman, B.W. (1966) Aust. J. exp. Agric. Anim. Husb. 6, 22.

McLean, J.W., Thompson, G.G., Iversen, C.E., Jagusch, K.T. and Lawson, B.M. (1962) Proc. N.Z. Grassld Ass. p.57.

———, ———, Jagusch, K.T. and Lawson, B.M. (1965) Proc. Ruakura Fmrs' Conf. Week, p.1.

MacLusky, D.S. (1955) Proc. Br. Soc. Anim. Prod. p.45.

——— and Morris, D.W. (1964) Agric. Prog. 39, 97.

McManus, W.R. (1961) Aust. J. exp. Agric. Anim. Husb. 1, 159.

——— (1962) Aust. J. agric. Res. 13, 907.

——— (1966) Wool Technol. Sheep Breed. 13 (2), 97.

——— and Arnold, G.W. (1965) Aust. vet. J. 41, 365.

———, ——— and Hamilton, F.J. (1962) Aust. vet. J. 38, 275.

———, ——— and Paynter, J.R. (1964) Aust. J. exp. Agric. Anim. Husb. 4, 404.

———, ——— and Ball, J. (1968) J. Br. Grassld Soc. 23, 223.

McMeekan, C.P. (1940a) J. agric. Sci., Camb. 30, 276.

——— (1940b) J. agric. Sci., Camb. 30, 387.

——— (1940c) J. agric. Sci., Camb. 30, 511.

——— (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.146.

——— (1961) Proc. N.Z. Soc. Anim. Prod. 21, 47.

McQueen, I.P.M. (1965) Proc. Ruakura Fmrs' Conf. Week, p.204.

Marshall, C. and Sagar, G.R. (1965) Ann. Bot. 29, 365.

——— and ——— (1968) Ann. Bot. 32, 715.

May, L.H. (1960) Herb. Abstr. 30, 239.

Meyer, J.H. and Clawson, W.J. (1964) J. Anim. Sci. 23, 214.

———, Lofgreen, G.P. and Ittner, N.R. (1956) J. Anim. Sci. 15, 64.

Miles, D.G., Walters, R.J.K. and Evans, E.M. (1969) Anim. Prod. 11, 19.

Milford, R. and Minson, D.J. (1964) Proc. 9th int. Grassld Congr., São Paulo p.815.

——— and ——— (1966) J. Br. Grassld Soc. 21, 7.

Milthorpe, F.L. and Davidson, J.L. (1965) Proc. 12th Easter School agric. Sci., Nottingham Univ. p.241.

Minson, D.J. (1968) Proc. Aust. Grassld Conf. 2, 25.

——— and Raymond, W.F. (1958) Exp. Grassld Res. Inst., Hurley 10, 92.

———, Harris, C.E., Raymond, W.F. and Milford, R. (1964) J. Br. Grassld Soc. 19, 298.

Mitchell, K.J. (1954) Physiol. Plant. 7, 51.

——— (1957) Emp. J. exp. Agric. 25, 69.

——— and Coles, S.T.J. (1955) N.Z. Jl Sci. Technol. A 36, 586.

——— and Denne, M.P. (1967) "The Lucerne Crop" Ed. R.H.M. Langer.

Moir, R.J. (1968) Proc. Aust. Grassld Conf. 2, 153.

Montgomery, M.J. and Baumgardt, B.R. (1965) J. Dairy Sci. 48, 569.

Moore, R.M. (1966) Proc. 9th int. Congr. Anim. Prod. p.188.

——— and Biddiscombe, E.F. (1964) "Grasses and Grasslands" Ed. C. Barnard, MacMillan.

Morley, F.H.W. (1966a) Proc. N.Z. Soc. Anim. Prod. 26, 8.

——— (1966b) Proc. Aust. Soc. Anim. Prod. 6, 127.

——— and Spedding, C.R.W. (1968) Herb. Abstr. 38, 279.

———, Bennett, D. and McKinney, G.T. (1969) Aust. J. exp. Agric. Anim. Husb. 9, 74.

Mott, G.O. (1960) Proc. 8th int. Grassld Congr., Reading p.606.

Moule, G.R. (1965) "Field Investigations with Sheep. A Manual of Techniques." C.S.I.R.O.

Murnane, D. (1934) J. Counc. Sci. Ind. Res. (Australia) 7, 143.

Norman, M.J.T. (1957) J. Br. Grassld Soc. 12, 246.

——— (1960) J. Br. Grassld Soc. 15, 145.

O'Connor, K.F. (1956) Proc. N.Z. Soc. Soil Sci. 2, 35.

Oh, H.K., Baumgardt, B.R. and Scholl, J.M. (1966) J. Dairy Sci. 49, 851.

Ormrod, J.F. (1966) Proc. 8th Br. Weed Control Conf. 3, 861.

Osbourn, D.F., Thomson, D.J. and Terry, R.A. (1966) Proc. 10th int. Grassld Congr., Helsinki p.363.

O'Shea, J. and Wilson, R.K. (1965) Ir. J. agric. Res. 4, 235.

Oswalt, D.L., Bertrand, A.R. and Teel, M.R. (1959) Proc. Soil Sci. Soc. Am. 23, 228.

Owen, J.B. and Ingleton, Jean W. (1963) J. agric. Sci., Camb. 61, 267.

Pålsson, H. (1955) "Progress in the physiology of farm animals" 2, ch.10. Butterworths, London.

——— and Verges, J.B. (1952) J. agric. Sci., Camb. 42 (1), 93.

Panaretto, B.A. (1964) Aust. J. agric. Res. 15, 771.

Peart, G.R. (1968) Proc. Aust. Soc. Anim. Prod. 7, 110.

Peel, Lynnette, J. and Wilson, A.D. (1964) Aust. J. agric. Res. 15, 625.

Petersen, R.G., Lucas, H.L. and Woodhouse, W.W. (1956) Agron. J. 48, 440.

———, ——— and Mott, G.O. (1965) Agron. J. 57, 27.

Pigden, W.J. and Brisson, G.J. (1957) Can. J. Anim. Sci. 37, 185.

Piper, L.R. and Dolling, C.H.S. (1969) Aust. J. agric. Res. 20, 561.

Pritchard, G.I., Folkins, L.P. and Pigden, W.J. (1963) Can. J. Pl. Sci. 43, 79.

Purser, A.F. and Roberts, R.C. (1964) Anim. Prod. 6, 273.

Rattray, P.V. and Joyce, J.P. (1969) Proc. N.Z. Soc. Anim. Prod. 29, 102.

Raymond, W.F. (1963) "Animal Health, Production and Pastures" Ed. A.N. Worden, K.C. Sellers, and D.E. Tribe. Longmans, London p.261.

——— and Harris, C.E. (1954) J. Br. Grassld Soc. 9, 119.

——— and Minson, D.J. (1955) J. Br. Grassld Soc. 10, 282.

———, Harris, C.E. and Harker, V.G. (1953) J. Br. Grassld Soc. 8, 301.

———, ——— and Kemp, C.D. (1954) J. Br. Grassld Soc. 9, 209.

———, Minson, D.J. and Harris, C.E. (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.123.

Reardon, T.F. and Lambourne, L.J. (1966) Proc. Aust. Soc. Anim. Prod. 6, 106.

Reid, J.T. and Kennedy, W.K. (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.116.

———, Woolfolk, P.G., Richards, C.R., Kaufmann, R.W., Loosli, J.K., Turk, K.L., Miller, J.I. and Blaser, R.E. (1950) J. Dairy Sci. 33, 60.

Reis, P.J. and Schinckel, P.G. (1963) Aust. J. biol. Sci. 16, 218.

——— and Williams, O.B. (1965) Aust. J. agric. Res. 16, 1011.

Ridgman, W.J. (1960) J. Br. Grassld Soc. 15, 291.

Riewe, M.E. (1961) Agron. J. 53, 309.

Robards, G.E., Leigh, J.H. and Mulham, W.E. (1967) Aust. J. exp. Agric. Anim. Husb. 7, 426.

Robinson, P. (1948) J. agric. Sci., Camb. 38, 345.

Roe, R. and Mottershead, B.E. (1962) Nature, Lond. 193, 255.

———, Southcott, W.H. and Turner, H.N. (1959) Aust. J. agric. Res. 10, 530.

Ross, D.A. (1965) N.Z. Jl agric. Res. 8, 585.

Rossiter, R.C. (1966) Adv. Agron. 18, 1.

Russel, A.J.F., Gunn, R.G. and Doney, J.M. (1968) Anim. Prod. 10, 43.

Ryder, M.L. and Stephenson, S.K. (1968) "Wool Growth." Academic Press.

Sagar, G.R. and Marshall, C. (1966) Proc. 9th int. Grassld Congr., São Paulo p.493.

Schinckel, P.G. (1955a) Aust. J. agric. Res. 6, 68.

——— (1955b) Aust. J. agric. Res. 6, 308.

——— (1963) Proc. 1st Wld Conf. Anim. Prod., Rome 1, 199.

——— and Short, B.F. (1961) Aust. J. agric. Res. 12, 176.

Scoffield, J.E. (1969) N.Z. agric. Sci. In press.

Scott, R.S. (1963) Proc. N.Z. Grassld Ass. p.119.

Sears, P.D. (1950) J. Br. Grassld Soc. 5, 267.

——— (1953) N.Z. Jl Sci. Technol. A 35, 1.

——— (1956) Proc. 7th int. Grassld Congr., Palmerston North, N.Z. p.92.

——— (1960) Proc. 8th int. Grassld Congr., Reading p.130.

——— and Newbold, R.P. (1942) N.Z. Jl Sci. Technol. A 24, 36.

——— and Goodall, V.C. (1948) N.Z. Jl Sci. Technol. A 30, 231.

——— and Thurston, W.G. (1952) N.Z. Jl Sci. Technol. A 34, 445.

Sharkey, M.J. and Hedding R.R. (1964) Proc. Aust. Soc. Anim. Prod. 5, 284.

———, Davis, I.F. and Kenney, P.A. (1962) Aust. J. exp. Agric. Anim. Husb. 2, 160.

———, ——— and ——— (1964) Aust. J. exp. Agric. Anim. Husb. 4, 34.

Shaw, P.G., Brockman, J.S. and Wolton, K.M. (1966) Proc. 10th int. Grassld Congr., Helsinki p.240.

Short, B.F. (1955) Aust. J. agric. Res. 6, 62.

Slee, J. and Carter, H.B. (1961) J. agric. Sci., Camb. 57, 11.

Smith, A. (1968) J. Br. Grassld Soc. 23, 294.

Smith, A.M. and Reid, J.T. (1955) J. Dairy Sci. 38, 515.

Snedecor, G.W. and Cochran, W.G. (1967) "Statistical Methods" Iowa State College Press.

Southcott, W.H., Heath, D.D. and Langlands, J.P. (1967) J. Br. Grassld Soc. 22, 117.

Spedding, C.R.W. (1954) J. comp. Path. 64, 5.

——— (1965a) Wld Rev. Anim. Prod. (1), 107.

——— (1965b) Herb. Abstr. 35, 77.

——— (1966) Proc. 8th Br. Weed Control Conf. 3, 854.

———, Large, R.V. and Kydd, D.D. (1966) Proc. 10th int. Grassld Congr., Helsinki p.479.

———, Betts, J.E., Large, R.V., Wilson, I.A.N. and Penning, P.D. (1967) J. agric. Sci., Camb. 69, 47.

Squires, V.R. (1964) Aust. J. exp. Agric. Anim. Husb. 4, 92.

Stevenson, Audrey E. and de Langen, H. (1960) N.Z. Jl agric. Res. 3, 314.

——— and Clare, N.T. (1963) N.Z. Jl agric. Res. 6, 121.

Stewart, A.M., Moir, R.J. and Schinckel, P.G. (1961) Aust. J. exp. Agric. Anim. Husb. 1, 85.

Stockdill, S.M.J. and Cossens, G.G. (1966) Proc. N.Z. Grassld Ass. p.168.

Story, L.F. and Ross, D.A. (1960) N.Z. Jl agric. Res. 3, 113.

Suckling, F.E.T. (1964a) Proc. N.Z. Grassld Ass. p.137.

——— (1964b) Sheepfmg A. p.18.

Sumner, R. and Wickham, G.A. (1969) Proc. N.Z. Soc. Anim. Prod. 29, 208.

Swain, F.G. (1968) Proc. Aust. Grassld Conf. 2, 85.

Tayler, J.C. (1954) Proc. Brit. Soc. Anim. Prod. p.3.

——— and Deriaz, R.E. (1963) J. Br. Grassld Soc. 18, 29.

Terry, R.A. and Tilley, J.M.A. (1964) J. Br. Grassld Soc. 19, 363.

Tilley, J.M.A. and Terry, R.A. (1963) J. Br. Grassld Soc. 18, 104.

———, Deriaz, R.E. and Terry, R.A. (1960) Proc. 8th int. Grassld Congr., Reading p.533.

Torell, D.T. (1954) J. Anim. Sci. 13, 878.

Tribe, D.E. (1946) J. agric. Sci., Camb. 39, 309.

——— (1950) Nature, Lond. 166, 74.

——— and Gordon, J.G. (1946) J. agric. Sci., Camb. 39, 313.

———, Freer, M. and Coombe, J.B. (1963) "Animal Health, Production and Pasture" Ed. Worden, A.N., Sellers, K.C. and Tribe, D.E., Longmans.

Troelsen, J.E. (1963) Can. J. Anim. Sci. 43, 389.

Troughton, A. (1957) Bull. Commonw. Bur. Past. Fld Crops, No. 44.

Ulyatt, M.J. (1969) Proc. N.Z. Soc. Anim. Prod. 29, 114.

———, Blaxter, K.L. and McDonald, I. (1967) Anim. Prod. 9, 463.

Underwood, E.J. (1966) "The Mineral Nutrition of Livestock" C.A.B.

Van der Kley, F.K. (1956) Neth. J. agric. Sci. 4, 197.

Van Dyne, G.M. (1962) J. Range Mgmt. 15, 303.

——— (1968) "A practical guide to the study of the productivity of large herbivores" IBP Handbook No. 7. Blackwell Scientific Publications.

——— and Lofgreen, G.P. (1964) J. Anim. Sci. 23, 823.

——— and Torell, D.F. (1964) J. Range Mgmt. 17, 7.

——— and Weir, W.C. (1964) J. Range Mgmt. 17, 327.

——— and Heady, H.F. (1965a) Hilgardia 36, 465.

——— and ——— (1965b) J. Range Mgmt. 18, 78.

———, Thomas, O.O. and Van Horn J.L. (1964) Proc. west. Sect. Am. Soc. Anim. Sci. 14, LXI, 1.

Van Soest, P.J. (1962) J. Dairy Sci. 45, 664.

——— (1964) J. Anim. Sci. 23, 838.

Vartha, E.W. (1966) Proc. N.Z. Grassld Ass. p.102.

Walker, T.W. (1956a) Proc. 7th int. Grassld Congr., Palmerston North p.157.

——— (1956b) Proc. 6th int. Congr. Soil Sci., Paris p.409

———, Orchiston, H.D. and Adams, A.F.R. (1954) J. Br. Grassld Soc. 9, 249.

Wallace, L.R. (1948) J. agric. Sci., Camb. 38, 367.

——— (1961) Proc. N.Z. Soc. Anim. Prod. 21, 64.

Ward, C.Y. and Blaser, R.E. (1961) Crop Sci. 1, 366.

Waite, R., Holmes, W., Campbell, Jean I. and Fergusson, D.L. (1950) J. agric. Sci., Camb. 40, 392.

Watkin, B.R. (1954) J. Br. Grassld Soc. 9, 35.

——— (1957) J. Br. Grassld Soc. 12, 264.

Watson, D.J. (1947) Ann. Bot. 11, 41.

Watson, E.R. and Lapins, P. (1969) Aust. J. exp. Agric. Anim. Husb. 9, 85.

Watson, N. (1965) Sheepfmg A. p.23.

Weinmann, H. (1961) Herb. Abstr. 31, 255.

Weston, R.H. (1967) Aust. J. agric. Res. 18, 983.

Wheeler, J.L. (1958) J. Br. Grassld Soc. 13, 196.

——— (1960) Divl Rep. No. 20, Div. Plant Ind., C.S.I.R.O., Canberra.

———, Reardon, T.F. and Lambourne, L.J. (1963) Aust. J. agric. Res. 14, 364.

Whittaker, I.A.McD. (1965) Ph.D. Thesis, University of Adelaide.

Wildman, A.B. (1958) J. agric. Sci., Camb. 51, 308.

——— (1965) J. agric. Sci., Camb. 65, 301.

Wilkins, R.J. (1969) J. agric. Sci., Camb. 73, 57.

Williams, C.H., David, D.J. and Iismaa, O. (1962) J. agric. Sci., Camb. 59, 381.

Williams, O.B. (1964) Proc. Aust. Soc. Anim. Prod. 5, 280.

——— and Schinckel, P.G. (1962) Proc. Aust. Soc. Anim. Prod. 4, 38.

——— and Suijdendorp, H. (1968) Aust. J. exp. Agric. Anim. Husb. 8, 653.

Willoughby, W.M. (1959) Aust. J. agric. Res. 10, 248.

——— (1968) Proc. Aust. Grassld Conf. 2, 165.

Wilson, A.D. (1966) Proc. Aust. Soc. Anim. Prod. 6, 179.

———, Leigh, J.H. and Mulham, W.E. (1969) Aust. J. agric. Res. 20, 1123.

Wilson, G.F. (1967) Proc. N.Z. Grassld Ass. p.102.

Wilson, P.N. (1954a) J. agric. Sci., Camb. 44, 67.

——— (1954b) J. agric. Sci., Camb. 45, 110.

——— (1958a) J. agric. Sci., Camb. 50, 198.

——— (1958b) J. agric. Sci., Camb. 51, 4.

——— (1960) J. agric. Sci., Camb. 54, 105.

——— and Osbourn, D.F. (1960) Biol. Rev. 35, 324.

Woodman, H.E. and Norman, D.B. (1932) J. agric. Sci., Camb. 22, 852.

Yates, F. (1933) Emp. J. Exp. Agric. 1, 129.

Young, B.A. and Corbett, J.L. (1969) Proc. Aust. Soc. Anim. Prod. 7, 327.

Addendum

Lancashire, J.A. and Latch, G.C.M. (1966) N.Z. J. agric. Res. 9, 628.

Leigh, J.H., Wilson, A.D. and Mulham, W.E. (1968) Aust. J. agric. Res. 19, 947.

Parks, S.H. (1966) M. Agr. Sc. Thesis, Massey University.

APPENDIX I

Meteorological Data for Palmerston North

Recorded at Grasslands Division D.S.I.R. - 8 miles from the experimental area.

Temperature $^{\circ}F$ 1968

	Mean Maximum	Mean Minimum	Mean	Maximum Absolute	Minimum Absolute
Jan.	70.4	54.1	62.3	82.0	44.6
Feb.	71.3	53.6	62.5	81.9	42.9
Mar.	76.4	58.7	67.6	85.1	44.8
Apr.	65.2	51.6	58.4	77.9	40.6
May	60.7	46.6	53.7	67.2	33.8
June	56.2	43.2	49.2	59.7	29.8
July	53.1	39.0	46.1	61.1	30.8
Aug.	56.1	41.4	48.7	65.0	31.6
Sept.	56.6	43.1	49.9	65.5	33.1
Oct.	58.9	46.4	52.7	64.6	34.9
Nov.	63.0	47.5	55.3	74.9	37.0
Dec.	67.7	53.1	60.4	76.7	37.1

Rainfall 1968

	Inches	No. of days	30 year average
Jan.	2.30	7	3.39
Feb.	2.02	6	2.71
Mar.	0.91	8	2.82
Apr.	4.54	16	3.04
May	5.05	17	3.32
June	6.02	21	3.81
July	2.93	16	3.51
Aug.	2.51	14	3.32
Sept.	2.64	18	2.75
Oct.	5.33	24	3.40
Nov.	1.92	13	3.20
Dec.	5.92	12	4.03
TOTAL	42.09	172	39.30

APPENDIX II

Soil contamination of faeces

(a) Differentiation between faecal OM due to loss in weight of undigested plant material and due to loss in weight of faecal soil.

Faecal dry matter output (A) may be considered to be made up of an ash component from soil (B), an ash component from ingested plant material (C) and OM components from soil (D) and ingested plant material (E). This can be shown in an equation:-

$$\begin{array}{ccccccccc} \text{Faecal DM} & = & \text{Soil ash} & + & \text{Plant ash} & + & \text{Soil OM} & + & \text{Plant OM} \\ A & = & B & + & C & + & D & + & E \end{array}$$

Faecal soil (B + D) can be calculated knowing both faecal DM output (A) and the percentage soil content of the faeces.

Assuming a value for the percentage loss in weight of soil on ashing, the value of soil OM (D) can be calculated. Soil samples from the experimental area, collected and processed in several ways, gave a mean value for loss in weight of 8% and this value has been assumed throughout all calculations.

Subtraction of soil OM (D) from total faecal OM (D + E), which is known, gives the required value of plant OM (E).

An example will clarify the procedure used:-

Mean faecal DM output/day for collection period $= A = 1586$ g.

Faeces OM % $= 13\%$

$\therefore$ Faecal OM $= D + E = \frac{13}{100} \times 1586 = 206$ g.

Faeces soil % $= 70\%$

$\therefore$ Faecal soil $= B + D = \frac{70}{100} \times 1586 = 1110$ g.

Soil OM % $= 8\%$

$\therefore$ Soil OM $= D = \frac{8}{100} \times 1110 = 89$ g.

$\therefore$ Plant OM $= E = 206 - 89 = 117$ g.

Soil contamination of faeces

(b) Experimental results (All weights are expressed in g.)

Paddock	Month	Sheep	Faecal DM	% OM	Faecal OM	% soil	Faecal soil	Soil OM	Plant OM
1	May	A	320.8	79.8	256	1.0	-	-	256
		B	314.0	80.4	252	1.0	-	-	252
	June	A	328.0	79.2	260	5.0	16.4	1	259
		B	356.1	79.5	283	3.0	10.7	1	282
	July	A	354.7	75.4	267	13.0	46.1	4	263
		B	387.4	77.4	300	9.5	36.8	3	297
	Aug.	A	335.7	74.2	249	13.0	43.6	3	246
		B	362.3	75.9	275	10.0	36.2	3	272
	Sept.	A	294.0	75.6	222	9.5	27.9	2	220
		B	378.2	76.6	290	5.5	20.8	2	288
	Oct.	A	361.7	77.8	281	7.0	25.3	2	279
		B	363.4	79.2	288	4.0	14.5	1	287
	Nov.	A	319.0	79.5	254	6.5	20.7	2	252
		B	431.6	81.5	352	4.5	19.4	2	350
2	May	A	246.5	78.4	193	3.5	8.6	1	192
		B	261.8	79.4	208	2.0	5.2	-	208
	June	A	362.7	55.9	203	34.0	123.3	10	193
		B	335.2	60.5	203	28.0	93.9	8	195
	July	A	610.0	26.4	161	59.5	363.0	29	132
		B	630.3	24.6	155	61.0	384.5	31	124
	Aug.	A	561.3	25.1	141	66.0	370.5	30	111
		B	549.6	22.3	123	63.5	349.0	28	95
	Sept.	A	491.3	30.9	152	58.5	287.4	23	129
		B	579.2	26.0	151	61.0	353.3	28	123
	Oct.	A	435.8	37.4	163	57.0	248.4	20	143
		B	481.1	30.2	145	60.0	288.7	23	122
	Nov.	A	310.5	44.7	139	45.5	141.3	11	128
		B	278.3	39.7	110	50.5	140.5	11	99

Paddock	Month	Sheep	Faecal DM	% OM	Faecal OM	% soil	Faecal soil	Soil OM	Plant OM
3	May	A	247.9	69.4	172	17.0	42.1	3	169
		B	253.1	68.1	172	17.5	44.3	4	168
	June	A	641.0	25.3	162	64.0	410.2	33	129
		B	778.2	25.9	202	70.0	544.7	44	158
	July	A	1586.3	13.0	206	70.0	1110.4	89	117
		B	1903.0	13.0	247	72.5	1379.7	110	137
	Aug.	A	762.4	14.8	113	69.0	526.1	42	71
		B	1091.6	14.0	153	70.0	764.1	61	92
	Sept.	A	556.4	22.0	122	72.0	400.6	32	90
		B	879.7	18.0	158	68.5	602.6	48	110
	Oct.	A	548.0	31.3	172	59.0	323.3	26	146
		B	647.2	32.2	208	57.0	368.9	30	178
	Nov.	A	420.0	50.2	211	38.5	161.7	13	198
		B	398.1	55.8	222	32.0	127.4	10	212
4	May	A	311.6	69.6	217	16.0	49.9	4	213
		B	293.6	68.6	201	18.0	52.8	4	197
	June	A	504.1	46.5	234	47.0	236.9	19	215
		B	443.6	43.7	194	49.0	217.4	17	177
	July	A	1221.2	23.9	292	65.0	793.8	64	228
		B	958.8	26.2	251	65.0	623.2	50	201
	Aug.	A	1038.1	24.0	249	68.0	705.9	56	193
		B	845.4	25.2	213	71.0	600.2	48	165
	Sept.	A	464.9	44.9	209	45.0	209.2	17	192
		B	414.2	42.4	176	48.0	198.8	16	160
	Oct.	A	330.0	71.5	236	13.0	42.9	3	233
		B	242.6	71.3	173	13.0	31.5	3	170
	Nov.	A	364.8	79.1	289	4.5	16.4	1	288
		B	265.4	75.7	201	9.0	23.9	2	199

Paddock	Month	Sheep	Faecal DM	% OM	Faecal OM	% soil	Faecal soil	Soil OM	Plant OM
5	May	A	260.8	60.1	157	27.0	70.4	6	151
		B	327.4	60.1	197	25.0	81.9	7	190
	June	A	509.6	34.9	178	51.5	262.4	21	157
		B	530.1	36.8	195	52.5	278.3	22	173
	July	A	796.0	22.6	180	70.5	561.2	45	135
		B	798.5	20.8	166	69.0	551.0	44	122
	Aug.	A	780.8	24.2	189	67.0	523.1	42	147
		B	745.1	23.6	176	65.5	488.0	39	137
	Sept.	A	421.7	47.9	202	37.5	158.1	13	189
		B	374.8	39.7	149	47.0	176.2	14	135
	Oct.	A	323.5	68.3	221	17.5	56.6	5	216
		B	315.7	67.5	213	20.0	63.1	5	208
	Nov.	A	325.8	75.0	244	9.5	31.0	2	242
		B	285.4	76.8	219	9.5	27.1	2	217
6	May	A	334.7	79.3	265	-	-	-	265
		B	332.1	81.1	269	-	-	-	269
	June	A	373.5	77.6	290	5.0	18.7	1	289
		B	376.6	79.9	301	3.0	11.3	1	300
	July	A	301.9	79.7	241	4.0	12.1	1	240
		B	326.9	78.5	257	6.5	21.2	2	255
	Aug.	A	337.2	78.1	263	6.0	20.2	2	261
		B	337.5	75.6	255	7.5	25.3	2	253
	Sept.	A	318.6	78.7	251	2.5	8.0	1	250
		B	240.9	74.3	179	6.0	14.5	1	178
	Oct.	A	314.6	80.3	253	2.0	6.3	1	252
		B	294.6	77.9	229	6.0	17.7	1	228
	Nov.	A	378.4	80.5	305	3.0	11.4	1	304
		B	315.7	79.6	251	5.5	17.4	1	250

Paddock	Month	Sheep	Faecal DM	% OM	Faecal OM	% soil	Faecal soil	Soil OM	Plant OM
7	May	A	303.1	76.4	232	7.5	22.7	2	230
		B	251.1	79.0	198	3.0	7.5	1	197
	June	A	367.4	57.4	211	31.5	115.7	9	202
		B	341.8	71.2	243	13.0	44.4	4	239
	July	A	658.2	26.9	177	61.5	404.8	32	145
		B	640.5	34.4	220	53.5	342.7	27	193
	Aug.	A	646.9	21.1	136	71.0	459.3	37	99
		B	981.9	21.5	211	71.0	697.1	56	155
	Sept.	A	492.8	27.3	135	64.5	317.9	25	110
		B	643.6	33.5	216	56.0	360.4	29	187
	Oct.	A	485.8	36.3	176	54.0	262.3	21	155
		B	430.9	46.1	199	41.5	178.8	14	185
	Nov.	A	318.6	49.2	157	39.0	124.3	10	147
		B	521.7	51.4	268	34.0	177.4	14	254
8	May	A	298.8	78.8	235	4.0	12.0	1	234
		B	327.3	79.2	259	3.0	9.8	1	258
	June	A	395.4	57.1	226	31.5	125.0	10	216
		B	384.3	52.5	202	37.5	144.1	12	190
	July	A	804.2	21.3	171	66.5	534.8	43	128
		B	789.8	25.8	204	62.5	493.6	39	165
	Aug.	A	750.5	18.1	136	76.0	570.4	46	90
		B	744.5	19.4	144	65.5	487.6	39	105
	Sept.	A	547.0	26.6	146	65.0	355.6	28	118
		B	478.3	30.1	144	64.0	306.1	24	120
	Oct.	A	468.8	40.5	190	48.5	227.4	18	172
		B	449.7	38.4	173	49.5	222.6	18	155
	Nov.	A	359.9	51.3	185	32.5	117.0	9	176
		B	399.2	47.1	188	36.5	145.7	12	176

Paddock	Month	Sheep	Faecal DM	% OM	Faecal OM	% soil	Faecal soil	Soil OM	Plant OM
9	May	A	348.4	56.0	195	30.0	104.5	8	187
		B	234.4	64.9	152	24.0	56.3	5	147
	June	A	1338.9	15.5	208	69.5	930.5	74	134
		B	937.0	17.0	159	69.0	646.5	52	107
	July	A	1795.3	12.0	215	71.0	1274.7	102	113
		B	1573.5	11.7	184	69.5	1093.6	87	97
	Aug.	A	1288.1	13.2	170	75.0	966.1	77	93
		B	917.1	13.1	120	73.5	674.1	54	66
	Sept.	A	877.3	17.0	149	74.0	649.2	52	97
		B	699.0	16.8	117	73.5	513.8	41	76
	Oct.	A	525.4	31.8	167	55.0	289.0	23	144
		B	447.0	25.2	113	64.5	288.3	23	90
	Nov.	A	387.5	55.5	215	34.5	133.7	11	204
		B	249.7	46.5	116	39.0	97.4	8	108
10	May	A	232.0	72.6	168	15.5	36.0	3	165
		B	276.8	70.2	194	16.0	44.3	4	190
	June	A	992.8	23.1	229	75.5	749.6	60	169
		B	801.0	24.7	198	70.0	560.7	45	153
	July	A	1554.5	12.9	201	83.0	1290.2	103	98
		B	1379.6	12.2	168	83.5	1152.0	92	76
	Aug.	A	1393.3	13.2	184	83.0	1156.4	93	91
		B	1184.2	13.1	155	77.0	911.8	73	82
	Sept.	A	1236.2	13.5	167	84.5	1044.6	84	83
		C	1576.2	12.4	195	84.5	1331.9	107	88
	Oct.	A	1000.2	14.8	148	89.5	895.2	72	76
		C	1304.0	13.8	180	77.5	1010.6	81	99
	Nov.	A	596.1	18.4	110	80.0	476.9	38	72
		C	895.4	16.6	149	100.0	895.4	72	77

APPENDIX III

OM digestibility of diet samples

(a) Regression relating in vitro to in vivo OM digestibility.

The regression was obtained using four feeds of known *in vivo* OM digestibility, ranging from 84.6% to 60.9% OM digestibility. These were the only four feeds having this data which were available to the author at the time of analysis.

The regression obtained was:-

$$y = 1.07x - 4.31 \quad (S_{y.x} = 1.7)$$

where x = *in vitro* OM digestibility

and y = *in vivo* OM digestibility

(b) Method used to correct in vitro OM digestibility estimates of diet samples for soil contamination.

The method is most clearly demonstrated in an example.

Let a diet sample have:-

(i) OM content = 63.24%

(ii) Soil content = 41.0%

(iii) *In vitro* OM digestibility = 66.3%

∴ Total OM in a 1 g. sample = 0.6324 g.

and Soil in 1 g. sample = 0.4100 g.

Assuming soil looses 8% of its weight on ashing

then 0.41 g. soil contains $\frac{8}{100} \times 0.41$ = 0.0328 g. OM

∴ Plant OM = 0.6324 - 0.0328 = 0.5996 g.

OM removed by digestion $= \frac{66.3}{100} \times 0.6324$

= 0.4193 g.

∴ Assuming this OM is all of plant origin

then corrected *in vitro* OM digestibility $= \frac{0.4193}{0.5996} \times 100$

= 69.9%

(c) Corrected and uncorrected in vitro OM digestibility values for standard feeds mixed with known amounts of soil.

(i) Feed A

Uncorrected value	Soil %	OM %	Corrected value
64.4	0.0	90.22	64.4
63.1	15.8	78.43	64.2
61.9	31.3	66.05	64.5
59.6	46.5	53.06	64.4
55.3	61.4	40.96	63.4
50.9	71.2	28.94	64.5
49.5	81.0	25.04	68.4

(ii) Feed B

75.1	0.0	91.97	75.1
73.1	16.1	77.16	74.4
71.8	31.7	64.55	74.8
70.4	47.1	52.16	75.9
65.9	61.9	40.64	75.1
60.9	71.7	31.35	74.6
55.9	81.3	24.50	74.8

(iii) Feed C

78.4	0.0	88.86	78.4
77.2	16.1	76.74	78.6
74.3	31.8	63.81	77.6
71.5	47.0	51.92	77.5
68.7	62.0	40.47	79.1
64.6	71.7	32.89	79.4
57.0	81.3	25.58	78.2

(d) Experimental Results.

Paddock and month	Uncorrected *in vitro* OM digestibility	% OM	% soil	Corrected *in vitro* OM digestibility	Predicted *in vivo* OM digestibility
1 May	71.3%	85.20	0.0	71.3%	72.0%
June	68.6	86.24	1.0	68.6	69.1
July	70.4	85.83	0.0	70.4	71.0
Aug.	68.7	85.90	1.5	68.7	69.2
Sept.	68.8	84.66	0.0	68.8	69.3
Oct.	71.7	85.05	0.5	71.7	72.4
Nov.	75.6	85.11	0.0	75.6	76.6
2 May	73.8	87.43	0.0	73.8	74.7
June	74.5	76.69	12.0	75.4	76.4
July	62.2	61.29	40.0	65.7	66.0
Aug.	62.7	58.66	42.5	66.6	67.0
Sept.	69.2	68.36	26.5	71.4	72.1
Oct.	71.5	77.92	17.5	72.8	73.6
Nov.	72.1	78.43	13.0	73.1	73.9
3 May	77.9	84.34	3.0	78.1	79.3
June	71.0	54.21	48.0	76.4	77.4
July	62.0	49.20	55.0	68.1	68.6
Aug.	73.1	49.99	49.0	79.3	80.5
Sept.	74.0	62.79	35.5	77.5	78.6
Oct.	74.6	76.82	20.0	76.2	77.2
Nov.	73.0	88.59	9.5	73.6	74.4

Paddock and month		Uncorrected *in vitro* OM digestibility	% OM	% soil	Corrected *in vitro* OM digestibility	Predicted *in vivo* OM digestibility
4	May	77.5	88.21	1.5	77.5	78.6
	June	74.1	76.57	22.0	75.8	76.8
	July	66.6	59.61	31.0	69.5	70.1
	Aug.	66.3	63.24	41.0	69.9	70.5
	Sept.	75.2	81.57	12.5	76.1	77.1
	Oct.	73.1	85.35	0.0	73.1	73.9
	Nov.	75.2	87.25	0.0	75.2	76.2
5	May	75.3	84.65	7.0	75.8	76.8
	June	74.6	72.22	25.5	76.8	77.9
	July	75.1	58.54	28.0	78.1	79.3
	Aug.	74.1	57.73	40.0	78.4	79.6
	Sept.	74.9	79.70	13.0	75.9	76.9
	Oct.	73.0	84.12	3.0	73.2	74.0
	Nov.	76.6	85.70	1.5	76.6	77.7
6	May	63.4	86.06	0.0	63.4	63.5
	June	67.5	85.71	0.0	67.5	67.9
	July	69.6	84.85	1.0	69.6	70.2
	Aug.	73.7	87.80	0.0	73.7	74.5
	Sept.	72.8	85.21	0.0	72.8	73.6
	Oct.	69.6	83.40	0.0	69.6	70.2
	Nov.	70.4	83.90	0.0	70.4	71.0

Paddock and month	Uncorrected *in vitro* OM digestibility	% OM	% soil	Corrected *in vitro* OM digestibility	Predicted *in vivo* OM digestibility
7 May	71.1	87.12	0.0	71.1	71.8
June	70.6	74.72	17.0	71.9	72.6
July	68.5	61.16	40.0	72.3	73.1
Aug.	69.7	56.95	44.0	74.3	75.2
Sept.	73.7	68.54	27.0	76.1	77.1
Oct.	73.2	75.34	21.0	74.9	75.8
Nov.	71.8	77.05	11.5	72.7	73.5
8 May	67.3	86.65	0.0	67.3	67.7
June	71.0	79.59	8.5	71.6	72.3
July	61.2	50.27	49.0	66.4	66.7
Aug.	64.9	58.02	46.5	69.3	69.8
Sept.	71.2	67.56	24.5	73.3	74.1
Oct.	74.4	75.45	13.5	75.5	76.5
Nov.	74.2	81.80	3.5	74.5	75.4
9 May	78.3	85.60	9.5	79.0	80.2
June	64.0	37.23	59.5	73.4	74.2
July	50.6	21.05	70.0	68.9	69.4
Aug.	49.4	28.63	67.0	60.8	60.7
Sept.	68.0	38.88	57.5	77.1	78.2
Oct.	71.2	65.21	36.0	74.5	75.4
Nov.	73.9	78.83	14.5	75.0	75.9

Paddock and month		Uncorrected *in vitro* OM digestibility	% OM	% soil	Corrected *in vitro* OM digestibility	Predicted *in vivo* OM digestibility
10	May	81.9	88.66	3.0	82.1	83.5
	June	73.8	53.55	58.0	80.8	82.1
	July	51.0	22.10	83.0	72.9	73.7
	Aug.	49.4	22.29	87.0	73.6	74.4
	Sept.	48.7	23.29	83.0	68.1	68.6
	Oct.	63.3	38.38	67.0	73.6	74.4
	Nov.	69.0	48.82	52.0	75.4	76.4

APPENDIX IV

Percentage contribution of pasture components to diet of fistulated sheep and to total pasture availability.

Paddock	Month	Grass available	Grass selected	Dead available	Dead selected	Clover available	Clover selected	Weed available	Weed selected
1	May	83	98	16	1	1	1	-	-
	June	76	93	24	7	-	-	-	-
	July	72	92	28	6	-	2	-	-
	Aug.	45	93	55	7	-	-	-	-
	Sept.	63	95	31	4	6	1	-	-
	Oct.	70	98	30	2	-	-	-	-
	Nov.	60	98	38	2	2	-	-	-
6	May	88	-	10	-	2	-	-	-
	June	79	95	21	5	-	-	-	-
	July	69	95	31	5	-	-	-	-
	Aug.	54	94	46	6	-	-	-	-
	Sept.	50	96	50	4	-	-	-	-
	Oct.	73	97	27	1	-	2	-	-
	Nov.	73	97	27	2	-	1	-	-
2	May	86	-	8	-	5	-	1	-
	June	84	88	16	12	-	-	-	-
	July	67	87	30	12	-	1	3	-
	Aug.	69	91	8	7	8	2	15	-
	Sept.	79	92	7	6	7	2	7	-
	Oct.	68	93	21	4	11	3	-	-
	Nov.	45	89	25	5	5	6	25	-

Paddock	Month	Grass available	Grass selected	Dead available	Dead selected	Clover available	Clover selected	Weed available	Weed selected
8	May	84	95	12	3	3	2	1	-
	June	76	90	14	9	5	1	5	-
	July	56	93	44	6	-	1	-	-
	Aug.	90	88	10	10	-	2	-	-
	Sept.	91	94	3	3	6	3	-	-
	Oct.	74	95	17	4	6	1	3	-
	Nov.	63	94	26	4	7	2	4	-
7	May	84	-	14	-	1	-	1	-
	June	71	94	19	4	5	-	5	2
	July	62	80	23	20	7	-	8	-
	Aug.	64	87	27	7	-	6	9	-
	Sept.	84	92	8	6	4	2	4	-
	Oct.	78	98	18	1	4	-	-	1
	Nov.	53	95	28	2	11	3	8	-
5	May	8	23	10	1	77	76	5	-
	June	24	54	16	2	52	43	8	1
	July	26	68	16	4	26	28	32	-
	Aug.	44	68	-	5	45	27	11	-
	Sept.	60	83	10	1	20	15	10	1
	Oct.	60	84	24	1	16	15	-	-
	Nov.	56	57	17	4	23	39	4	-

Paddock	Month	Grass available	Grass selected	Dead available	Dead selected	Clover available	Clover selected	Weed available	Weed selected
4	May	2	7	66	1	31	92	1	-
	June	6	30	47	10	38	60	9	-
	July	13	53	35	6	26	40	26	1
	Aug.	28	63	24	5	34	32	14	-
	Sept.	50	88	29	1	21	11	-	-
	Oct.	63	82	17	1	14	17	6	-
	Nov.	59	67	15	1	24	32	2	-
3	May	3	13	16	-	46	87	35	-
	June	11	25	15	9	48	61	26	5
	July	7	56	10	6	83	38	-	-
	Aug.	33	74	-	6	50	20	17	-
	Sept.	58	84	-	2	11	14	31	-
	Oct.	56	78	16	1	19	20	9	1
	Nov.	47	87	18	2	23	10	12	1
9	May	15	27	60	2	22	71	3	-
	June	32	65	26	7	42	28	-	-
	July	7	65	10	10	83	25	-	-
	Aug.	36	70	4	9	56	21	4	-
	Sept.	83	88	5	1	10	11	2	-
	Oct.	70	86	26	1	4	13	-	-
	Nov.	61	79	14	2	25	19	-	-

Paddock	Month	Grass available	Grass selected	Dead available	Dead selected	Clover available	Clover selected	Weed available	Weed selected
10	May	2	14	6	-	92	86	-	-
	June	13	25	9	3	78	72	-	-
	July	36	41	7	4	53	55	4	-
	Aug.	14	50	-	10	86	40	-	-
	Sept.	60	69	7	4	33	27	-	-
	Oct.	67	95	4	-	21	5	8	-
	Nov.	56	89	6	1	25	10	13	-

APPENDIX V

Foraging Behaviour

Paddock	Period	Sheep	Mean total foraging time/day (hours)	% total foraging time in daylight hours	Mean length foraging period (hours)
4	4 - 9 Aug.	A	11.7	79.2	1.13
	10 - 16 Aug.	A	11.6	77.1	1.10
	17 - 21 Aug.	A	11.2	81.3	0.90
	24 - 29 Aug.	A	11.1	75.7	0.81
	30 - 5 Sept.	A	11.9	70.3	1.02
	7 - 12 Sept.	A	9.8	78.9	0.51
	14 - 18 Sept.	A	8.0	74.8	0.35
	23 - 28 Sept.	B	6.9	84.0	0.66
	29 - 4 Oct.	B	7.0	74.5	0.56
	6 - 9 Oct.	C	8.0	86.1	0.86
	10 - 15 Oct.	B	7.0	78.0	0.39
	17 - 23 Oct.	C	7.3	75.4	0.61
	30 - 1 Nov.	A	7.0	83.2	0.60
	3 - 8 Nov.	A	7.7	68.4	0.48
9	4 - 9 Aug.	A	8.9	83.9	1.40
	4 - 9 Aug.	B	13.0	76.1	2.49
	10 - 16 Aug.	A	10.2	81.2	1.43
	10 - 16 Aug.	B	11.6	81.0	2.07
	17 - 21 Aug.	A	8.3	98.1	1.12
	17 - 21 Aug.	B	12.1	88.2	5.49
	24 - 29 Aug.	B	13.1	83.5	4.10
	24 - 29 Aug.	C	10.5	79.0	2.10
	30 - 2 Sept.	C	11.2	72.7	2.99
	30 - 5 Sept.	B	11.7	79.1	3.77
	7 - 10 Sept.	D	12.7	83.0	2.03
	6 - 12 Sept.	B	12.9	74.8	3.31
	13 - 18 Sept.	B	11.9	69.0	3.60
	16 - 18 Sept.	D	8.3	92.7	0.83
	23 - 28 Sept.	E	11.8	86.0	2.14
	23 - 27 Sept.	B	10.3	91.5	3.69

Paddock	Period	Sheep	Mean total foraging time/day (hours)	% total foraging time in daylight hours	Mean length foraging period (hours)
9	29 - 4 Oct.	E	11.5	80.7	2.35
	29 - 4 Oct.	F	10.0	69.7	1.63
	6 - 10 Oct.	A	9.1	92.5	1.52
	6 - 10 Oct.	G	12.3	92.7	3.84
	11 - 15 Oct.	A	10.8	95.6	2.58
	11 - 15 Oct.	G	10.6	99.8	2.53
	26 - 28 Oct.	G	9.9	96.4	1.75
	3 - 6 Nov.	G	10.3	98.9	1.72
6	2 - 9 Aug.	A	8.3	64.2	0.75
	10 - 16 Aug.	A	7.9	71.2	0.64
	17 - 21 Aug.	A	7.6	70.5	0.89
	24 - 29 Aug.	A	8.6	78.4	0.83
	30 - 6 Sept.	A	9.0	70.5	0.82
	7 - 13 Sept.	A	7.9	76.5	0.67
	14 - 18 Sept.	A	6.8	73.6	0.64
	23 - 28 Sept.	A	6.7	83.9	0.59
	2 - 4 Oct.	B	7.1	75.7	0.64
	6 - 8 Oct.	B	6.7	80.3	0.65
	17 - 23 Oct.	C	6.6	80.7	0.35
	26 - 2 Nov.	A	8.4	85.9	0.72
	3 - 6 Nov.	A	8.2	83.5	0.75
7	2 - 9 Aug.	B	10.2	74.6	0.96
	7 - 9 Aug.	A	11.5	76.7	1.49
	10 - 16 Aug.	A	12.3	78.1	1.31
	10 - 16 Aug.	B	11.5	76.8	0.79
	17 - 21 Aug.	A	12.4	80.6	1.38
	17 - 21 Aug.	B	11.7	81.3	1.78
	24 - 29 Aug.	A	11.5	82.2	1.35
	24 - 29 Aug.	B	9.1	80.9	0.42
	30 - 5 Sept.	A	12.9	74.4	1.53
	30 - 6 Sept.	B	11.1	72.5	0.92
	6 - 12 Sept.	A	11.8	82.5	1.33
	7 - 13 Sept.	B	11.3	77.5	1.16
	13 - 18 Sept.	A	11.4	85.8	1.19

Paddock	Period	Sheep	Mean total foraging time/day (hours)	% total foraging time in daylight hours	Mean length foraging period (hours)
7	14 - 18 Sept.	B	10.8	76.3	0.76
	23 - 28 Sept.	A	12.1	85.1	1.26
	2 - 4 Oct.	C	12.3	84.9	2.05
	6 - 9 Oct.	C	11.5	91.2	2.40
	8 - 10 Oct.	D	12.1	90.2	2.42
	10 - 16 Oct.	E	10.4	93.5	1.74
	11 - 16 Oct.	D	12.5	89.7	1.92
	17 - 23 Oct.	D	12.8	84.9	1.53
	17 - 23 Oct.	E	10.0	93.8	2.09
	26 - 27 Oct.	A	11.4	96.3	1.90
	2 - 8 Nov.	B	13.7	91.1	3.13
	3 - 8 Nov.	D	12.9	90.4	1.19

APPENDIX VI

Soil ingestion and in vivo digestibility

The data summarised in this appendix are derived from a soil feeding experiment carried out jointly by the author and Mr J.B. Mackintosh.

Introduction

Increasing use is being made of *in vitro* techniques to measure the digestibility of diet samples collected from grazing animals. Normally such techniques enable the prediction of *in vivo* from *in vitro* digestibility, the appropriate regression being derived under pen feeding conditions.

Where soil contamination of the diet is high the continued use of such regressions assumes that the *in vitro* : *in vivo* digestibility relationship is unaffected by soil ingestion.

Soil contamination might affect both *in vitro* and *in vivo* digestion processes. An initial appraisal of the former possibility has already been reported in Appendix III. The present experiment was designed to give a preliminary assessment of the possible effects of soil ingestion on the *in vivo* digestibility of dried grass.

In order to achieve this, sheep were offered a constant daily amount of feed while varying amounts of soil were introduced into the rumen. By this means OM digestibility could be measured under varying conditions of soil contamination.

Materials and Methods

Herbage - Commercial dried grass was used throughout the experiment. This was thoroughly mixed and bagged prior to the start of the experiment.

Soil - Approximately 5 cwt. of soil from the 0 - 1" horizon were collected from the experimental area, all plant material above the soil surface having been removed. This soil was dried at room temperature and ground to pass a 3 mm. sieve.

Animals - Four 2-year-old N.Z. Romney wethers fistulated at the rumen were used throughout the experiment. These animals were individually housed indoors so that their feed intakes could be measured accurately. The sheep were fitted with harnesses and bags for faecal collection.

Experimental procedure - The experiment consisted of a series of digestibility trials arranged in a 4 x 4 balanced Latin Square design using four sheep, four levels of soil administration and four treatment periods. 450 g. of dried grass were offered to each sheep twice daily, at 8.30 a.m. and 4.30 p.m., throughout the experiment. At this level of feeding sheep showed little change in liveweight - a situation likely to occur where soil ingestion is high. Soil contamination was achieved by introducing 0 g. (level 1), 250 g. (level 2), 500 g. (level 3) or 1000 g. (level 4) of soil into the rumen each day. Half the daily level of soil contamination was administered immediately before each of the two daily feeds. This was achieved by mixing the appropriate amount of soil with 400 ml. of warm water to form a slurry which was then placed in the rumen through the fistula by means of a large syringe.

Digestibility was measured over 7 day periods, the change-over period between measuring periods lasting for 14 days.

Analytical methods - Faeces were weighed daily and after thorough mixing a 10% subsample was removed and stored at 20°F. A further subsample of approximately 200 g. was dried at 85°C to give an estimate of DM content. The frozen subsamples for any particular sheep were bulked over each collection period, freeze dried and milled to pass a 1 mm. sieve. Estimates of OM content of these bulked samples were obtained by measuring the loss in weight on ashing at 600°C overnight.

The feed to be used during any one measuring period was weighed out into 450 g. lots and placed in plastic bags prior to the start of the period. Subsamples of feed were taken at this time to give a composite sample from which DM and OM determinations were made.

Results and Discussion

Sheep 4 refused to eat shortly after the start of the third period and was removed from the experiment. There were no feed refusals from the other three sheep.

Because soil loses weight on ashing it will, when excreted, contribute to the loss in weight of faeces on ashing and hence to faecal OM output. If it is assumed that soil passes through the rumen unaltered, then the loss in weight of faeces due to a given amount of "ingested" soil can be calculated. Furthermore if this quantity is added to the faecal OM output due to the ingestion of a given amount of soil-free plant material, an estimate of total faecal OM output can be made, assuming that the OM digestibility of feed remains constant. If the actual value of faecal OM output is above the theoretical estimate then OM digestibility of the feed will have decreased and if it is below this value then digestibility will have increased.

The following table shows the differences between actual and theoretical faecal OM outputs found in this experiment.

		Sheep			
		1	2	3	4
Period	I	+ 10.7 (4)	+ 1.4 (3)	- 2.8 (2)	0 (1)
	II	- 0.2 (3)	0 (1)	- 1.1 (4)	+ 1.4 (2)
	III	+ 1.0 (2)	+ 15.8 (4)	0 (1)	+ 2.7 (3)*
	IV	0 (1)	- 0.9 (2)	- 11.8 (3)	+ 5.4 (4)*

Figures in brackets denote levels of soil administration.

*Missing values substituted by the method of Yates (1933).

This data was examined by analysis of variance, the corresponding table being given below:-

Source of Variation	D.F.	Mean Squares
Sheep	3	51.5
Periods	3	43.3
Soil levels:		
Direct effects (unadj.)	3	
Residual effects (adj.)	3	5.6
Direct effects (adj.)	3	77.0
Residual effects (unadj.)	3	
Residual	3 - 2 = 1	28.3
Total	15	

It will be noted that none of the sources of variation had a significant effect on the discrepancy between actual and theoretical faecal OM outputs. However it will be seen that sheep 1 and 2 reacted in a different way to sheep 3 in which increasing soil "ingestion" tended to increase OM digestibility. If the effects with sheep 1 and 2 were real, OM digestibility would have dropped by about two digestibility units at the highest level of soil contamination.

Thus although the results of this experiment do not indicate that soil "ingestion" affects *in vivo* digestibility, they do indicate that there may be considerable variation in response between sheep. For this reason and because this result only applies to one level of feed intake and one soil type, it is suggested that further research is necessary before any real appreciation of the effects of soil intake on *in vivo* digestibility is possible.