A STUDY OF HERBAGE PRODUCTION AND ITS UTILISATION BY DAIRY CATTLE FROM CONTINUOUSLY GRAZED SWARDS

by

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CONTENTS

ABSTRACT

1. The literature is reviewed on the effect of frequency and severity of defoliation on herbage production and quality; on factors affecting herbage utilisation; and on the estimation of herbage mass from measurements of herbage height.

2. Three experiments were carried out: in Experiment 1 a study was made with dairy cows of the effect of stocking rate in the early season on herbage parameters; Experiment 2 examined the growth of herbage within protected areas of the sward; and in Experiment 3, three methods for measuring herbage height were evaluated.

3. In Experiment 1, a high stocking rate (H) in the early season produced a sward of short dense herbage with a greater crude protein, P and K content than medium (M) and low (L) stocking rates although D-values varied little between treatments. Herbage production and utilisation were increased. Selective grazing by the cows kept at a low stocking rate in the early season resulted in patches of long rank rejected herbage. These under-grazed areas were characterised by increased aerial tillering and accumulation of litter in the base of the sward.

4. Tiller population increased throughout the grazing season in contrast to the decline which is often reported under cutting managements and rotational grazing. The difference between treatments in tiller population was small and non-significant.

5. Difficulties were experienced in the calibration of the grass disc to establish a relationship between herbage height and herbage

mass, but a better fit and lower S.E. of the estimate was given by a quadratic regression through the origin than the 'best-fit' linear regression. The results suggest that it is essential for the calibrations to cover an adequate range of heights to avoid extrapolation from limited data. The overestimation of herbage production was thought to be due to high estimates of growth recorded in protected areas of the sward.

6. Many of the differences in the results of sward parameters between the day and the night field could be attributed to a difference in grazing pressure rather than to the different sward composition in the two fields. Results for the two fields may have been similar had the grazing area been divided more equally rather than on the 60:40 ratio in favour of the day field.

7. Cows were able to overcome constraints imposed on them at high stocking rates in spring by increasing their frequency of defoliation. They utilised more herbage (kg DM ha^{-1}) and produced on average 1 kg more milk per day over the season than cows at low stocking rates in spring.

8. Results in Experiment 2 tended to confirm that the high estimates of herbage production in Experiment 1 were due to over-estimation of growth in the protected areas. This suggests that protected areas should be moved sufficiently often for growth within them to be representative of growth on the grazed area - leaving them in one position for 2 weeks when conditions were suitable for rapid regrowth gave an overestimation of growth compared with that on the grazed area.

9. Results in Experiment 3 suggest that estimates of herbage height vary according to the technique used to measure them and that there is a need to define the technique used in experiments involving the measurement of herbage height. The ratio of herbage height measured by a graduated rule, grass disc and grass meter was 1:1.63:1.53.

INTRODUCTION

Forages are a primary constituent of most dairy rations for physiological and economic reasons. They can make up 60 to 70 % of the total dry matter intake for dairy cattle supplying approximately 80 % of their annual energy requirement in the United Kingdom (EDCA Report, 1974). Grazing remains the major method of utilisation of grass and alone provides almost 50 % of the annual food intake of the dairy cow. Because forages are of little use as a nutrient source for humans and other monogastric animals, and because the entire plant rather than just the seed is consumed, the cost per unit of nutrient from forages is usually much lower than the cost per unit of nutrient from concentrate feeds. The relative costs per unit of metabolisable energy from grass, forage and bought-in concentrate are approximately in the ratio 1:2:4. Therefore as margins decline a greater effort must be made to make more use of the grazed crop by effective production and utilisation.

Continuous stocking was the traditional system of grazing until the 1950's. More complex systems of grazing were then devised to facilitate the use of the intensively produced grass resulting from an increase in technical knowledge and fertilizer use. Controlled grazing (rotational in paddocks or strips) gave the necessary discipline of applying fertilizer regularly and matching herbage production to utilisation, and led to an average increase in stocking rate of 25 % between 1958/60 and 1972 in the United Kingdom (EDCA Report, 1974). The more intensive and sophisticated the system of grazing however, the greater the demand for management skill and higher cost involved, and this appears to have restricted the general adoption of highly intensive controlled grazing systems. As costs have increased relatively more than incomes, there has been a need for simple systems which partly explains the return to continuous stocking in recent years but at a higher stocking rate and nitrogen fertilizer level than previously.

In Scotland in 1977, 36 % of dairy farmers practised continuous stocking compared with 34 % strip-grazing, 17 % paddock grazing, 1 % zero grazing and 24 % used undefined systems. The numbers rotationally grazing have fallen and developments since the 1960's appear to confirm that this trend is likely to continue (Scottish Milk Marketing Board, 1978).

Early work indicated that high levels of grass and animal production can be maintained on pasture continuously stocked throughout the grazing season (McMeekan, 1960; McMeekan and Walshe, 1963). More recent investigations comparing continuous stocking and rotational grazing using high stocking rate and high nitrogen regimes indicate that equally high milk outputs can be obtained from either system (Hood, 1964), although milk production in the second half of the grazing season may be lower on continuously stocked pastures because of a decline in the amount of herbage available after late July (eg Castle and Watson, 1978). Clearly management practices can affect the output from both grazing systems, and further work is needed to give a fuller definition of the circumstances that lead to a depression in sward and animal production. Our understanding of the physiology of growth of the grass sward in the field has increased but much of the work has been based on swards harvested by cutting. While grazing continues as the primary utilisation technique, a major effort must be made to understand the growth of the grazed sward, and the interactions of plant and animal in the grazing complex.

Little is known about the defoliation and regrowth of swards grazed continuously by dairy cows, and this study deals with some aspects of these processes. This thesis reports on an investigation made into the effect of differential stocking rates in the early part of the grazing season on growth of the sward, tiller population, frequency of defoliation of individual tillers and the utilisation of the herbage produced. A report is also given on work comparing three methods of measuring herbage height for the estimation of herbage yield.

REVIEW OF LITERATURE

SECTION I The effect of frequency and severity of defoliation on herbage production and quality

Introduction

Management factors can influence the yield and quality of herbage. The height of defoliation and the frequency of defoliation are two such factors that individually and in combination have a marked effect upon the dry matter yield and quality of a sward.

The method of defoliation can also affect the subsequent regrowth of herbage. Grazing animals selectively defoliate whole plants and parts of plants at random heights, exert a treading effect and return nutrients to the sward in dung and urine. In contrast, cutting is at a predetermined level, palatable and unpalatable plants are equally defoliated, erect plants may be more severely defoliated than prostrate ones, and the amount of foliage removed may differ from that removed by grazing.

In this review, herbage production in cutting experiments is referred to as herbage yield ie the amount of herbage harvested. Herbage production in grazing experiments is the net accumulation of herbage between successive times of sampling, representing the balance between the processes of growth and decay (see Hodgson, 1979). It is the amount of herbage available for utilisation by the grazing animal and does not necessarily involve any assumptions about harvesting.

The effect of frequency of defoliation

Herbage production

The effect of frequency of defoliation on herbage yield has been widely investigated in the past and detailed reviews made (eg Brougham, 1959; Huokuna, 1964). Various frequency scales have been used: stages of growth eg 'silage stage'; heights of herbage, often assumed to represent particular stages of growth eg 15 cm tall herbage (grazing stage); herbage quantities eg 1250 kg DM ha^{-1}, or more commonly set time intervals eg monthly.

In Britain, early experiments on machine-cut swards of individual grasses and grass/clover mixtures established that the yield of dry matter at each defoliation and the annual yield increases as the frequency of cutting decreases (eg Stapledon, 1924; Roberts and Hunt, 1936; Hamblyn, 1954), although more than one cut per season is required for maximum yield (Collins and McCarrick, 1969). This principle is supported by recent studies in Britain (eg GRI, 1960; Holliday and Wilman, 1962; Wolton, 1972), Finland (Huokuna, 1960, 1964), Canada (Ashford and Troelsen, 1965), and the United States (eg Bryant and Blaser, 1961) (see Table I.1).

The relationship between cutting interval and yield appears to be quadratic; increasing the interval from 2 to 5 weeks results in a greater increase in yield than increasing the interval from 5 to 8 weeks. Drought conditions may override the influence of regrowth intervals on dry matter yields which explains the decrease in yield obtained by Kunelius and Calder (1978) with increasing cutting interval (see Table I.1). A clear interaction also exists between cutting frequency and annual nitrogen applications, although the pattern of response differs between experiments. It appears that while a greater response to lower levels of nitrogen occurs with infrequent cutting (Ashford and Troelsen, 1965), the response to nitrogen under frequent cutting will continue at higher levels (Holliday and Wilman, 1965), so

Table I.1 The influence of frequency of defoliation on net herbage dry matter yield in cut swards

(Relative to value at 3-4 week interval = 100)

Reference	Defoliation interval (weeks)													
	1		2		3		4		5	6		8	10	15
Woodman et al (1928)	62		80		100									
Hamblyn (1954)	63		84		100					132				
GRI (1960)		52					100							
Reid and MacLusky (1960)						100		107						
Ashford and Troelsen (1965)			76		100		117			166		190		
Holliday and Wilman (1965)				77			100							134
Anslow (1967)					100					166				
Reid (1966)			55				100			123				
Collins and McCarrick (1969)			75				100		122		133		151	221
Frame and Hunt (1971)					100		116							
Binnie and Harrington (1972)					100					127			164	
Wolton (1972)					87	100		109	123					
Chestnutt et al (1977)			70		81		100		100	106		111		
Kunelius and Calder (1978)					82		100		92	98				

that frequently cut grass responds better to high levels of nitrogen application than infrequently cut grass (Chestnutt et al, 1977).

Studies on the effect of grazing frequency on herbage yield confirm the results obtained in cutting trials although the effects appear to be less pronounced (Table I.2). Net herbage accumulation was depressed by 30-40 % when the interval between defoliations was reduced below 2 weeks. Extending the interval to 5 weeks increased herbage accumulation by 15-17 % in experiments where the frequency and severity of defoliation were controlled separately but had no effect in studies involving rotational grazing management (Table I.2 (b)). There are few studies comparing continuous stocking with managements involving some degree of grazing control. Results are variable ranging from no direct evidence of increased production (Boswell et al, 1974) to a 23 % increase in herbage accumulation from controlled grazing (Marsh and Laidlaw, 1978). On the basis of the observed depression in annual dry matter yield from a clipped sward defoliated frequently, Woodman and Norman (1932) advocated the adoption of rotational grazing systems. But the superiority of rotational grazing over continuous stocking has been questioned; the latter need not involve either frequent or severe defoliation of individual plants (Hodgson, 1966; Hodgson and Ollerenshaw, 1969) unless there is overstocking. The lack of a consistent difference can perhaps be expected on consideration of the limited sward responses shown in Tables I.2 and I.5.

In the past, reduced yield from frequent defoliation has been attributed mainly to exhaustion of food reserves in the plants brought about by the effort of repeated initiation of regrowth (Sullivan and Sprague, 1943; Weinmann, 1948). These reserves, mainly in the form of

Table I.2 The influence of frequency of defoliation on net herbage dry matter accumulation in grazed swards

(Relative to value at 3-4 week interval = 100)

Reference	Defoliation interval (weeks)									
	1		2		3		4		5	6
(a) Intermittent grazing-height controlled										
Williams (1952)				100			115			
Bosch (1956)							100		106	111
Brougham (1959)				100			115			
Weeda (1965)		61			100					
Frame and Hunt (1971)					100		116			
Frame (1976)					100		117			
(b) Grazing rotation-height not controlled										
Campbell (1969)	67						100			
Bryant (1970, 1971)			112			100				
Leaver (1975)					100			102		
McFeelly *et al* (1975)			105				100			

non-structural carbohydrates such as fructosans, sugars and starch, were observed to decline sharply after defoliation followed by a gradual restoration to predefoliation levels (Alberda,1957; May and Davidson,1958). But the belief that they play a pre-eminent role in the rate of regrowth is now in question and it has been claimed that most of the reserves are used for respiration rather than as substrate for the synthesis of new growing points (May, 1960). Davidson and Milthorpe (1965) attempted to explain the fluctuations in the concentration of carbohydrate reserves and concluded that the concentration in a tissue at any one time is the result of the past and current rates of photosynthesis, translocation, respiration, and synthesis of new structural compounds. Reserve sugars form only a part of a 'labile pool' and other substances must be regarded as being quantitatively of equal significance, especially in the case of a severe defoliation when the decline in soluble carbohydrates is inadequate to account for new growth. Non-structural carbohydrates may be important reserve substances under certain conditions (Alberda, 1966).

Pioneer work by Brougham (1955, 1956) showed the dependence of regrowth on the leaf area remaining after defoliation and considerations of leaf area per unit area of land (Leaf Area Index) and light interception have dominated more recent thought. Optimum leaf area indices have been put forward over the years for various species at which it is suggested complete light interception, and hence maximum growth rate, can occur (Brougham,1958; Davidson and Donald,1958). If a sward is frequently defoliated reducing leaf area to below the optimum, yields can be depressed because of poor light interception and low growth rates (Donald,1963). Leaf removal will however benefit growth rate once the leaf area index is greater than optimum because it improves the light supply to leaves that would otherwise be starved for lack of light. Ideally a pasture should be maintained at an optimum leaf area index, with leaf being removed at the rate it is produced (Donald and Black,1958). Such a theoretical state cannot be maintained in practice, but the concept serves to emphasise the disability of the low leaf area on one hand or the heavily overgrown sward on the other, and also the importance at the beginning of the season of permitting pasture to develop sufficient leaf before grazing begins.

The effect of cutting and grazing on tiller numbers can be extremely variable depending on the treatment imposed and the environment (Langer,1963). In an established sward a marked fall in plant numbers between April and July, plus a concomitant decline in tiller numbers per plant until June, reduces the total number of tillers per unit area (Langer et al,1964). The fall can be reduced by frequent defoliation. A rapid increase in the production of new tillers occurs after cutting followed by a gradual slowing down with time. Anslow (1967) showed that long-rest swards of perennial ryegrass had significantly more tillers per unit area from July onwards because of the extremely rapid production of new tillers during early regrowth after removal of 6 weeks growth compared to 3 weeks growth. Their average weight was also greater after the longer regrowth period.

These are several possible reasons for the low response in net herbage dry matter accumulation on grazed swards to increased rest periods between harvests. In cut swards, machines harvest indiscriminately at the same height above ground level, but when different lengths of rest period are compared under grazing conditions, herbage is unlikely to be defoliated at the same height from ground level.

An animal is selective, grazing preferentially those plant parts that are more attractive, more nutritious or more easily apprehended, and avoiding those which are unpleasant, injurious, soiled or difficult to obtain. The comparison of different rest periods are therefore confounded by interactions between the animal and the sward, and the possible advantages of longer rest periods might be neutralised by simultaneous variations in defoliation intensity. This may also explain why in some instances rotational grazing systems fail to give greater production than continuous stocking systems (McMeekan, 1960).

Herbage quality

Pasture quality and the maintenance of a high digestibility in the sward are also influenced by the frequency of defoliation. As the growth period of grass increases nutritive value decreases (Ashford and Troelsen, 1965; Wolton, 1972; Chestnutt et al, 1977) particularly in spring and early summer as herbage develops to the flowering stage (Reid, 1968; Wolton, 1972). After ear emergence digestibility declines rapidly by as much as 0.5 units per day. Prevention or reduction of flowering by regular defoliation can do much to stop this rapid decline in nutritive value. After flowering the decline moves more slowly and this relative stability in nutritive value, the reduction in growth rate after midsummer and the small effect of length of growth period on digestibility has led to the recommendation of less frequent defoliations as the season progresses. Woodman and Norman (1932) observed that nutritive value did not seriously decline until defoliation intervals exceeded 5 weeks. Chestnutt et al (1977) observed little increase in digestible dry matter yields from lengthening the cutting interval beyond 4 weeks but a highly significant increase between 3 and 4 weeks (Table I.3). The sharp decline in percentage

Table I.3 Effect of cutting frequency on digestibility of the dry matter (DMD) (%) and digestible dry matter (DDM) yield ($t\ ha^{-1}$) from Chestnutt et al, 1977)

	Cutting interval (weeks)						
	2	3	4	5	6	8	SE mean
DMD (%)	79.1	75.4	73.8	70.8	71.1	67.0	1.32
DDM yield ($t\ ha^{-1}$)	7.15	7.83	9.35	9.00	9.53	9.42	0.215

digestibility with increasing length between defoliations can be partly offset by nitrogen fertilizer (Ashford and Troelsen, 1965). Ashford and Troelsen (1965) also observed that a combination of increasing dry matter yields and decreasing crude protein percentage causes an increase in crude protein yields from 2 to 5 weeks, but once the cutting interval exceeds 6 weeks, crude protein yield drops sharply.

The chemical composition and digestibility value vary greatly between species, so the quality of a sward also depends on its botanical composition which is affected by grazing or cutting. Changes in botanical composition, reduction in yield and vigour, and general deterioration of the sward have been noted with repeated cutting (Weeda, 1965). Some herbage species such as timothy cannot persist when continually defoliated (Roberts and Hunt, 1936) while others such as perennial ryegrass, white clover, browntop and Yorkshire fog are not affected (Smethan, 1973). The location of a plants food reserves, whether in the roots as in perennial ryegrass or stem base as in timothy and cocksfoot, and the effects of competition between plants especially for light, are important factors affecting the vigour and persistency of individual strains or species in the sward under different managements. Frequent defoliation is thought to induce and favour prostrate species (Brougham, 1959; Weeda, 1965). It also affects the relative proportions of grass and clover in the sward as reviewed by Martin (1960). The growth of ryegrass is favoured by long defoliation intervals; red clover is tolerant of most frequencies of defoliation, and white clover is encouraged by frequent grazing which depresses taller growing companion grass species (Brougham, 1959).

The effect of severity of defoliation

Herbage production

The severity of defoliation is the height of defoliation from ground level as opposed to the height at defoliation. Closeness of defoliation to ground level, height of stubble or of residual herbage are other synonymous terms for severity used in the literature.

The influence of severity of defoliation on herbage yield has been investigated mainly by cutting techniques. In general herbage dry matter yields are increased by defoliating closer to the ground rather than at higher levels (see Table I.4). Reid (1959) found that herbage dry matter yield on a perennial ryegrass/white clover sward was increased by 39-44 % from close defoliation to within 2.5 cm of ground level compared with lax defoliations to within 5.0-6.3 cm. In other experiments with different severities of cutting, increased yields from close defoliation compared with lax have been obtained on ryegrass (MacLusky and Morris, 1964; Binnie and Harrington, 1972), cocksfoot (GRI, 1960; Huokuna, 1960) and timothy swards (GRI, 1960; Reid, 1962).

Some results in Table I.4 suggest increased yields from lax cutting relative to close in sward studies (Brougham, 1956; Drake et al, 1963) or using single spaced plants (Stapledon, 1924; Roberts and Hunt, 1936). Brougham (1956) working with mixed swards of short-rotation ryegrass with red and white clover showed that yield from a

Table I.4 The influence of severity of defoliation on herbage dry matter yield in cut swards

(Relative to value at less severe defoliation = 100)

Reference	Height of defoliation from ground level (cm)									
	Ground		2.5		5.0		7.5	10.0		15.0
Stapledon (1924)	83				100					
Roberts and Hunt (1936)	34	77	100							
Brougham (1956)			80						100	
Burger et al (1958)			131		117			100		
Reid (1959)			143			100				
GRI (1960)			150				100			
Huokuna (1960)			147			126		100		
Bryant and Blaser (1961)		127				100				
GRI (1961)			117		100					
Morris (1961, 1962)			158					100		
Reid (1962)			129			100				
Drake et al (1963)				86			100			
Hunt and Wagner (1963)					136			100		
Huokuna (1964)			147			127		100		
Reid (1966)			120			100				
Reid (1968)			107			100				
Binnie and Harrington (1972)			135				105		100	
Binnie et al (1974)			112				106		100	

single lax defoliation to 12.5 cm was greater than that from close defoliation to 2.5 cm. Since the rate of regrowth of the close-cut swards was highest at the end of the experimental period, it is conceivable that the results might have been reversed had he allowed a longer recovery period - his levels of cutting were similar to those of Reids (eg 1959; 1962), but the average interval between cuts was 3 weeks as opposed to 4-5 weeks in Reids experiments. It would appear that the benefits of close cutting are only attained when adequate time for recovery is allowed between cuts although Hodgson (1978) found little evidence of an interaction between the severity and frequency of defoliation in the grazing experiments he examined. The amount of photosynthetic tissue actually removed by hand clipping or mechanical cutting may affect the yield result as may the length of the experimental period; many of the single plant studies were only conducted over short-term periods of 2-3 months. Closely defoliated swards may be particularly affected during dry conditions in summer leading to lower yields (eg Drake et al, 1963).

It has also been considered that herbage species and varieties differ in their reaction to varying severities of defoliation. The main generalization is that prostrate-growing species can withstand a greater degree of defoliation than erect-growing species because a smaller amount of photosynthetic tissue is removed (Brougham,1959). Since some results indicate yield advantage from close cutting for erect as well as prostrate species (eg GRI,1960; Hunt and Wagner,1963) this generalization is dubious.

Stapledon found that cocksfoot cut at 5 cm outyielded cuts at ground level but his data was based on a very limited number of plants, the variety of cocksfoot is unspecified and the cutting to ground level was closer than can be achieved in farm practice.

Few critical trials have been conducted to investigate the effects on herbage of grazing down to specified heights from ground level presumably because of the difficulties involved in grazing evenly to fixed levels. Those that have suggested that the effect of severity of defoliation is small (Table I.5) with, in most cases, a slight reduction in herbage accumulation on swards grazed to 2.5-3 cm compared with swards grazed to 5-10 cm. Brougham (1959) obtained higher yields from grazing 15-22.5 cm herbage down to 2.5 cm compared with grazing 7.5-10 cm herbage to 2.5 cm, 17.5-20 cm herbage to 7.5 cm or 22.5-30 cm herbage to 7.5-10 cm. He stressed the importance of adequate rest periods after close grazing and noted that under frequent grazing, a more lenient defoliation was necessary to maintain high yield. Some results in Table I.5 suggest an increase in yield from close grazing to 2.5 cm as opposed to more lax grazing at 5 cm, but the increases are small. There is no indication of sward type , animal species or rate of defoliation having a consistent effect on response between experiments.

Reid (1959; 1962), Reid and MacLusky (1960) and MacLusky and Morris (1964) have all attributed the increased yield from close cutting to the inhibition of stem and flower production and the resultant stimulation of tiller and leaf production. Wilson and McGuire (1961) suggested that the beneficial effects of close cutting in dense swards may have resulted from the need of a high light intensity near the base of the plants for the initiation of regrowth or from the removal of old non-functional plant material that shaded

Table I.5 The influence of severity of defoliation on net herbage dry matter accumulation in grazed swards

(Relative to value at less severe defoliation = 100)

Reference	Height of defoliation from ground level (cm)							
	2.5		5.0		7.5		10.0	15.0
Brougham (1959)	95				100			
Brougham (1960)	80				100			
Weeda (1965)		93				100		
Frame and Hunt (1971)	90			100				
Frame (1976)	104		100					
Boswell (1977)					103			100
Hunt (1979)	102		100					

younger functional leaves. The importance of light intensity has been recorded recently by King et al (1979) who identified several factors limiting regrowth on swards subject to a variety of defoliation regimes. In their experiments, regrowth was most closely related to photosynthesis per unit area of land. Weekly as opposed to 3-weekly cutting reduced leaf angle and increased the proportion of leaf left unharvested leading to higher rates of photosynthesis. Increasing cutting height from 2 to 4 cm increased residual leaf area index and weight of total green crop in the stubble but led to lower photosynthesis rates per leaf area index because of mutual shading by leaves. Interactions occurred between leaf area index and photosynthesis rate per leaf area index so that the photosynthesis rate was similar for swards cut weekly to 2 cm and 3-weekly to 4 cm. Regrowth or increase in leaf area index was more closely related to net canopy photosynthesis than to residual leaf area index. On continuously stocked pastures, King et al (1979) found that net canopy photosynthesis, leaf area index and hence rate of regrowth fell as relative stocking density increased, with least dry matter production at the highest stocking rate.

Hunt (1965) has drawn attention to the build-up of dead material that can occur in a sward. He concluded that good herbage production is only likely when cutting or grazing management aims to keep dry matter gains by photosynthesis at a high level. This necessitates a compromise because minimal decay demands a close cut shortly after the stand becomes dense enough to intercept virtually all daylight whereas a high level of photosynthesis requires the continual presence of herbage dense enough to intercept all daylight (Donald and Black, 1958). A build up of herbage residue may reduce tiller development, eventually lowering the capacity of the sward for regrowth following defoliation.

Defoliation can have a profound effect on root growth and activity. During their studies on carbohydrate reserves in cocksfoot, Davidson and Milthorpe (1965) noted that root extension almost ceased after severe defoliation and was curtailed even when a high concentration of carbohydrates was present. This reduction or cessation in root growth can be accompanied by decomposition and a marked decrease in nutrient uptake, decreases in root respiration and phosphorus uptake (Davidson and Milthorpe, 1965). Root extension and mineral uptake did not begin again until leaves had expanded to an area which was sufficient to supply photosynthate adequate to meet all current needs. Milthorpe and Davidson (1966) suggest that mature leaves are important in maintaining root activity as there is a greater reduction in root activity under frequent defoliations which prevent the development of mature leaves.

There are several possible reasons for the minor impact of differences in defoliation severity upon rates of herbage accumulation on grazed swards. Adaptive changes in sward structure and morphology can limit the influence of defoliation treatment on leaf area and on the photosynthetic efficiency of leaf tissue (eg King et al, 1979). Complex elements of height and frequency as quantified by Hodgson and Ollerenshaw (1969) are involved in the concept of pattern of defoliation. Since grazing occurs in a situation of choice, the combined effects of selection by the animal and the distribution of morphological components within the sward result in heterogenous defoliation. This produces a sward that is irregular in height and 'age', and these continually changing patterns of height distribution may be of importance to the leaf area present and regrowth of completely defoliated areas. Although different defoliation regimes produce swards of contrasting growth form, sward morphology has an effect on the pattern of defoliation in return (Jackson, 1976). Changes in tiller population or leaf turnover which together determine rates of herbage growth and decomposition can largely explain the grazed sward responses summarized in this review section. Total net herbage accumulation may be as high under continuous stocking as under rotational grazing because the tiller population is sustained throughout the season and does not show the decline that occurs under rotational grazing. The tiller population also appears to be more sensitive to increases in grazing pressure under rotational grazing than under continuous stocking (see Hodgson, 1978). Although compensating changes in tiller population and leaf production per tiller occur over a range of treatments under both systems of grazing management, it is not necessarily the case under particularly frequent and severe defoliation (Brougham, 1959). Hodgson (1978) suggests that when grazing management does have an effect on net herbage accumulation it is through the effect on tiller population and the decomposition of ungrazed herbage, rather than on the amount of leaf area and consequently photosynthetic activity. But rates of leaf and tiller development and rates of photosynthesis are often closely correlated, and it is difficult to separate their effects on herbage accumulation.

Herbage quality

Binnie et al (1974) found that cutting height had no significant effect upon the mean herbage digestibility; at cutting heights of

2.5, 7.6 and 10.7 cm, digestibility was 72.2, 71.5 and 71.4 % respectively. This agrees with the work of Binnie and Harrington (1972) where only small and variable changes occurred with different cutting heights.

The crude protein content of the herbage usually decreases with decreasing cutting height though the effects of different cutting heights on crude protein content are not always significant or consistent (Reid, 1959; Binnie et al, 1974).

The crude fibre content of the herbage decreases with decreasing cutting height, accompanying a slight increase in digestibility Binnie and Harrington, 1972; Binnie et al, 1974).

Severe grazing encourages a better quality sward to emerge, since some desirable species can survive whereas most weed species are trampled or grazed out. Lenient grazing can produce a more open sward enabling the encroachment of weeds and weed grasses (Weeda, 1965). The intensity of defoliation can also affect the relative proportions of grass and clover in the sward. The growth of ryegrass and red clover is favoured by less severe defoliations (Weeda, 1965), while white clover is encouraged by severe grazing which depresses companion grass species. Although clover is maintained in a sward under severe and frequent grazing, this management reduces total dry matter yields of grass and clover emphasizing the importance of the balance between quantity and quality of herbage produced.

Seasonal variations in the effects of frequency and severity of grazing on herbage production and sward composition

Season of grazing and sward composition

By controlling the time and severity of grazing, and the time of spelling, Jones (1933) showed that extremely wide changes in sward composition can be achieved. When animals are housed in winter, the composition of pastures may be controlled to some extent by the earliness or lateness of the commencement of grazing in the spring. Grazing at any time weakens the grass species producing most growth during that period. Withholding grazing at the beginning of the growing season favours species which begin growth early and are normally subjected to heavy grazing pressures. Ivins (1966) regarded severe early spring grazing as one of several factors contributing to sward deterioration because the early growing species, often including the better grasses, are handicapped in the competition with species which begin growth later in the season. The interaction between stage of growth, dominance and intensity of defoliation has been shown with associations of ryegrass and cocksfoot (Jones, 1933) and ryegrass and meadow fescue (Rhodes, 1970).

Overgrazing in spring, by weakening ryegrasses and other productive grasses, can cause an open sward and rapid headway of white clover if present and weedgrasses, especially if conditions are unfavourable for the ryegrasses to make rapid progress during periods of recovery. An over-riding factor is that of species tolerance of grazing and trampling. Ryegrass therefore tends to dominate other grasses and survive hard grazings even in spring, merely because of inherently better tolerance.

Season of grazing and herbage production

The work of Jones (1933) and others was mainly concerned with composition, but later work by Brougham (1959, 1960) confirmed their results in terms of the production of individual species. Grazing in one season affects production in another (Brougham, 1959, 1960, 1971; Ivins, 1966) and the timing of severe or frequent defoliation has a differential effect on net herbage accumulation; eg Brougham (1960) found that the lowest annual rate of net herbage accumulation of ryegrass followed hard and frequent spring and summer grazing, of cocksfoot followed severe summer grazing, of red clover followed spring and summer grazing and of white clover followed spring or autumn grazing. This again demonstrates that grazing a plant at the time of maximum growth rate tends to depress it more than associated species which have a different time of maximum growth.

In spring and early summer as grasses approach the flowering stage, the leaf canopy is raised above ground level (Langer, 1959) and a higher proportion of tillers have growing points susceptible to trampling and defoliation by stock, particularly when hard grazed and in dry conditions (Brougham, 1971). During the rapid development and extension of the stem delaying defoliation by only a few days may remove the stem apex and seriously reduce yield (Jones, 1954). Once the stem apex is removed, no further growth can occur on a tiller unless and until new tillers arise in the axils of cut leaves at the base of the stem. Severe grazing in spring can reduce summer production (Ivins, 1966) but as long as there are no detrimental effects on plant survival of any of the sown species, dry matter accumulation can increase once the management system reverts to a less intensive one (Brougham, 1960).

Continued frequent hard grazing in summer led to widespread death of all species except white clover, and reduced herbage dry matter accumulation (Brougham, 1960). Death of ryegrass plants can also occur to a lesser extent when pastures are grazed leniently and less frequently in spring because of a greater degree of base shading (Brougham, 1959).

The reason for the reduction in herbage accumulation appears to lie in the decreased tiller population and tiller size after frequent severe grazing in spring and a less rapid production of new tillers during early regrowth. It may be that severe grazing encourages a prostrate growth habit so that at any defoliation a higher proportion of the crop is left behind, with a higher average age of leaves in the early stages of regrowth and a lower average efficiency. In perennial herbageous plants there is universally a decline in stored carbohydrates with the onset of spring growth (Smith, 1972). Complete defoliation severely drains reserve carbohydrates which are at their lowest in spring. In good conditions new leaves can grow quickly to replenish supplies, but constant removal of this new growth can bring about the death of these plants through carbohydrate starvation as reserves are drained. The date of initial harvest may offset carbohydrate reserve levels but the extent differs between species (Mislevy et al, 1978).

Tainton (1974) showed little response to management during the largely reproductive period in spring and early summer from a mixed sward of perennial ryegrass, white clover, cocksfoot, Yorkshire fog and Poa species. Differences in net accumulation arose more from differences in the rate of senescence and decay rather than from differences in growth rate. Dry conditions with extremely slow pasture growth were responsible for the increase in net herbage accumulation under lax infrequent grazing in this case.

In autumn hard frequent grazing can reduce immediate dry matter accumulation by as much as 20 % (Brougham, 1960) because at this stage a pasture is recovering from the stresses imposed by summer conditions and hard grazing if applied earlier in the season. This necessitates the development of a large number of new tillers with their associated root systems, so that pasture is extremely sensitive to hard grazing. Autumn management also affects the weight of harvestable herbage in spring; swards rested in autumn and winter usually produce more herbage in spring than from swards defoliated later, or later and more often (Jones, 1933; Lockhart, et al, 1969; Davies and Simons, 1979). Rested swards produce longer leaves and sheaths (Davies and Simons, 1979) so that the higher crop growth rates of autumn rested swards in spring is due to the greater bulk of herbage present to absorb light, and possibly changes in the proportion of reproductive and vegetative tillers (Davies, 1971). The dramatic decrease in the lengths of leaves and sheaths subsequently produced after late or frequent autumn defoliation persists into the spring (Thomas and Norris, 1977). Despite the initially depressed rate of leaf appearance and tillering in autumn and winter utilized swards, Davies and Simons (1979) showed that these swards exhibited the major increase in tiller numbers once fertilizer was applied in spring. In denser autumn rested swards new tiller production is limited by direct shading of the tiller bases and the accumulation of long dead sheaths. The development of lush autumn growth by deferring defoliation may also increase the likelihood of winterkill particularly if late application of fertiliser nitrogen is made, although the age of the sward, varietal susceptibility and winter severity will affect its significance (Hunt et al, 1976).

Thus the optimum date from which swards should be rested for maximum spring growth depends on the advantage of higher crop densities in early spring with associated increases in growth rate, and the disadvantage of increased tiller death in dense swards in winter. The choice of date will be modified by the region in which the plants are grown and on the plant material. The commencement of active growth in spring varies between species along with vigour and rapidity of growth thereafter. A long winter rest period is especially important for the production and persistency of early species such as perennial ryegrass, alone and in mixtures (Jones, 1933).

Conclusion

With few exceptions, cutting studies reviewed above have shown increased herbage yields with longer intervals between defoliations and with close cutting (provided adequate recovery periods are allowed between defoliations). Cutting intervals of 5 weeks or more also reduce the nutritive value of the herbage but only small and variable effects of cutting height have been found. Herbage species differ in their reaction to varying grazing intensities and the timing of severe or frequent defoliation has a differential effect on herbage production and the botanical composition of the sward.

Grazing experiments confirm the above results although effects are less pronounced. The evidence suggests that annual herbage accumulation is relatively insensitive to variations in grazing management although experimental evidence is limited compared to that available from cutting experiments. Experimentation is needed to determine factors influencing sward parameters which affect net herbage accumulation and herbage quality.

SECTION II Pasture herbage utilisation

Introduction

Grass is a cheap source of feed relative to purchased feeds but unless it is utilised effectively, it is an unprofitable way of using land. Utilisation, in a grassland context, refers to the proportion of herbage present that is harvested by an animal or machine.

In any particular grazing situation the percentage of the herbage available which is utilised will depend on factors associated with the intake drive of the animal, the sward conditions, and environmental conditions. The response of a cow to a particular condition will determine the extent to which it achieves its potential voluntary intake. Daily intake can be divided into components, each of which may be affected by a change in condition and alter the intake as a whole.

eg Daily herbage intake = Grazing time x Rate of biting x Intake per bite. The total utilisation of herbage/herbage availability (ha) over the whole grazing season is a function of the utilisation at each grazing and the regrowth between grazings. The utilisation at one grazing can affect that of the next by changes it may produce in sward composition and digestibility.

Characteristics associated with the animal

Physiological state

Variation in voluntary food intake associated with physiological changes such as growth, fattening, pregnancy and lactation is not well documented for ruminants. In general, the physiological state of an animal will influence food intake according to the demand for energy (Table II.1). Thus the lactating cow will use more energy than an otherwise similar but non-lactating cow and have an intake 30-50 % higher (Hutton, 1963; Campling, 1966; Leaver et al, 1969).

As an animal grows, abdominal volume increases thereby increasing the amount of food which can be eaten. This increase in intake varies in proportion to the metabolic weight of the animal (Bines, 1976). Compensatory growth occurs after a period of underfeeding as a result of increased food intake when rate of eating and time spent eating may increase (Meyer et al, 1965).

Fatness reduces intake in cattle, the fat cow having a reduced 'requirement' for nutrients for fat synthesis (Bines, 1971). Also, deposition of fat within the abdominal cavity will cause a reduction in the effective volume of the cavity into which the rumen can expand during feeding.

There is evidence to suggest that pregnancy may have an effect on food intake.

Table II.1 Daily metabolisable energy allowance (MJ) for a 500 kg Friesian cow relating to physiological state (from MAFF, 1975)

Physiological state	ME allowance (MJ day^{-1})
Dry, non-pregnant (maintenance)	54
8 months pregnant	122
Producing 30 kg milk per day	200

Two opposing effects influence food intake during pregnancy as cited in a review of literature by Forbes (1970). In early pregnancy the increased demand for nutrients for development of the foetus causes intake to rise. But in late pregnancy there is a reduction in food intake because the effective volume of the abdominal cavity for expansion of the rumen during feeding is reduced as the foetus grows. This depression in intake relative to demand is greater when the concentration of the ration is low (Hutton, 1963).

Early estimates of feed intake of grazing cattle showed a correlation with milk yield (eg Sjollema, 1950), which has been confirmed by clipping methods (Cox et al, 1956) and indigestible marker/faecal index methods (Smith and Reid, 1955). No attempt will be made to survey completely the extensive literature relating food intake to lactation, the physiological control of which is comprehensively reviewed by Baile and Forbes (1974).

Chromic oxide-faecal N techniques have been used to measure individual feed intakes of grazing cattle at various Research Institutions and several of these studies show that feed intake is largely accounted for by liveweight, liveweight gain and milk yield. Changes in liveweight of the cow which occur simultaneously make it difficult to quantify the effect of level of lactation on intake, but in general, increases in intake from the time of calving to the time of peak lactation are of the order of 30-40 per cent. The effect of these variables on herbage intake, has led to the formation of equations to predict intakes for individual animals;typical equations are:

$DMI = 0.025\ W + 0.1\ Y$ (MAFF, 1975)

$DOMI = 0.21\ FCM + 0.095\ W^{0.73} + 1.64\ LWG$ (Hutton, 1962),

where DMI = dry matter intake , DOMI = digestible organic matter intake, W = weight of cow, Y = milk yield, FCM = fat corrected milk yield, and LWG = liveweight gain.

Curran and Holmes (1970) used several variables to produce models predicting organic-matter intake, digestible organic-matter intake and faecal output in 72 grazing cows. Fat-corrected milk and $W^{0.73}$ gave better results than milk yield and liveweight, and together with age were all significant variables for the prediction of the dependent variable. However they concluded that the intakes of individual grazing cows cannot be predicted within population tolerance limits of about ± 25 %; due to the large number of factors involved in the control of food intake and its inter-relationship with regulation of energy balance, prediction equations for food intake are only generalisations.

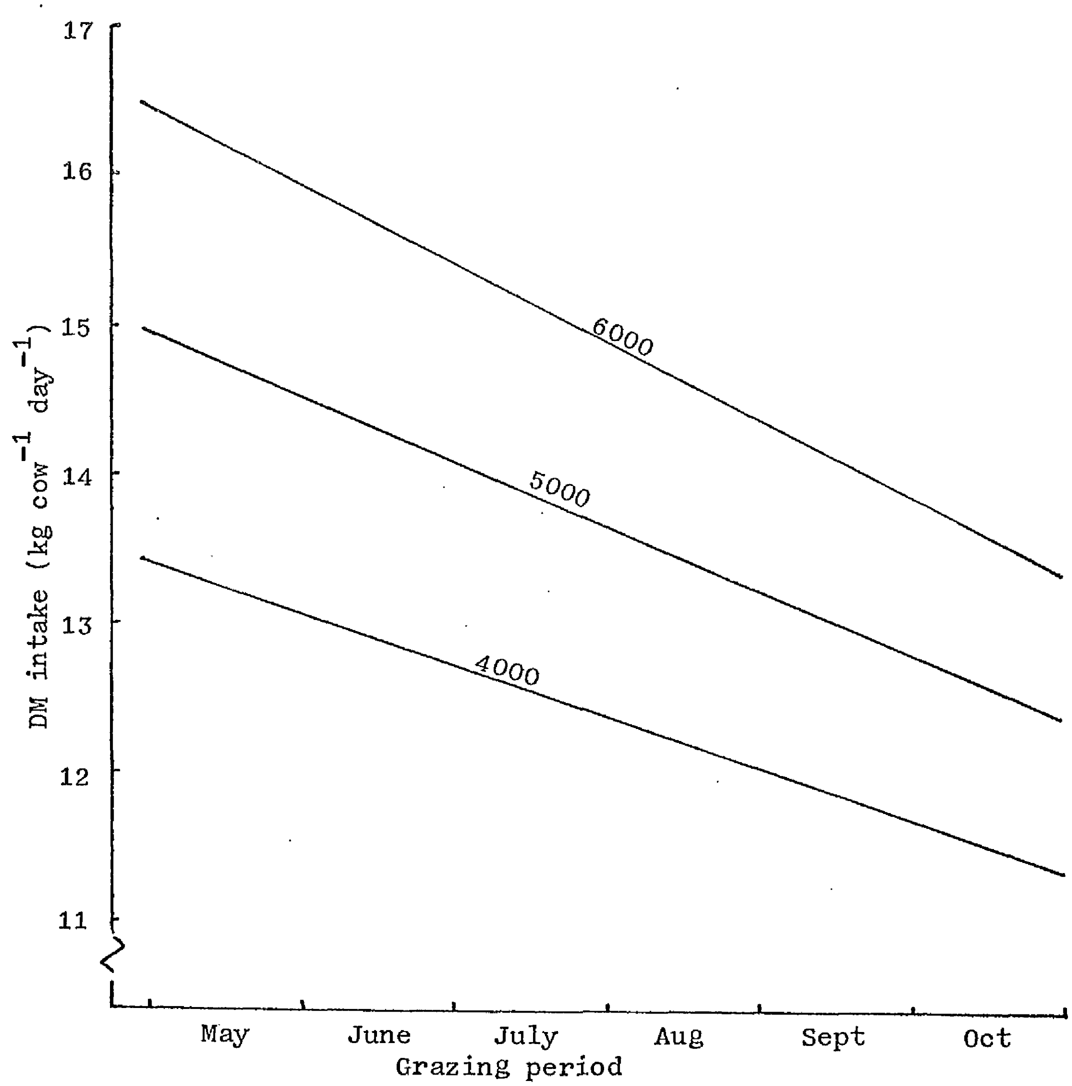
It is often difficult to show a clear relationship between level of yield and intake because of differences due to animal liveweight. Recently in the Netherlands, however, data from grazing experiments on the amount of herbage consumed by grazing cows has been collected to show the effect of different milk yields on dry matter intake (Kemp et al, 1979). The intake of a milking cow with an annual production of 6000 kg was shown to be approximately 20 % higher than that of one with an annual production of 4000 kg (See Fig II.1). During the lactation period the dry matter intake decreased by 15 %.

The relationship between the yield and intake of individual cows at different stages of lactation is poor because the latter reaches its peak several weeks after the former and then declines more rapidly (Hutton, 1963).

Supplementary feeding

Supplementary feeds, mainly in the form of concentrates, are widely

Fig II.1 Dry matter intake by grazing milking cows with different milk yields (from Kemp et al, 1979)



given in this country to dairy cows during the grazing season, although it is possible to produce high outputs of milk per unit of land from intensively managed grassland alone (eg Gordon, 1976; Castle and Watson, 1978). Concentrates are often used as a buffer when drought causes herbage shortages, but their use has increased generally from 1210 kg per cow (0.31 kg per litre) in 1967-68 to 1783 kg per cow (0.38 kg per litre) in 1976-1977 (MMB, 1977). Experimental evidence suggests that the effect of supplementary feeding on animal production and herbage utilisation differs according to the amount of herbage available (Leaver, 1976), the digestibility of the herbage eaten, the type of supplement and the time of year (Leaver et al, 1968).

At relatively low stocking rates cattle have available more herbage than they can eat; under these conditions the supplement may largely replace herbage in the diet with little increase in total nutrient intake. From a survey of published data Holmes and Jones (1964) calculated that when concentrates were added to a roughage diet:

$$I = 2.8 - 0.034\ D,$$

where I = kg increase in total feed intake per kg concentrate consumed, and D = digestibility of the organic matter of the roughage to which the concentrate was added. Assuming a 70-80 % D for grazed pasture they obtained an expected increase of only 0.1-0.4 kg per kg concentrates OM. A similar response has been calculated for dry cows (Sarker and Holmes, 1974) and lactating cows (Leaver, et al, 1969; Marsh et al, 1971), and heifers grazing tropical grasses (Combellas, Baker and Hodgson, 1979). The reduction in herbage intake can be explained by reductions in the time spent grazing (Sarker and Holmes, 1974; Combellas et al, 1979), the rate of biting and the size of each bite, with reductions in the time spent grazing having the dominant effect (see Table II.2).

Milk yields are usually increased when concentrates are fed to cows on good quality pasture, but most experimental studies have shown that the short-term response to feeding supplementary concentrates to grazing cows is low. In their review, Leaver, Campling and Holmes (1968) showed a response of only 0.3 kg milk per additional kg of concentrate fed. This small and uneconomical response is little affected by feeding concentrates at a standard rate (Shepherd, 1962) or according to yield (Castle et al, 1964) or using high yielding animals (Gordon, 1974).

If pasture is restricted, there is more efficient removal of herbage from the sward (Raymond, 1964) and at high stocking rates when the quantity of herbage is reduced, an improved response to supplements is obtained. Increased total organic matter intakes per unit OM of supplement have been obtained (Gomez and Holmes, 1976; Vadiveloo and Holmes, 1979) although herbage OM intakes may still be depressed but to (Vadiveloo and Holmes, 1979) a lesser extent. Long and short-term experiments demonstrate a large response of 1.25-1.35 kg milk per kg of concentrate fed when herbage is scarce (Wallace, 1957; Hutton and Parker, 1967) and support the conclusion that giving supplements to grazing cows should only be contemplated where herbage availability is limited or conversely where the utilisation of herbage will not be substantially reduced.

The higher the digestibility of forage, the greater is the substitution effect of concentrates, that is the greater the depression

Table II.2 The effect of concentrate supplementation on total and herbage organic matter intakes (kg day^{-1}) and on grazing behaviour

Reference	Level of concentrate (kg day^{-1})							
	0	1	2	3	3.6	4	6	8
Herbage OM intake (kg day^{-1})								
Leaver *et al* (1969)		11.3			9.7			
Marsh *et al* (1971)	10.7				9.6			
Sarker and Holmes (1974)			9.9			8.8	8.0	7.4
Combellas *et al* (1979)	9.3			7.6			6.4	
Total OM intake (kg day^{-1})								
Leaver *et al* (1969)		12.0			13.1			
* Marsh *et al* (1971)	8.6				10.1			
Sarker and Holmes (1974)			11.5			11.9	12.7	13.6
Combellas *et al* (1979)	9.3			10.2			11.7	
Grazing time (mins day^{-1})								
Stobbs (1970)	594					508		
Sarker and Holmes (1974)			495			430	408	359
Combellas *et al* (1979)	462			432			396	
Rate of biting (bites min^{-1})								
Combellas *et al* (1979)	51.7			50.4			49.9	
Bite size (g OM $bite^{-1}$)								
Combellas *et al* (1979)	0.41			0.36			0.34	

* Total digestible OM intake (kg day^{-1})

in voluntary forage intake (Leaver, 1973). As forage quality falls their supplementary effect increases (Holmes, 1976).

The protein content of the concentrate has been shown to affect the extent of substitution for grass silage (Castle and Watson, 1976) but Castle, Watson and Leaver (1979) showed little advantage between different protein contents of supplements with an ample supply of herbage of high crude protein concentration.

Supplementary concentrates may have a greater effect on the increase in total feed intake in autumn when cows less readily eat autumn grown herbage which may be less digestible and contaminated with excreta.

Characteristics associated with the sward

Digestibility

The close link between voluntary intake of forages and digestibility is widely recognised (eg Campling et al, 1961; Blaxter and Wilson, 1962; Conrad et al, 1964). The reviews of Balch and Campling (1962), Blaxter (1962) and Jarrige et al (1974) support the hypothesis that the voluntary intake of forages by ruminants is determined mainly by the bulkiness of the digesta in, and its rate of disappearance from, the reticulo-rumen.

The higher the digestibility, the quicker the rate of passage through the gut and the higher the daily intake of cattle (Blaxter and Wilson, 1962). Most of the general relationships between voluntary intake and digestibility have been found with animals fed indoors on conserved grass products but although the accurate estimation of the intake of a grazing animal is more difficult, a relationship has also been found between the digestibility of a diet and its intake by grazing cattle (Corbett et al, 1963; Hodgson, 1968; Hodgson and

Wilkinson, 1968; Rodriguez, 1973).

Earlier workers proposed a linear relationship between intake and digestibility up to digestibilities of 65-70 % beyond which Blaxter and Wilson (1962) and Corbett et al (1963) described a curvilinear relationship, while others could find no relationship (Hutton, 1962; Conrad et al, 1964). It has been suggested that physical factors limit intake up to forage diet digestibilities of 70-75 %, beyond which metabolic control occurs (Balch and Campling, 1969). Many of these results come from indoor trials as reviewed by Jarrige et al (1974), but results from grazing experiments report a linear relationship between the two variables up to digestibility levels of 80-82 % for calves (Hodgson, 1968; Rodriguez and Hodgson, 1974) and lactating cows (Corbett et al, 1963; Holmes, Campling and Joshi, 1972; Stehr and Kirchgessner, 1976). These differing results demonstrate how the physiological state of an animal may affect its sensitivity to the physical control of food intake; early experiments were carried out on non-productive, mature animals with lower nutrient demands, whereas in the trials of Hodgson (1968) and others quoted above, animals with high nutrients demands (lactating cows or animals with some capacity for growth) were used. It may be concluded that under grazing conditions the herbage intake of productive animals is seldom, if ever, likely to be affected by metabolic limits. However this response is likely to be reinforced to some degree by other sward variables such as the proportion of live to dead tissue and leaf density, which are closely associated with herbage digestibility, and which can themselves affect grazing behaviour (Chacon and Stobbs, 1976). The type of diet offered may also affect the relationship; those experiments where a linear relationship was established offered dry or fresh herbage only, and supplementation of forage with concentrates (eg Conrad et al, 1964) is known to have variable effects on food intake (Blaxter and Wilson, 1962; Campling, 1966).

The digestibility of grass is determined by fertilizer treatment, variety, stage of growth and time of year. In a young leaf or stem the fibre content is relatively low and highly digestible. As the plant ages, the fibre content increases and becomes lignified and more difficult to digest. In temperate grasses, if growth is uninterrupted, digestibility and hence intake fall rapidly after ear or flower emergence (MAFF, 1977). At grazing, cattle frequently show a greater response to first growth than to second growth (Corbett et al, 1963; Alder, 1968) and this observation may apply over a wide range of digestibility (Rodriguez and Hodgson, 1974). Jamieson (1975), however, noted that when grazed at a young stage, first growth had a low voluntary intake value compared to later growths. Seasonal changes in herbage composition resulting in changes in the rate of breakdown of herbage in the reticulo-rumen, is one possible explanation for the differences in intake between early and late season growths with similar digestibility (Reed, 1978).

Botanical composition

Although the gross energy contents of grass and legume species are similar (Hunt, 1966) chemical composition and hence digestibility vary greatly with stage of growth and between species.

The level of herbage intake by sheep is usually higher on leguminous swards than on grass swards at similar levels of digestibility but results for cattle are less clear. Smaller and less consistent differences occur between individual grass species or hybrids: Alder (1970) reported similar levels of herbage intake on perennial ryegrass, meadow fescue and timothy, but lower intakes have been found on cocksfoot (eg Alder and Cooper, 1967); higher intakes on Italian than on perennial ryegrass (Jackson, 1976), and higher on short-rotation than on perennial ryegrass (Ulyatt, 1971).

The intrinsic characteristics of plants determining digestibility are not necessarily the same as those affecting intake, so that at the same digestibility differences can occur in intake between species (Walters, 1971). Biochemical differences exist between plant genotypes and Ulyatt (1971) also reported differences between species in the efficiency of utilisation of the products of digestion. Differences in plant morphology and sward structure are also probably responsible for the differences in herbage intake. Upright species like cocksfoot are easier to defoliate than species with a prostrate habit of growth; more herbage is carried in the upper horizons of the sward in Italian ryegrass than in perennial ryegrass (Jackson, 1976) and in legume swards compared with grass swards, and this will in itself enhance intake.

Although in general digestibility remains high until ear emergence and then declines rapidly, varietal differences occur in heading date with later flowering varieties also maintaining digestibility for a longer period (Dent and Aldrich, 1968). At the same stage of growth species may differ in digestibility; ryegrasses are normally more digestible than cocksfoot (Minson et al, 1960), but there is also a wide range between varieties within species (Dent and Aldrich, 1968).

Contamination

Contamination may occur from slurry applied to grassland or from dung returned by the grazing animal, and may affect the acceptability of herbage to grazing cattle.

Cow slurry may to some extent replace artificial fertilisers as it contains appreciable quantities of plant nutrients (MAFF, 1970). To be beneficial it should be applied in spring although on grazed areas it may initially cause reduced intakes in grazing cattle (Marten and Donker, 1966; Reid et al, 1972). If given the choice, cattle show a preference for clean herbage which is most marked at the first grazing after slurry application, as the effects are barely detectable by the second grazing (Broom et al, 1975). When there is no choice, slurry application will not necessarily lead to reduced intakes if the grazing pressure is low, although grazing behaviour may be modified (Pain et al, 1974).

As stocking rates increase greater amounts of dung and urine are deposited on the sward, and dung may cover 2-3 % of the surface area of intensively-managed pasture by the end of the grazing season. This subject has been reviewed by Marsh and Campling (1970) who estimated that the dung from one cow could cover 80-200 m^2 in a grazing season assuming no decomposition or overlapping of pats. This represents 10 % of the pasture required at high stocking rates, but is a maximal value as decomposition occurs due to climatic effects and the activities of birds, microbes and invertebrates.

Although urine does not lead to any major rejection of herbage, cattle reject dung-affected herbage in and adjacent to areas contaminated by dung pats (MacLusky, 1960; Marsh and Campling, 1970). The extent of this rejection depends on grazing intensity and the availability of alternative clean herbage (Greenhalgh and Reid, 1969).

Possible explanations for the rejection of fouled pasture by grazing animals include a P/N imbalance in the herbage, herbage maturation round dung pats, smell or taste of the dung. The reason appears to be smell rather than a difference in composition or taste; Marten and Donker (1966) showed that under grazing conditions heifers rejected herbage surrounding dung pats, but readily ate it when cut and fed indoors.

MacLusky (1960) suggests that herbage rejection due to fouling leads to a decrease in the quantity of herbage utilised but MacDiarmid and Watkin (1972) contend that the growth response to the nutrients deposited in the dung more than compensates for the initial rejection. To avoid the formation of clumps of long rank herbage, stocking rates should be increased so that cattle graze closer to the dung pats (MacLusky, 1960) thus increasing the utilisation of dung-affected herbage.

The importance of fouling can be exaggerated because its effects on the pasture, although not on the animal, are so clearly seen. With dairy cows offered either dung-fouled or clean pasture at two grazing intensities, daily DM intake was reduced by fouling, but DOM intake, milk yield and liveweight change were not significantly affected (Reid et al, 1972). Appropriately Marsh and Campling (1970) concluded that if "more emphasis were given to milk yield per ha rather than milk yield per cow or to sward appearance, it is probable that less importance would be attributed by graziers to dung fouling".

Herbage quantity

In conditions where herbage quantity per unit area or per animal is not limiting, the herbage intake of grazing cattle is related primarily to the digestibility of the herbage consumed (Hodgson et al, 1977). In most practical situations however, the quantity of herbage to which animals have access is controlled to some degree and has led several workers to study the effect of variations in the quantity of herbage present on herbage intake. This has been expressed as herbage mass and herbage allowance.

Herbage mass may be defined as the instantaneous measure of the total weight of herbage per unit area of ground. Herbage allowance is derived from estimates of herbage mass and may be defined as the weight of herbage per unit of animal liveweight. In comparing results it is important to take into account differences in experimental techniques, the most variable of which is the height above which herbage is cut for the estimation of herbage mass. If animals graze below a cutting height of 2-5 cm above ground level, they appear to consume more than they are offered when subjected to low allowances (eg Greenhalgh et al, 1966). It seems important to cut herbage close to ground level in order to estimate all the herbage on offer to grazing animals.

The relationship between herbage intake and herbage mass is asymptotic, intake declining at an increasing rate below some critical level of weight which varies between 1100 and 3000 kg of dry matter per hectare for cattle grazing temperate swards (Table II.3). The lowest recorded figures are underestimates because they were made at 2 cm or grazing height, and differences in animals, swards and

Table II.3 Cattle experiments demonstrating levels of herbage mass below which herbage intake is depressed (kg DM or OM ha^{-1})

Reference	Animal type	Sward type	Sampling height	Intake depressed below
Woodward (1936)	lactating cows	orchard grass	grazing height	1100 kg DM ha^{-1}
Johnstone -Wallace and Kennedy (1944)	suckler cows	Kentucky bluegrass/ clover	2 cm	1100 kg DM ha^{-1}
Waite et al (1950)	lactating cows	cocksfoot ley	2 cm	1450 kg DM ha^{-1}
Van der Kley (1956)	lactating cows	permanent and temporary grassland	not clear probably 2 cm	2800 kg DM ha^{-1}
Tayler (1966)	2 yr steers	perennial ryegrass	ground	1900 kg OM ha^{-1}
Hodgson et al (1971)	calves	perennial ryegrass	ground	2300 kg OM ha^{-1}
Rodriguez (1973)	calves	perennial ryegrass	ground	2500 kg OM ha^{-1}
Jamieson (1975)	calves	perennial ryegrass	ground	3000 kg OM ha^{-1}
Hodgson et al (1977)	calves	pangola grass	ground	1500-2500 kg DM ha^{-1}
Jamieson and Hodgson (1979 b)	calves	perennial ryegrass	ground	3000 kg OM ha^{-1}

techniques further explain the variation between results. The high values obtained by Jamieson (1975) and Jamieson and Hodgson (1979 b) may reflect either the high potential nutrient intakes or the greater sensitivity to sward conditions of the young animals used in these studies. They may also be due in part to the reinforcing effects of increasing digestibility and increasing herbage mass.

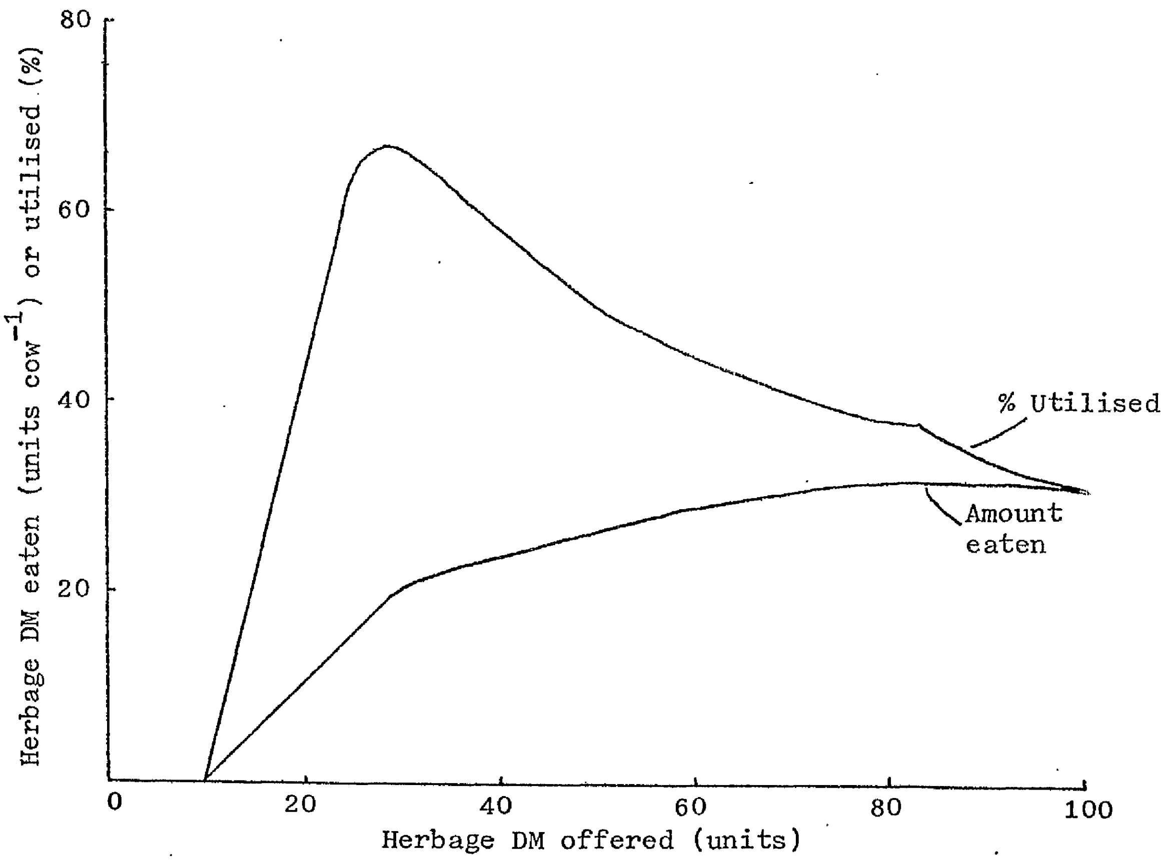
Intakes may also be reduced at high levels of herbage mass when the weight of crop exceeds an optimum value (Van der Kley, 1956; Hodgson et al, 1977). Reardon (1977) observed intake to decline rapidly over a range of herbage dry matter from 2000 to 4000 kg per hectare but in many cases variations in herbage mass and maturity were probably confounded. In some cases no clear relationship has been found between intake and herbage mass (Hodgson and Wilkinson, 1968) which may also have been due to the confounding of digestibility and weight of the crop.

Similarly the relationship between herbage intake of grazing dairy cows and daily herbage allowance is asymptotic, intake declining at a progressively faster rate when the daily herbage allowance is reduced below some critical level which varies between 15-20 kg dry matter per cow or 40-60 g per kg liveweight (Table II.4). (In earlier experiments, herbage allowance was defined as the weight of herbage per cow per day above an arbitary sampling height, but later re-defined in terms of the weight of herbage per unit of animal liveweight (LW) and all herbage measurements made to ground level). The theoretical relationship between herbage allowance, intake and utilisation is expressed graphically in Fig II.2. At high levels of daily herbage allowance the proportion utilised is low although animal intakes are maximal, but as herbage allowance decreases intakes decline slowly and

Table II.4 Cattle experiments demonstrating levels of daily herbage allowance below which herbage intake is depressed (kg DM cow^{-1} or g DM kg^{-1} LW)

Reference	Animal type	Sward type	Sampling height	Intake depressed below
Gordon *et al* (1966)	lactating cows	orchard grass/ Ladino clover	not clear - probably 3-5 cm	22 kg DM cow^{-1}
Greenhalgh *et al* (1966)	lactating cows	mixed pastures	2.5 - 5 cm	20 kg DM cow^{-1}
Greenhalgh *et al* (1967)	lactating cows	mixed pastures	2.5 - 5 cm	16-20 kg DM cow^{-1}
Jamieson and Hodgson (1974)	calves	perennial ryegrass	ground	60 g DM kg^{-1} LW
Combellas and Hodgson (1975)	lactating cows	perennial ryegrass	ground	50 g DM kg^{-1} LW
Jamieson (1975)	calves	perennial ryegrass	ground	60 g DM kg^{-1} LW
Combellas and Hodgson (1979)	lactating cows	perennial ryegrass	ground	60 g DM kg^{-1} LW
Jamieson and Hodgson (1979 a)	calves	perennial ryegrass	ground	60 g DM kg^{-1} LW
Le Du *et al* (1979)	lactating cows	perennial ryegrass	ground	50 g DM kg^{-1} LW

Fig II.2 Theoretical relationship between the amount of herbage offered, the amount eaten, and the percentage utilised at a single grazing assuming a maximum intake of 30 units cow^{-1} (from Leaver, 1976)



utilisation increases slowly. Further decreases in herbage allowance cause a more rapid change in intake and utilisation until a point is reached when the animal cannot utilise any more of the herbage available because of its inaccessibility in the base of the sward, and intakes and percentage utilisation reach zero.

Results of recent trials with lactating dairy cows (Combellas and Hodgson, 1979) are in agreement with those for calves (Jamieson, 1975; Jamieson and Hodgson, 1979 a) under strip grazing management involving similar short experimental periods and measurement techniques. Le Du et al (1979) obtained depressed intakes and milk yields once the cows were forced to consume more than 50 % of herbage on offer (approx 40-50 g per kg LW). Stehr and Kirchgessner (1976) found that intake increased progressively up to daily herbage dry matter allowances of 35 kg per cow (approx 50 g per kg LW) but their treatments were not applied simultaneously and the effect of allowance could have been confounded with variations in sward conditions and in the milk yield of the cows. Results from other cattle experiments have shown no clear effect of herbage allowance on herbage intake (Waite et al, 1950; Tayler, 1966). In the former case differences in allowances were confounded with differences in herbage quality and in the latter the lack of a relationship may have been due to animals on low allowances grazing under fences, thereby increasing their effective daily allowance. In a long term experiment by Leaver (1974), grazing pressure figures may be interpreted in terms of herbage allowance and indicate a linear relationship between animal performance and allowance over the range studied.

Several workers have noted a seasonal variation in the relationship between intake and allowance. Jamieson (1975) showed that a 67 % reduction in the area offered daily to calves led to a greater reduction in digestible organic matter of the diet,and consequently a greater reduction in digestible organic matter intake,for calves grazing autumn pastures than for calves grazing spring pastures. This author also noted a higher intake for calves in spring than in autumn at similar levels of allowance and digestibility. Jamieson (1975) suggested that the spring sward was more readily apprehended by grazing animals because of its erect growth habit and that pasture allowance could be restricted more in spring than in autumn without reducing intake. This seasonal effect was confirmed in a recent experiment with strip-grazed calves (Jamieson and Hodgson, 1979 a). Leaver (1974) suggested that one cause of lower average daily liveweight gain in autumn may be a reduced intake attributable to the greater area of dung-fouled pasture at that time.

Behavioural limitations have not often been considered in theories of the control of feed intake in ruminants, though assumptions about their effects have been implicit in many publications referring to work on herbage intake from tropical and sub-tropical swards (Stobbs, 1973 a, 1973 b; Chacon and Stobbs, 1976). Changes in grazing behaviour at different allowances are primarily determined by changes in sward conditions. As the quantity of herbage available declines, the harvesting process becomes harder as cattle graze closer to the ground and they consume less. Both the rate of biting (Jamieson, 1975) and bite size fall (Stobbs, 1973 a) although rate of biting may initially increase (Hodgson and Wilkinson, 1968). The animal attempts to compensate in continuous stocking systems by increasing the time spent grazing in order to maintain herbage intake (Hancock, 1954; Freer, 1960). Although some compensation in this way is possible, a point is eventually reached where the hours of daylight, the need to ruminate or possible fatigue limit further increase in grazing time and so intake falls. Canopy structure of the sward may modify these relationships as bulk density, a low stem content and a high leaf/weight ratio all give rise to increases in bite size (Stobbs, 1973 a, 1973 b). Bite size was found to be bigger on a spring sward than on autumn sward for strip-grazed calves (Jamieson and Hodgson, 1979 a).

Work has been done to illustrate the effects of daily herbage allowance and sward characteristics upon the ingestive behaviour of calves under different grazing management (Jamieson, 1975). Strip-grazed calves graze down through a sward in 24 hours, whereas for continuously stocked calves there may be virtually no change in sward conditions over 24 hours or even several days. Strip-grazed calves at low allowances suffered a reduction in bite size and rate of biting in association with the fall in herbage mass from the beginning to the end of grazing. Intakes were reduced because there was no compensating increase in grazing time which agrees with recent evidence from strip-grazed dairy cows (Combellas and Hodgson, 1979; Le Du et al, 1979). This may be due in part to the difficulty of prehending increasing short herbage (Jamieson, 1975; Jamieson and Hodgson, 1979) and because the calves behaviour was conditioned by anticipation of an imminent fence move and new allocation of herbage, an idea supported by Le Du et al (1979) from their work with strip-grazed dairy cows. In contrast continuously grazed calves on low levels of herbage mass have a smaller bite size but ease of prehension is similar over the course of the day, and intake is eventually limited by the balance of drives between grazing and other activities which dictate an upper limit to grazing time.

Spatial distribution and sward structure

Sward height has been the most commonly used measurement of spatial distribution although techniques measuring it vary widely and should be borne in mind when comparing absolute values reported by various authors. This characteristic has been considered the next most important after herbage digestibility and herbage mass in accounting for variations in herbage intake (Rodriguez, 1973). Herbage intake of cattle declines when the height of stubble on grazed areas falls below a critical height ranging from 7 to 10 cm between experiments (Tayler, 1966; Jamieson, 1975; Le Du et al, 1978; Le Du et al, 1979). There is evidence of a difference between grazing systems; Baker et al (1978) showed that the intakes of rotationally grazed calves declined when herbage height fell below 7.5-9.5 cm but the intakes of continuously grazed calves were unaffected until herbage height fell below 7 cm. Similar results have been achieved with lactating cows (Le Du et al, 1978). Increases in sward height from 11 to 23 cm have also been shown to reduce intake (Johnstone-Wallace and Kennedy, 1944; Waite et al, 1950) but changes in sward digestibility appear to have been dominant in these cases. Rodriguez (1973) and Hodgson et al (1977) demonstrated that maximum intake occurred at an extended height of 40-45 cm for young cattle. Grazing behaviour responses to changes in sward height are similar to those for herbage allowance; as sward height increases, bite size and rate of intake increase (Allden and

Whittaker, 1970). Arnold (1963) demonstrated the expected fall in sheep grazing time with increasing sward height.

Although technically difficult to measure, sward density provides a measure of spatial distribution. These difficulties have prevented many investigations on the influence of sward density on herbage intake although its importance is recognised (Allden and Whittaker, 1970). Stobbs (1973 a, 1973 b) upheld sward density in tropical pastures as the most important quantitative sward characteristic determining bite size, and suggested that the high grazing times of animals on tropical pastures may be due to a lower sward density than temperate pastures.

There is evidence of a difference of opinion as to whether the height (Tayler, 1966; Jamieson, 1975) or the weight (Hodgson et al, 1971) of herbage remaining after grazing exerts the greater influence on intake. This has led Hodgson (1976) to suggest that variations in sward structure as a whole are responsible for variations in the rate of herbage intake as measurements of total herbage weight and overall sward height may be inadequate in themselves to explain variations in herbage intake. Hodgson (1977) re-analysed information collected by Jamieson (1975) to illustrate this point further. He concluded that the rate of intake at any one time is influenced directly by the height and density of the grazed horizon and that a more detailed description of sward structure is required.

Environmental factors

Season

The distribution of grazing over a day is affected by season. Hafez (1968) has reviewed grazing periodicity and suggests that there are usually 4 or 5 periods of grazing during the day. This has been confirmed by Stobbs (1970) with Jersey cows. The beginning and end of grazing are closely related to dawn and dusk (Castle et al, 1950; Hughes and Reid, 1951), and 65-85 % of daily grazing takes place during daylight hours (Johnstone-Wallace and Kennedy, 1944; Hancock, 1954). As daylength shortens in autumn and winter, periods of grazing may run closer together (Tayler, 1953) and a greater proportion of the daily grazing takes place during darkness (Hancock, 1954). The extent to which cows can compensate in night grazing for the reduced intake during the day has not been estimated. Forbes et al (1975) have shown an increase in serum prolactin in growing sheep when daylength was increased and this was associated with increased food intake and live-weight gain. This phenomenon has yet to be investigated in cattle.

Temperature and rainfall

Continuous high temperatures prevent maintenance of energy balance due to reduced intakes and above 40^{o} C cattle of temperate breeds cease to eat altogether. No relationship has been found between air temperature and total grazing time in temperate regions (Castle et al, 1950) possibly because maximum day temperatures occur between 12.00 and 14.00 hr which is often a non-grazing period, and increased night grazing may compensate for reduced daytime grazing on very warm days (Seath and Miller, 1946).

Some workers have claimed or implied that the intake of pasture by cattle is partly influenced by rainfall (eg Marsh, 1975). Rain has little effect on grazing time except in heavy downpours when grazing time and hence herbage utilisation is depressed (Waite et al, 1951). Hancock (1954) reported intensive grazing between storms and showers in an attempt to compensate regardless of the time of night or day at the expense of idling time. Persistent heavy rain can cause poaching of the sward and hence a reduction in effective grazing area. In addition, particularly with an open sward, these conditions allow the deposition of soil from the animals' hooves on to the grass and thereby reduce its palatability and the quantity consumed (MAFF, 1977).

There is no evidence of high windspeeds having a significant effect on total daily grazing periods, but persistent heavy rain and a driving wind can reduce grazing time and grass intake (MAFF, 1977).

Conclusion

Under grazing conditions, sward and environmental factors as well as animal factors influence herbage utilisation. An increase in grazing pressure, a reduction in herbage quality, contamination of herbage, supplementary feeding, reduced daylength and inclement weather all impose constraints on herbage intake. The digestibility of the herbage selected from the sward exerts a dominant influence on herbage intake in conditions where herbage quantity is not limiting. Where quantity is controlled, the amount of herbage present per unit area and its distribution in space have been acknowledged as important factors limiting intake through their effects on the ease of prehension of herbage. Intakes are depressed below 1100-3000 kg DM ha^{-1} or below 7-10 cm herbage height. But there is evidence that measurements of total herbage weight and overall sward height are likely to be inadequate in themselves to explain variations in herbage intake. As yet there is no general agreement on how to describe spatial distribution, but it is doubtful whether any single measure can indicate the optimum sward structure for a grazing animal.

The extent to which the grazing cow achieves its potential intake which is governed by its size, physiological status and production level, depends on its ability to adapt its grazing behaviour to overcome the constraints applied.

SECTION III Estimation of herbage mass from measurements of herbage height

Introduction

The amount of above ground material present at any one time is the base measurement of nearly all assessments of vegetation; growth, production, utilisation and deterioration are all changes in quantity over time.

Destructive and non-destructive methods can be used to measure herbage mass, although all require some form of cutting. In the first group, herbage mass is estimated by cutting techniques only, and despite the accuracy of each individual measurement, the variability within pastures means that large numbers of samples must be cut. There are physical limitations to the cutting of large numbers of samples and cutting itself may become a significant treatment on the area if many samples are taken.

Sampling methods with minimal physical sampling for herbage mass have been developed for various reasons: to reduce labour, equipment, time and cost; for use in trials where it would not be possible to sample the sward intensively by cutting or where to do so would affect a large proportion of the treatment area; to rank treatments in trials with large comparative differences, and to be a guide to mass in development trials, farm practice and advisory work where absolute measures of herbage mass may not be necessary. Non-destructive methods usually involve the measurement of one or more variables that can be related to quantity by the destructive harvesting of only a small number of sampling plots. These samples are cut to obtain an accurate assessment of mass and a regression is calculated between measures of herbage mass and measures from 'non-cutting' methods.

This review examines the use of herbage height measurements for estimating herbage mass, although many other non-destructive methods have been developed, ranging from wholly objective to fairly subjective (see reviews by Brown (1954) and t'Mannetje (1978)).

The relationship of herbage height to herbage mass

Herbage height has been used as a criterion for estimating herbage mass with varying degrees of success. In some cases height has been combined with other variables, especially density, as these are the two main characteristics influencing herbage mass and its visual assessment. Brown (1954) reviewed early methods based on the relationship between herbage mass and the height and density of individual components. Numerous relationships have been proposed since as no one single method appears satisfactory for all vegetation types.

As sward density or sward height alone may not be an adequate index of herbage production (Spedding and Large, 1957; Evans and Jones, 1958), a combination of ground cover and sward height has been used on different types of grassland to estimate relative dry matter yield (eg Spedding and Large, 1957; Evans and Jones, 1958; Bakhuis, 1960; Hughes, 1962 and Alexander et al, 1962). Results are variable, although subdividing plants into young, mature and senescent individuals gave higher correlation coefficients between weight, height and area (Alexander et al, 1962).

On an individual plant basis Hurd (1959) found that 86 to 94 % of the variation in herbage weight of Festuca idahoensis could be accounted for by combining measurements of maximum leaf height, basal area and number of flower stalks. Leaf height was the best single measure related to dry weight.

Reppert et al (1963) found that height, visual cover and height x cover were of little use in estimating absolute herbage mass, but a multiple regression of yield on height, visual cover and height x cover accounted for 84 % of the variation associated with mass. Plant weight x plant density gave a better relationship although estimations of herbage mass were several times higher than those from clipped plots.

Teare and Mott (1966) used leaf area index (LAI) and length of longest leaf stem portion of the plant as parameters for estimating herbage mass in situ. This was best estimated by the product LAI x height, but they concluded that a new rapid technique for estimating herbage mass in situ could only be developed when a satisfactory method for measuring herbage density was devised.

In their discussion of non-destructive methods for measuring herbage mass, Symons and Jones (1971) point out that attributes such as height and density of vegetation are not easily defined and are therefore subject to error and bias. Plant height, for example, is subject to wind and lodging and difficulties arise as to how it should be measured. Height methods are more accurate on swards of simple botanical composition and uniform density, especially if the sward is short. Because of the inherent nature of the grazing process it is difficult to achieve consistently short dense swards although continuously stocked swards come nearer to the ideal for a sward height by mass relationship. Nevertheless, a number of methods are in use for measuring herbage height, several of which are discussed here.

Methods of measuring herbage height

Herbage height and herbage density have been combined into a single estimate by measuring the resting height of a cardboard box (Shrivastava *et al*, 1969), cardboard square (Sullivan *et al*, 1956), or plywood square (Alexander *et al*, 1962) placed on the herbage. Alexander *et al* (1962) noted good correlations between the average height of opposite sides of the board and the weight of herbage dry matter under it. Estimates of herbage mass were readily obtained for uniform swards after determining a conversion factor, but this relationship was not suitable for swards varying in height or density.

Jagtenburg (1970) was among the first to use a simple mechanical instrument to measure herbage height. It consisted of a weighted disc which descended slowly onto the sward by means of a counterweight hung beside one of two pipes making up the shaft. The other pipe was scaled to read off sward height.

Castle (1976) has described and reviewed one disc instrument developed at the Hannah Research Institute and used regularly for a variety of measuring purposes in both grazing and cutting conditions. While the regression between herbage mass and herbage height explained 86 % of the variation, pooled regressions only explained 61.5 and 38.7 % of the total variation for a paddock and Wye College system of grazing respectively. This confirms that in general herbage mass can be estimated with more accuracy in cutting experiments which have uniform swards than on uneven swards such as post-grazing swards with their range from tall unconsumed herbage to short 'stubby' herbage. In New Zealand, experiments have been conducted with a similar weighted disc on grassland of homogenous composition to measure daily increments in herbage accumulation (Phillips and Clarke, 1971). While these discs are lowered onto the sward, others are designed to be dropped on to the sward from a predetermined height (Bransby et al, 1977; Vartha and Matches, 1977).

While there can be highly significant relationships between herbage mass and herbage height, marked differences in the regressions occur for different periods of the year (Phillips and Clarke, 1971; Powell, 1974; Castle, 1976; Vartha and Matches, 1977) and between grass species (Castle, 1976). Vartha and Matches (1977) obtained correlation coefficients between herbage mean bulk-height and herbage mass of 0.714, 0.822 and 0.709 for spring, summer and autumn growth. The herbage mass per cm of scale will depend on the sampling height at which herbage mass is cut for the calibration regression. A rough approximation of the results suggests that each cm on the vertical scale represents 160-174 kg DM ha^{-1} on a pure grass sward (Phillips and Clarke, 1971; Castle, 1976), and 230 kg DM ha^{-1} on a clover sward (Phillips and Clarke, 1971).

Whitney's (1974) apparatus for measuring sward height consisted of a fresnel lens attached to a PVC pipe sliding over a steel pipe. The lens was lowered onto the sward and then lifted until only the tips of most of the leaves touched it. Correlation coefficients of 0.97 were obtained between herbage height and mass, but the regression slope was different for the two grasses studied.

The Grassmeter developed at Massey and provided by the Milk Marketing Board (MMB, The Grassmeter: Notes for Users) consists of an aluminium metal plate which slides over a calibrated metal stem. Instead of being lowered onto the sward, the plate is held up by the grass beneath it as the foot of the instrument is lowered onto the ground, and the height of it above ground level can be read off on the graduated scale. The use of the pasture meter at North Wyke (North Wyke Working Paper 3/78) has shown that regressions differ between grass species and unconverted meter readings are only of value when comparing swards of comparable botanical composition. The pasture meter was found to be of little use on very tall herbage, especially where this was laid. An automated plate meter based on the Massey Grass Meter (Holmes, 1974) has been constructed at the Dairy Research Institute, Ellinbank, Australia. Grass height is recorded on a ratchet counter and up to 20 readings can be made per minute (McGowan and Earle, 1978). The meter readings correlate linearly with pasture yield, and the coefficient of variation of calibrations averaged 13 % on any one date and 18 % when a large number of calibrations from separate dates were pooled (Earle and McGowan, 1979). This meter was also found to be unsuitable for comparing the production of swards of contrasting botanical composition and for use where there is marked variability in composition within a sward.

Dann (1966) used a ruler to measure height in small quadrats in a Paspalum ditatatum and Trifolium repens pasture of uniform density. He obtained a correlation coefficient of 0.95 between sward height and herbage mass, but in a variable stand of Sorghum species this value was reduced to 0.71. He concluded that the use of this relationship is unlikely to be suitable for open swards or where botanical composition and density vary widely. A graduated metre rule is used at the Grassland Research Institute, Hurley, to measure the height of the sward in grazing trials (Hodgson et al, 1971). With this 'extended grass height' method, a rule is held upright in the sward with its base on the ground, and the average height of a small number of adjacent leaves are measured after extending them fully up the rule.

The simple mechanical instruments outlined above have several advantages over more complex measuring devices such as the capacitance meter: they are extremely simple in construction and can be duplicated easily and inexpensively; they do not suffer from calibration drift due to battery or temperature changes; they are mechanically robust and will not readily lose calibration owing to mechanical changes resulting from mild abuse; the wetness or electrical conductivity of the pasture is unlikely to have any effect on the indicated mass; the method is quick and minimal training is required.

Conclusion

The smaller the expected differences between treatments, the less reliance should be placed on non-destructive techniques for measuring herbage mass. But although these methods may not be as accurate as cutting on a per sample basis, they frequently offer the possibility of a net increase in precision because of a large increase in sample size. They also obviate the cutting height problems which occur with all cutting methods.

To convert measurements of herbage height into actual herbage mass, calibration tests must be carried out. Several authors point out that these techniques are not always quicker or less tedious than cutting techniques, but for comparative purposes they can be truly non-destructive. Best results are obtained on monospecific swards of uniform density when the height of the sward is not too variable.

Although high accuracy cannot always be claimed for the simple mechanical height-measuring instruments outlined in this review, they are of great use in many instances where non-destructive assessment of herbage mass is required. They are capable of detecting relatively small differences in pasture growth and are a better guide in determining mass in cutting or grazing trials than visual estimation.

EXPERIMENTAL

EXPERIMENT 1 An investigation into the effect of stocking rate in the early part of the grazing season on herbage production and utilisation

Introduction

Any treatment affecting one phase of the growth cycle may indirectly affect subsequent phases to some extent. Experiments with grazing dairy cattle have shown the importance of spring and early summer grazing management to ensure the growth and survival of pasture species and their effect on changes in botanical composition and ultimately on total herbage yields (see Review, Section I).

A recent trial (Leaver, 1978, unpublished) emphasized the importance of the stocking rate in early season in a continuously stocked grazing system. The initial stocking rate of 5.6 cows ha^{-1} was not great enough to produce the dense type of sward necessary for continuous stocking and some aerial tillering occurred. At the same time silage trials highlighted the reduced yields which occur when aiming for high quality (Moisey and Leaver, 1979) and the advantage of increasing the stocking rate of grazing cows in spring to release hectares for conservation.

Present knowledge is limited on the growth and utilisation of herbage under grazing conditions, and it is essential to have this information if more efficient grazing systems are to be developed. Stocking rate in the early grazing season would appear to be an important factor determining grassland output and utilisation, and is examined in this experiment using continuously stocked late-winter calving cows. Three groups of cows were maintained at different stocking rates for the first third of the grazing season and detailed measurements made of grass production, utilisation and sward density. Records were also kept of the milk yield and composition, bodyweight change and concentrate input of the cows.

Experimental materials and methods

Animals

Sixty British Friesian cows were allocated to the experiment which ran from May to October 1979. Their calving dates ranged from 19 December 1978, to 15 April 1979; their average lactation number was 2 (range 1-6); average milk yield 28.8 kg day^{-1} (20-41.6 kg day^{-1}); average bodyweight 568 kg (465-725 kg) and average condition score 2¼ (¾-3¼).

Field layout

The grazing area was split into a day field and a night field in the ratio of approximately 60:40. Both fields were sown in 1977. A perennial ryegrass (Lolium perenne) ley, variety Perma of 6.06 hectares was used for the day field, and 4.73 hectares of a perennial ryegrass (Lolium perenne), Italian ryegrass (Lolium multiflorum), timothy (Phleum pratense) and white clover (Trifolium repens) ley were used for the night field. Each of these fields was then divided into three equal areas and the treatment groups assigned to these at random.

Treatments

The grazing season was split into three 7-week periods: Period I, 10 May to 28 June; Period II, 28 June to 16 August; Period III, 16 August to 4 October.

The treatments consisted of three stocking rates in Period I, and thereafter stocking rates were identical for all three treatments as shown in Table E1.1.

Table E1.1 Experiment 1 design

	Stocking rate (cows ha^{-1})		
		Treatment	
Period	L	M	H
I	4.7	5.6	6.4
II	4.2	4.2	4.2
III	3.1	3.1	3.1

In Period I there were 17, 20 and 23 cows on Treatment L, M and H respectively, with 15 and 11 cows on each treatment in Period II and Period III respectively. The 33 cows used in Period III were 'marker cows' and these were used for detailed animal measurements. They consisted of 9 heifers and 24 cows and were divided into three balanced groups on the basis of lactation number, milk yield, live weight and body condition (Appendix Table 1). The remaining 27 cows (Appendix Table 2) were allocated in such a way that treatment groups were balanced for the above parameters.

The experiment commenced on 10 May when the cows were allowed day and night grazing in the experimental fields, and ended on 4 October.

Management

Total fertilizer application over the grazing season was 395 kg ha^{-1} N; 65 kg ha^{-1} P_2O_5 and 55 kg ha^{-1} K_2O, applied as an inital nitrogen dressing in April of 110 kg ha^{-1} followed by four equal dressings of compound fertilizer in May, June, July and August.

Supplementary feeding was offered at the same level to all three groups of cows. The rate was calculated each week and based on the grass height and milk yield of Treatment M. This scale of feeding was devised from the milk yield responses in a recent trial at the

West of Scotland Agricultural College, Crichton Royal Farm, Dumfries (Leaver 1978, unpublished), (see Appendix Table 3). Up to 5 kg of concentrates per cow per day were fed during milking, and when grass growth and milk yield necessitated feeding above this level, the required amount was given on a group basis in a feeding passage after afternoon milking.

Cows were milked at 6.00 am and 2.30 pm and returned to the appropriate field at 7.30 am and 4.00 pm respectively. Water was freely available in the field.

Sward measurements

Herbage height: Herbage height was measured weekly using a simple disc instrument similar to that described by Castle (1976). On each occasion 30 height measurements were taken in each of the three treatment areas in the day field, and 20 in each treatment area in the night field. Measurements were taken at 30-pace intervals in a W pattern across each treatment area and used to calculate a weekly mean height for each treatment in both fields.

On three occasions during the growing season a record was made of the number of times, (expressed as a percentage), these measurements occurred on herbage immediately adjacent to a dung pat, and whether or not this herbage had been grazed.

Chemical composition: Chemical analysis was carried out weekly on herbage samples of approximately 1 kg fresh weight from each of the treatment areas in the day and night fields. These were collected by hand-plucking to prevent contamination with litter, soil and dung.

The fresh samples were dried overnight at 100^{o}C in a forced draught oven, ground through a 0.6 mm screen and analysed for dry matter (g kg^{-1}), crude protein (g kg^{-1} DM), organic matter (gm kg^{-1} DM), in vitro digestibility (%), metabolisable energy content (MJ kg^{-1} DM) and mineral content (g kg^{-1} DM). Techniques for chemical analysis were those in general use at the Analytical Services Unit, West of Scotland Agricultural College, Auchincruive (R.Alexander, personal communication).

Herbage growth and accumulation: Herbage growth on each treatment was measured over a fortnightly period using areas of 5 m x 5 m protected from the cattle by an electric fence (Plate 1). Twenty height measurements were made within each square when it was set up, and another twenty measurements taken a fortnight later before moving the square to another area of the sward. Growth was calculated as the difference between the means of the two sets of measurements, and summed over time to give an estimation of growth over the grazing season.

A height/weight relationship was established with the grass disc - every fortnight a range of grass heights at ten selected locations were clipped to 1 cm above ground level from an area of 0.07 m^2 under the disc; cutting to 1 cm corresponded to the zero reading on the disc instrument. All samples were weighed fresh, dried at 100^{o}C for 24 hr and reweighed. Regressions were obtained relating herbage height and dry matter (DM) yield for both fields in each period of the grazing season.

Using the estimations of growth and regressions relating herbage height

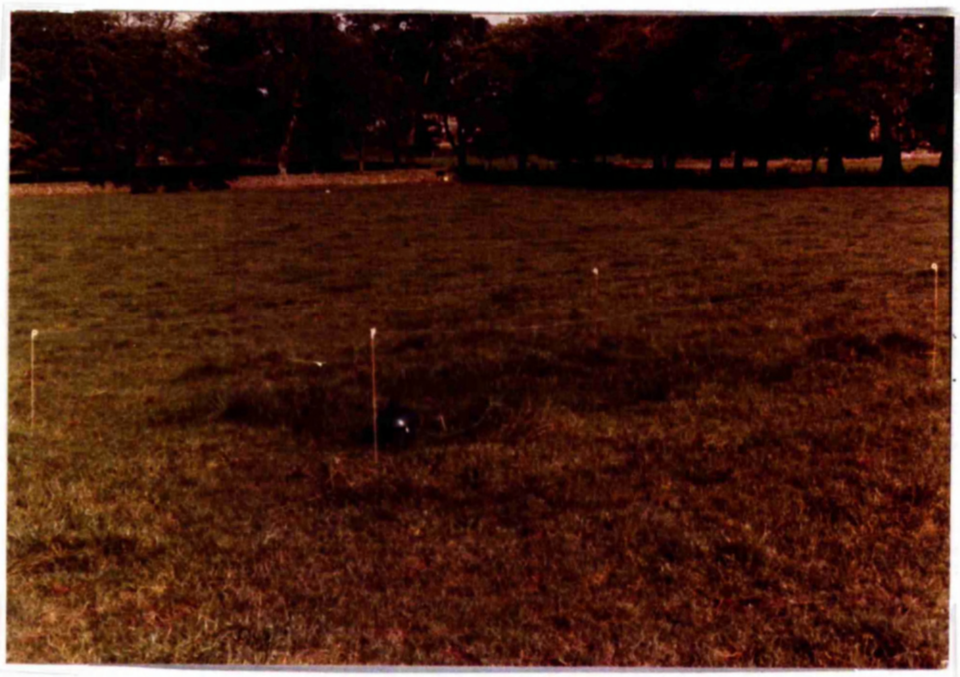


Plate 1 Protected area used to estimate herbage growth.

to yield outlined above, an estimation of herbage production over the grazing season was derived for each of the experimental treatments.

Sward density: Tiller counts were made every month as a quantitative measure of sward density on each treatment in both fields. Tillers were cut *in situ* at ground level from inside a metal ring (0.02 m^2) using a pair of scissors. Ten samples were taken at random from each treatment in the day field and seven from each treatment in the night field. Samples were taken to a field laboratory for separation into the following categories:

Live tillers - tillers where 50 % or more of leaf and sheath components were green.

Dead tillers - tillers where 80 % or more of leaf and sheath components were brown. (Tillers with 20-50 % green components were dissected, and classified according to the presence or absence of a green growing point).

Litter - all detached dead vegetable matter.

A separate count was made of live and dead tillers, and samples separated into the above three categories were then bulked together for each treatment in the day and night fields. These bulked samples were weighed, dried at 100°C for 12-24 hr and reweighed. Aerial tillers were observed in some samples from August onwards and a separate count of these was made in the October sampling.

Frequency of defoliation: A study was made of the defoliation frequency of individual tillers within a sward using a similar technique to that of Hodgson and Ollerenshaw (1969).

During each period in the grazing season, ten tillers were identified along each of five linear transects sited at random within each treatment area, giving a total of fifty marked tillers. The transects were fixed by means of white wooden pegs driven into the ground 2.5 m apart. A pole marked at ten regular intervals was laid between the pegs, during identification only, and a single tiller close to each mark on the pole was identified by means of a short length of coloured plastic-coated wire which was twisted round its base (see Plate 2 and Plate 3). In Period I a variety of coloured wires was used but because of the difficulty of finding tillers with green, brown or black wires, only orange, yellow, blue, turquoise and blue and white striped wires were used in Periods II and III. The tillers within each transect were marked with the same coloured wire, a different colour being used for each of the five transects within each treatment area.

Records were taken three times a week for two weeks between 20 June–4 July (Period I), 2–16 August (Period II) and 10–24 September (Period III). Each tiller was recorded as either grazed or ungrazed and by splitting the end of each leaf with a pin it was possible to tell if a tiller had been defoliated between observations. Losses of marked tillers were noted, but when an originally identified tiller could not subsequently be found, replacement tillers were not chosen.

Animal measurements

Milk yields (kg day^{-1}) of the 33 'marker' cows were recorded weekly. At the same time a sample was taken from each for chemical analysis of fat (%), protein (%) and lactose (%) from which total solids (%) and solids not fat (%) were calculated.

Cows were weighed each week and their liveweight change (kg cow^{-1} day^{-1}) calculated.

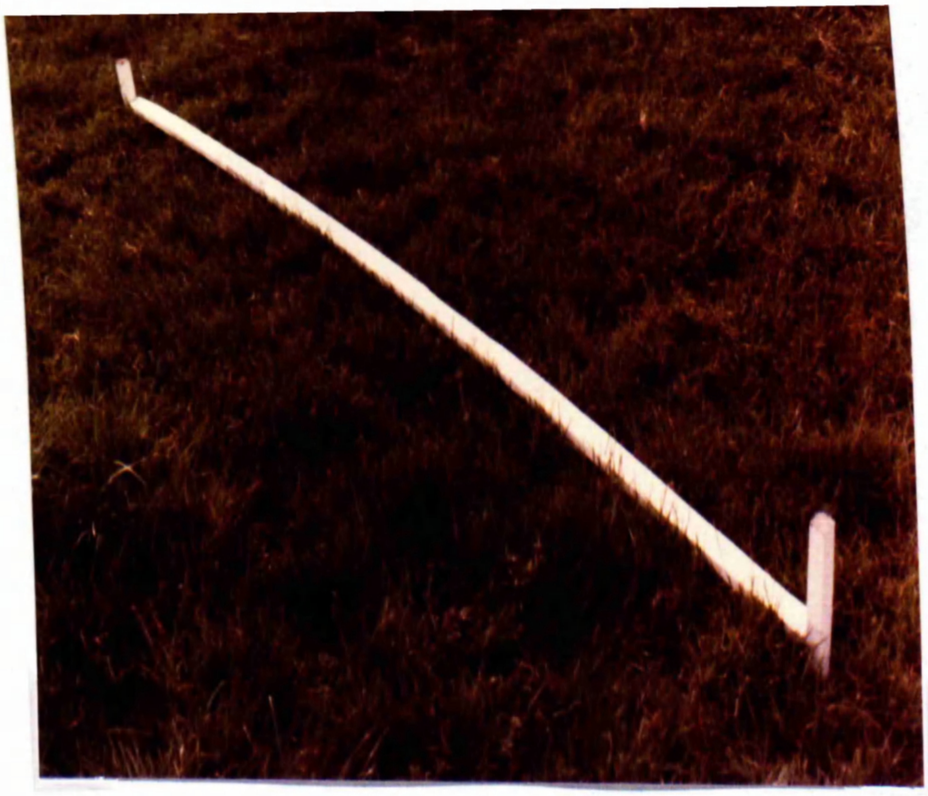


Plate 2 Apparatus used to establish transects of marked tillers in a study of defoliation frequency.

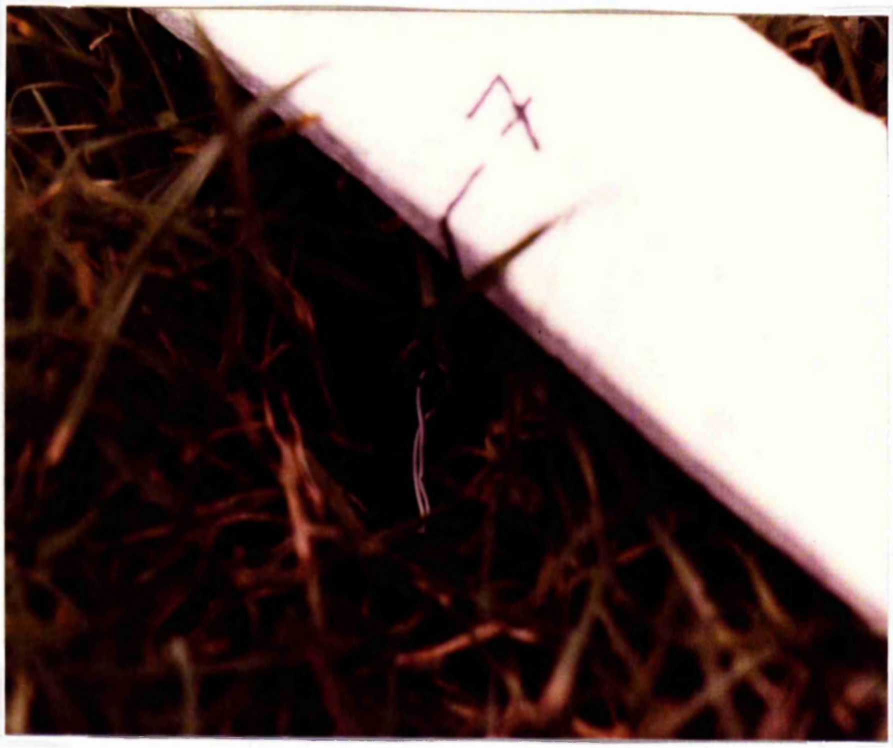


Plate 3 A marked tiller.

Statistical analysis

Sward parameters were analysed as a factorial design treating periods, fields and treatments as factors. Animal parameters were analysed similarly treating periods and treatments only as factors because it was impossible to separate the effects of the different fields on their performance.

The statistical significance of the factors on the parameters as determined by F-test is shown by asterisks accompanying the appropriate SED values in the tables (*, $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$), or NS in the case of non-significance. Tests of significance of the difference between individual mean values were carried out by t-test and are referred to in the text.

RESULTS

The objectives of the trial were to examine sward parameters in relation to grazing management. The animal parameters were therefore used only for estimates of herbage production and utilisation.

Results from sward parameters are presented separately for the day field and the night field because a highly significant difference was often revealed between fields.

Weather

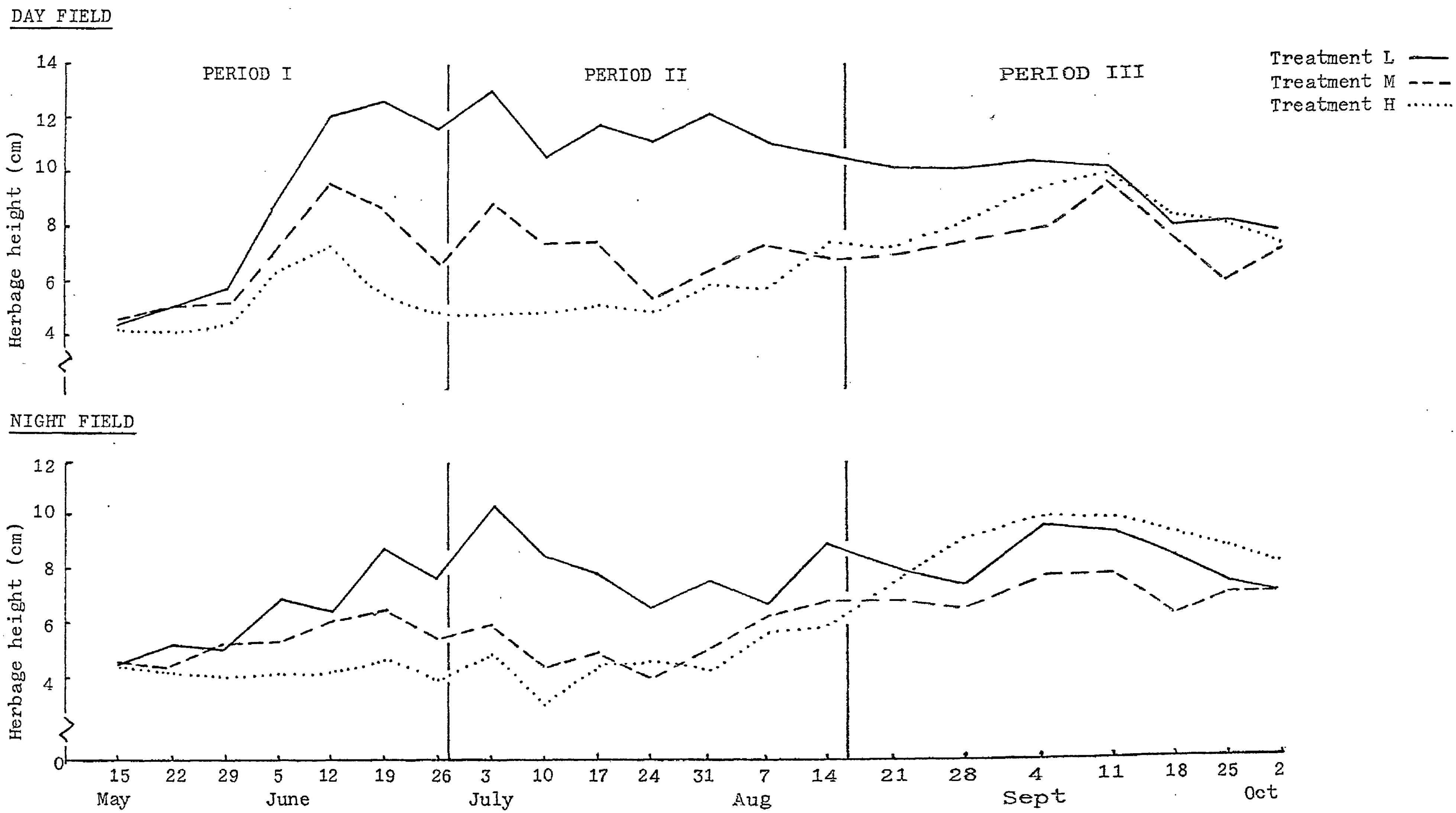
Comparative records of mean rainfall, mean daily temperature and total hours of sunshine for each month of the grazing system relative to 1978 and to a 30-year mean are presented in Appendix Table 4. Seasonal rainfall was similar to the long-term total although the distribution between months differed. Only 63 % of normal precipitation was recorded from May to July although August and October were much wetter. The 1979 season was cooler than the norm, otherwise the mean daily temperature pattern was typical of the long-term trend.

Herbage height

Weekly mean herbage heights over the grazing season are presented graphically in Figure E1.1. Table E1.2 summarizes the main effects of treatment, period and field on mean herbage height.

The pattern of herbage height was similar for both the day and the night field but values were significantly lower ($P < 0.001$) on the night field. Mean herbage height increased over the grazing season; values were significantly higher ($P < 0.01$) in Period II than Period I, and in Period III than in Period II ($P < 0.001$). Herbage height was inversely related to the stocking rate in Period I and this trend

Fig E1.1 Weekly mean herbage height



continued through Period II although by Period III differences between treatments were less marked. The difference in herbage height between Treatment L and Treatments M and H was greater from mid-June to mid-August and remained consistently so on the day field although the differences decreased with time on the night field (see Fig E1.1). Taking the grazing season as a whole, mean herbage height was significantly greater ($P < 0.001$) on Treatment L than on Treatments M and H but the difference between Treatment M and Treatment H was not significant.

Table E1.2 Main effects on mean herbage height (cm)

Treatment	L	M	H	SE of difference	Significance
	8.7	6.5	6.2	± 0.299	***
Period	I	II	III		
	6.1	7.0	8.2	± 0.299	***
Field	Day	Night			
	7.7	6.5		± 0.244	***

The analysis of variance (Appendix Table 5) also revealed interactions of field x period ($P < 0.05$), field x treatment ($P < 0.01$) and period x treatment ($P < 0.001$) to be significant.

Calculated standard deviations gave a measure of the variation of the estimated mean herbage heights (Table E1.3). The analysis of variance (Appendix Table 5) showed the differences in this variation between periods and treatments to be highly significant ($P < 0.001$), but the differences between fields was not significant reflecting similar levels of variation. In Period I, as the stocking rate increased, variation in sward height decreased. This trend continued through Period II but by Period III differences between treatments

Table E1.3 Mean herbage heights (cm), standard deviations and coefficients of variation (%)

FIELD	PERIOD	TREATMENT											
		L			M			H					
		Mean herbage ht	SD	CV	Mean herbage ht	SD	CV	Mean herbage ht	SD	CV	Period	Mean	
	I	8.6	2.74	31.4	6.6	2.23	32.6	5.2	1.66	33.1	6.8	2.21	32.4
Day	II	11.5	5.75	50.1	7.1	3.74	52.6	5.5	2.52	45.6	8.0	4.00	49.4
	III	9.3	4.35	47.4	7.5	4.05	54.0	8.4	4.07	49.3	8.4	4.16	50.2
Treatment mean		9.8	4.28	43.0	7.1	3.34	46.4	6.4	2.75	42.7			
	I	6.4	2.93	43.4	5.4	2.73	49.0	4.3	1.77	41.4	5.4	2.48	44.6
Night	II	8.1	5.64	69.6	5.4	3.66	67.9	4.7	2.73	56.7	6.1	4.01	64.7
	III	8.1	4.66	57.3	7.0	4.11	58.4	8.9	4.49	50.9	8.0	4.42	55.5
Treatment mean		7.5	4.41	56.8	5.9	3.50	58.4	6.0	3.00	49.7			

were less marked.

Table E1.3 also expresses this variation as coefficients of variation. Differences were significant between fields($P < 0.001$) as well as between treatments ($P < 0.05$) and periods ($P < 0.001$).

On three separate occasions at the end of each period, the percentage of height measurements which occurred on herbage rejected by the cows was calculated.

Table E1.4 Percentage of weekly height measurements which occurred on rejected herbage

Field	Date	Treatment L	M	H
		4.7	5.6	6.4
Day	3 July	13	3	0
	28 August	17	10	7
	2 October	10	3	10
Night	3 July	20	15	0
	28 August	5	5	10
	2 October	10	15	10

At the end of Period I, the number of measurements taken on rejected herbage was inversely related to the stocking rate in both fields ie. as the stocking rate increased the amount of rejected pasture decreased. This trend continued on the day field at the second observation when treatments were identical at 4.2 cows ha^{-1}, but not on the night field. At the last observation with identical stocking rates of 3.1 cows ha^{-1}, the amount of herbage rejected was similar on all treatment areas except Treatment M on the day field.

Over the grazing season as a whole, the percentage of measurements occurring on rejected herbage rose and then fell on the day field, but fell and then rose on the night field. The amount of rejected herbage was generally greater on the night field.

Chemical composition of herbage

The main effects of treatment, period and field on the components of chemical composition examined, are presented in Table E1.5 .

Dry matter (DM), expressed as g per kg of fresh sample, rose from an average of 140.3 g for all treatments when the experiment commenced to a peak of 224.0 g in mid-July, and then fell in Period III to similar levels as in Period I. The mean DM content was significantly higher ($P < 0.001$) in Period II than in Periods I and III, and the difference between Periods I and III was not significant. Treatment effects were not significant but lower DM values ($P < 0.01$) were recorded for the night field.

Herbage organic matter (OM), expressed as g per kg of dry matter, decreased as stocking rate increased in Period I and this inverse relationship was apparent throughout the grazing season. However the OM content of herbage on Treatment L ($P < 0.001$) and Treatment M ($P < 0.05$) was significantly higher than Treatment H, but the difference between Treatments L and M was not significant. The OM content rose from an average of 899 g for all treatments in May to a peak of 913 g before falling to an average value of 887 g when the experiment ended in October. Each change in OM content from Period I to III was highly significant ($P < 0.001$). Herbage from the night field had a lower OM content ($P < 0.001$) than that from the day field.

Figures E1.2 and E1.3 show the seasonal variation in herbage quality expressed as the crude protein content of the herbage and

Table E1.5 Main effects on the mean components of herbage chemical composition

Treatment	L	M	H	SE of difference	Significance
Dry matter (g kg^{-1})	165.31	162.79	157.07	± 4.791	NS
Organic matter (g kg^{-1} DM)	900.14	896.36	890.64	± 2.277	***
Crude protein (g kg^{-1} DM)	229.00	235.43	249.21	± 6.521	**
D-value	66.67	67.12	67.90	± 0.569	NS
Metabolisable energy (MJ kg^{-1} DM)	11.17	11.28	11.47	± 0.135	NS
Calcium content (g kg^{-1} DM)	4.79	4.86	4.78	± 0.113	NS
Phosphorus content (g kg^{-1} DM)	4.38	4.37	4.72	± 0.100	***
Magnesium content (g kg^{-1} DM)	2.39	2.44	2.52	± 0.062	NS
Potassium content (g kg^{-1} DM)	34.35	35.04	37.52	± 0.728	***

Period	I	II	III	SE of difference	Significance
Dry matter (g kg^{-1})	150.86	184.29	150.02	± 4.791	***
Organic matter (g kg^{-1} DM)	895.79	905.74	885.62	± 2.277	***
Crude protein (g kg^{-1} DM)	264.79	210.02	238.83	± 6.521	***
D-value	70.99	66.23	64.47	± 0.569	***
Metabolisable energy (MJ kg^{-1} DM)	12.10	11.12	10.71	± 0.135	***
Calcium content (g kg^{-1} DM)	4.86	4.54	5.03	± 0.113	***
Phosphorus content (g kg^{-1} DM)	4.68	3.79	5.00	± 0.100	***
Magnesium content (g kg^{-1} DM)	2.47	2.35	2.53	± 0.062	*
Potassium content (g kg^{-1} DM)	36.95	31.44	38.52	± 0.728	***

Field	Day	Night	SE of difference	Significance
Dry matter (g kg^{-1})	168.10	155.35	± 3.912	***
Organic matter (g kg^{-1} DM)	905.19	886.24	± 1.859	***
Crude protein (g kg^{-1} DM)	227.14	248.62	± 5.324	***
D-value	67.42	67.05	± 0.465	NS
Metabolisable energy (MJ kg^{-1} DM)	11.35	11.26	± 0.110	NS
Calcium content (g kg^{-1} DM)	4.77	4.85	± 0.093	NS
Phosphorus content (g kg^{-1} DM)	4.27	4.71	± 0.082	***
Magnesium content (g kg^{-1} DM)	2.78	2.12	± 0.050	***
Potassium content (g kg^{-1} DM)	32.03	39.24	± 0.595	***

its D-value. Treatment and period means for each field are presented in Table E1.6. The crude protein (CP) content of herbage dry matter on Treatment H was significantly higher than that on Treatment L ($P < 0.01$) whereas Treatment M was in an intermediate position and only differed significantly ($P < 0.05$) from Treatment H. Crude protein content fell from high values in Period I to their lowest at the beginning of Period II, before rising again in Period III (see Fig E1.2). Differences between periods were highly significant ($P < 0.001$). Herbage from the night field had a higher crude protein content ($P < 0.001$) than that from the day field. Although the overall pattern of crude protein content was similar for both fields, the difference between treatments was more marked on the day field (see Fig E1.2).

The mean D-value of the herbage, ie percentage of digestible organic matter in herbage dry matter, was determined by the <u>in vitro</u> technique of Alexander and McGowan (1966). The D-value of the herbage decreased progressively over the season (Fig E1.3) and each decrease was significant ($P < 0.01$). Although the F-value for treatments was not significant (see Table E1.6), herbage D-value was significantly higher ($P < 0.05$) on Treatment H than on Treatment L.

The difference between fields was small and not significant. The interaction of treatment and field was significant ($P < 0.05$) (Appendix Table 6) despite the non-significance of the main effects.

The metabolisable energy content (ME) of the herbage was derived from the D-value using the following equation:

$$\text{ME (MJ kg}^{-1}\text{ DM)} = 0.235\,D - 4.45 \qquad \text{... Eqn E1.1}$$

Fig E1.2 The change in crude protein (CP) content of herbage dry matter over the grazing season

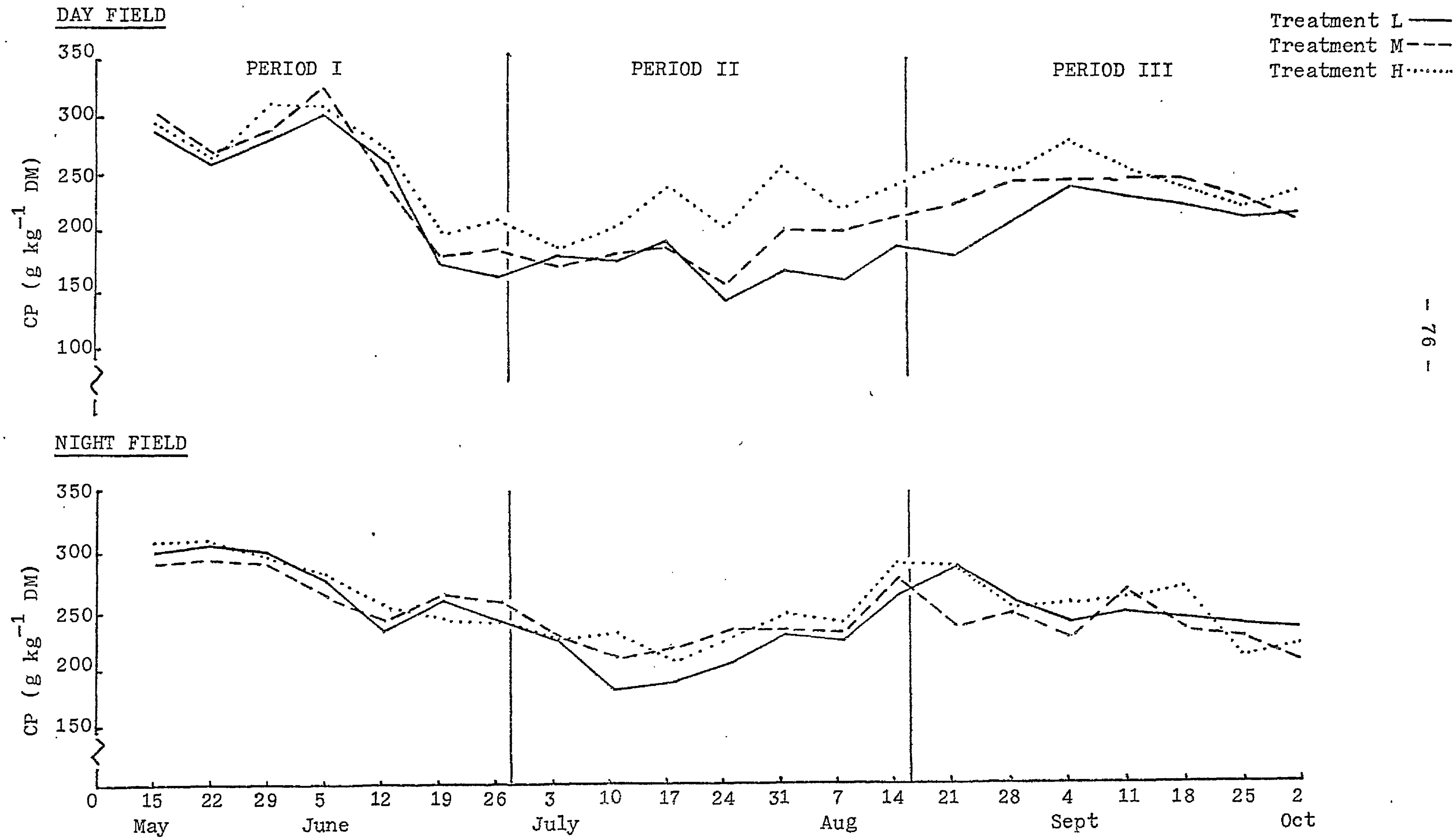


Fig E1.3 The change in herbage D-value over the grazing season

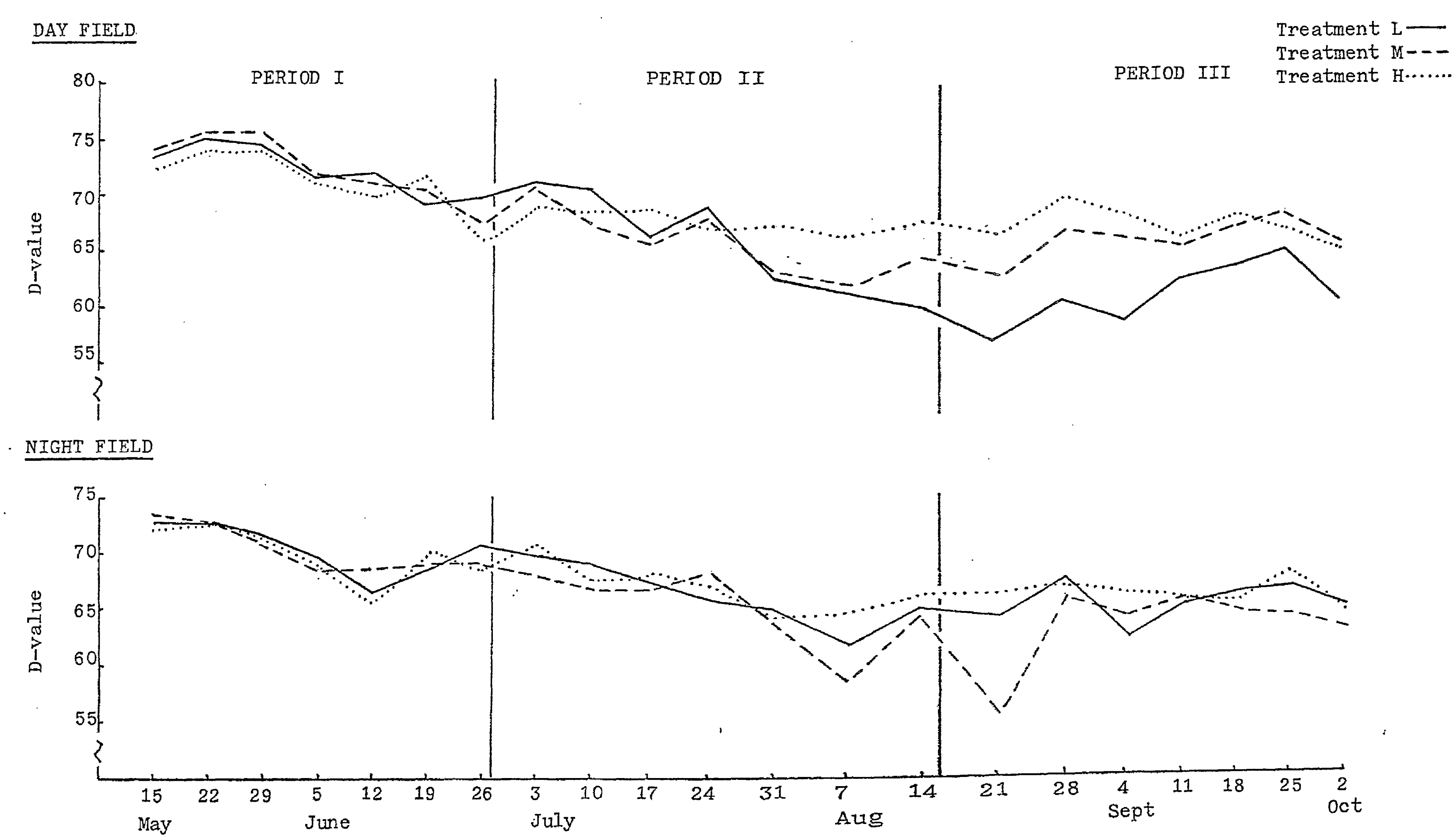


Table E1.6 Mean herbage D-value and crude protein (CP) content (g kg^{-1} DM)

Field	Period	TREATMENT L		M		H		Period mean	
		D-value	CP	D-value	CP	D-value	CP	D-value	CP
Day	I	72.0	246.9	72.2	256.6	71.0	265.1	71.8	256.2
	II	65.7	170.3	65.8	186.3	67.5	220.4	66.3	192.3
	III	60.4	216.3	65.6	234.9	66.6	247.6	64.2	232.9
	Treatment mean	66.0	211.1	67.9	225.9	68.4	244.4		
Night	I	70.4	273.9	70.4	271.3	69.9	275.0	70.2	273.4
	II	66.3	216.1	65.4	231.6	66.7	235.4	66.1	227.7
	III	65.3	250.6	63.2	232.0	65.8	251.7	64.8	244.8
	Treatment mean	67.3	246.9	66.4	245.0	67.5	254.0		

Thus the main effects of treatment, period and field were similar to the D-value (Table E1.5). The ME content declined significantly ($P < 0.01$) over the grazing season, and was higher ($P < 0.05$) on Treatment H than on Treatment L although the F-value for treatment effect was not significant. Field effect was not significant but the treatment x field interaction was ($P < 0.05$).

Herbage samples were analysed for their content of calcium (Ca), phosphorus (P), magnesium (Mg) and potassium (K) expressed as g per kg of dry matter. Herbage on Treatment H had a significantly higher ($P < 0.001$) K and P content than Treatments L and M but differences between treatments were not significant for Ca and Mg content. The mineral content of the herbage fell between Period I and Period II and then rose to maximal values in Period III. These changes were significant for Ca ($P < 0.01$), P ($P < 0.001$), Mg ($P < 0.05$) and K ($P < 0.001$). The Ca content of the herbage was similar in both fields, but the Mg content was lower ($P < 0.001$) and the K and P content higher ($P < 0.001$) in herbage from the night field.

Herbage production

Herbage growth in protected areas: Cumulative increases in herbage height as measured each fortnight within the protected areas of the sward, are shown in Table E1.7 . These gave an indication of herbage growth which declined on all treatments as the grazing season progressed.

Total herbage growth over the grazing season was greater on the night field than on the day field for Treatment L and Treatment M but not for Treatment H because of the lower values recorded in Period II and Period III.

Table E1.7 Cumulative increases in herbage height (cm) within protected areas

Field	Period	Treatment L	M	H
Day	I	35.8	34.1	35.7
	II	27.8	24.5	32.3
	III	13.9	12.1	19.1
	TOTAL	77.5	70.7	87.1
Night	I	45.0	44.1	39.1
	II	29.7	25.9	26.7
	III	15.2	20.0	19.0
	TOTAL	89.9	90.0	84.8

Relationship between herbage height and herbage mass: The relationship between herbage height and herbage mass (defined as the total weight of herbage per unit area of ground) for each field was established on three occasions in each period of the grazing season. The range of heights selected included some of 15-20 cm. These were excluded from the analysis as they were not representative of the mean height of the grazing swards at any time. Results in each period were plotted and regression analyses were carried out on the data (Appendix Table 8). Two types of equations were derived;

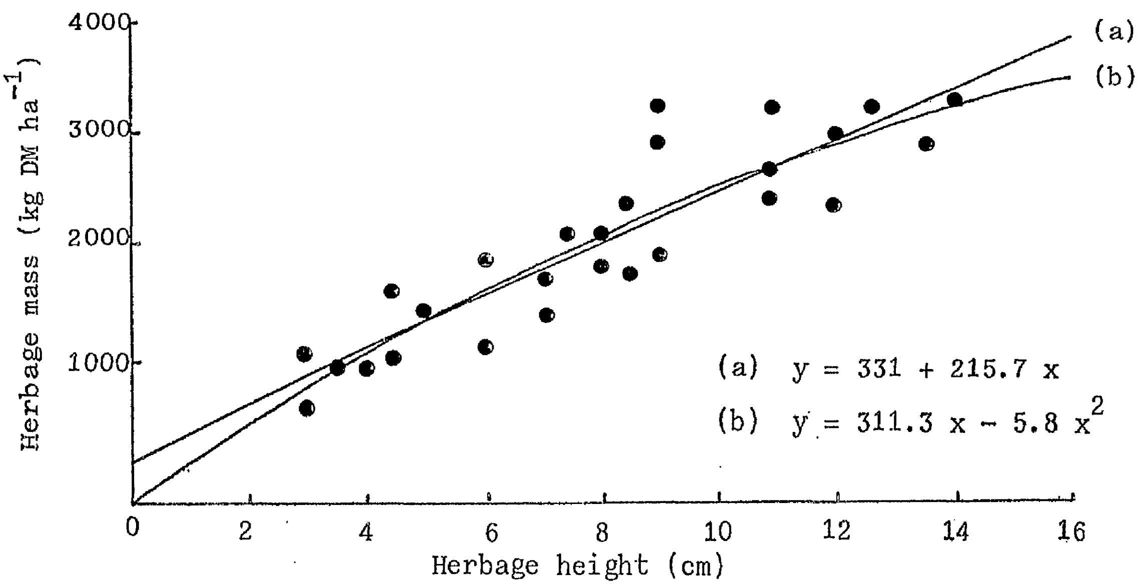
(a) 'best fit' linear regressions, which represented the simplest type of relationship, and

(b) quadratic regressions through the origin which represented the most logical relationship, as the samples were clipped to 0 cm height (see Figs E1.4 - E1.6).

Correlation coefficients and the coefficients of both regressions of herbage mass on herbage height are given in Table E1.8. The results show that in each period there were highly significant relationships ($P < 0.001$) between herbage mass and herbage height. The percentage of variation

Fig E1.4 The relationship between herbage mass and herbage height in Period I

DAY FIELD



NIGHT FIELD

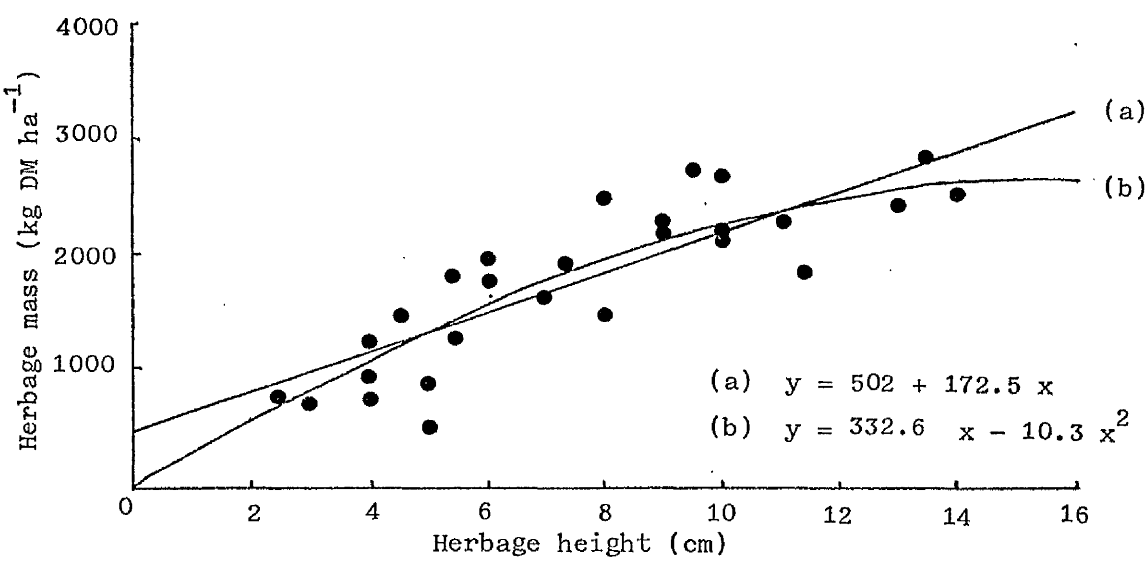
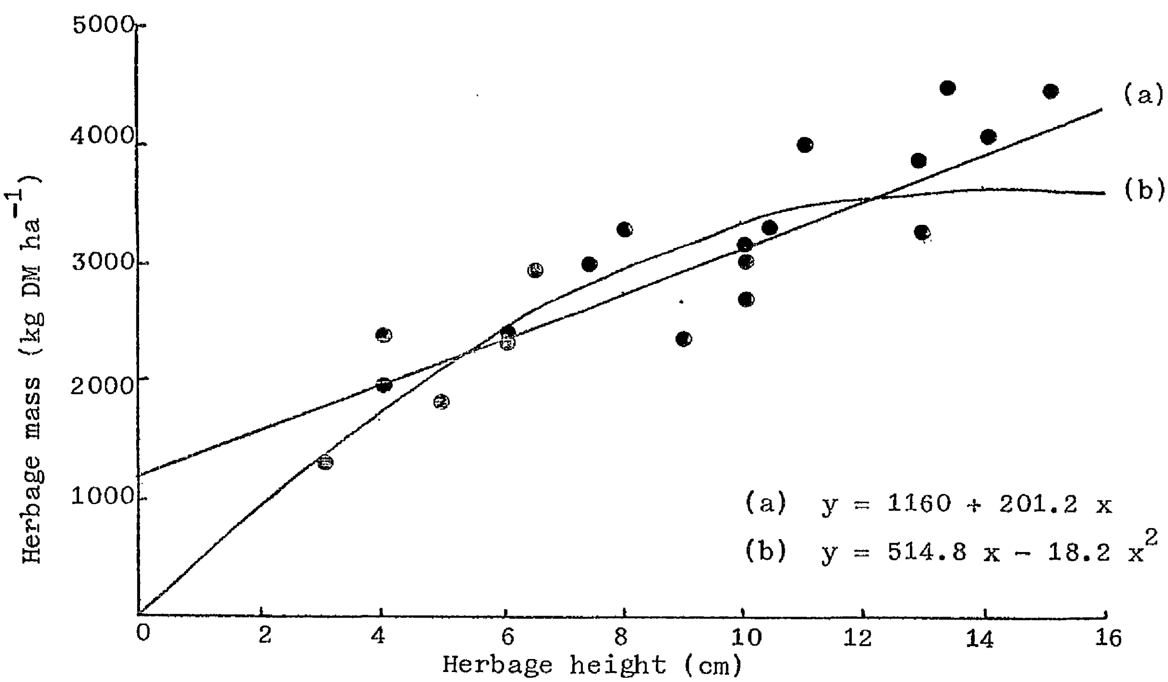


Fig E1.5 The relationship between herbage mass and herbage height in Period II

DAY FIELD



NIGHT FIELD

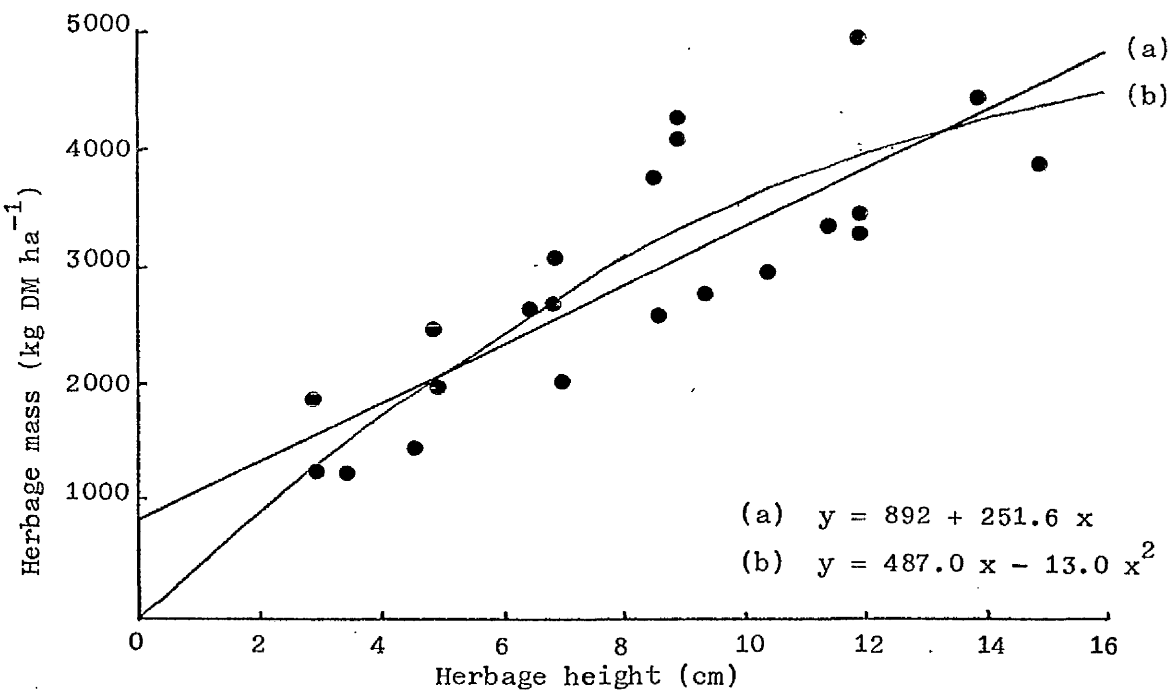


Fig E1.6 The relationship between herbage mass and herbage height in Period III

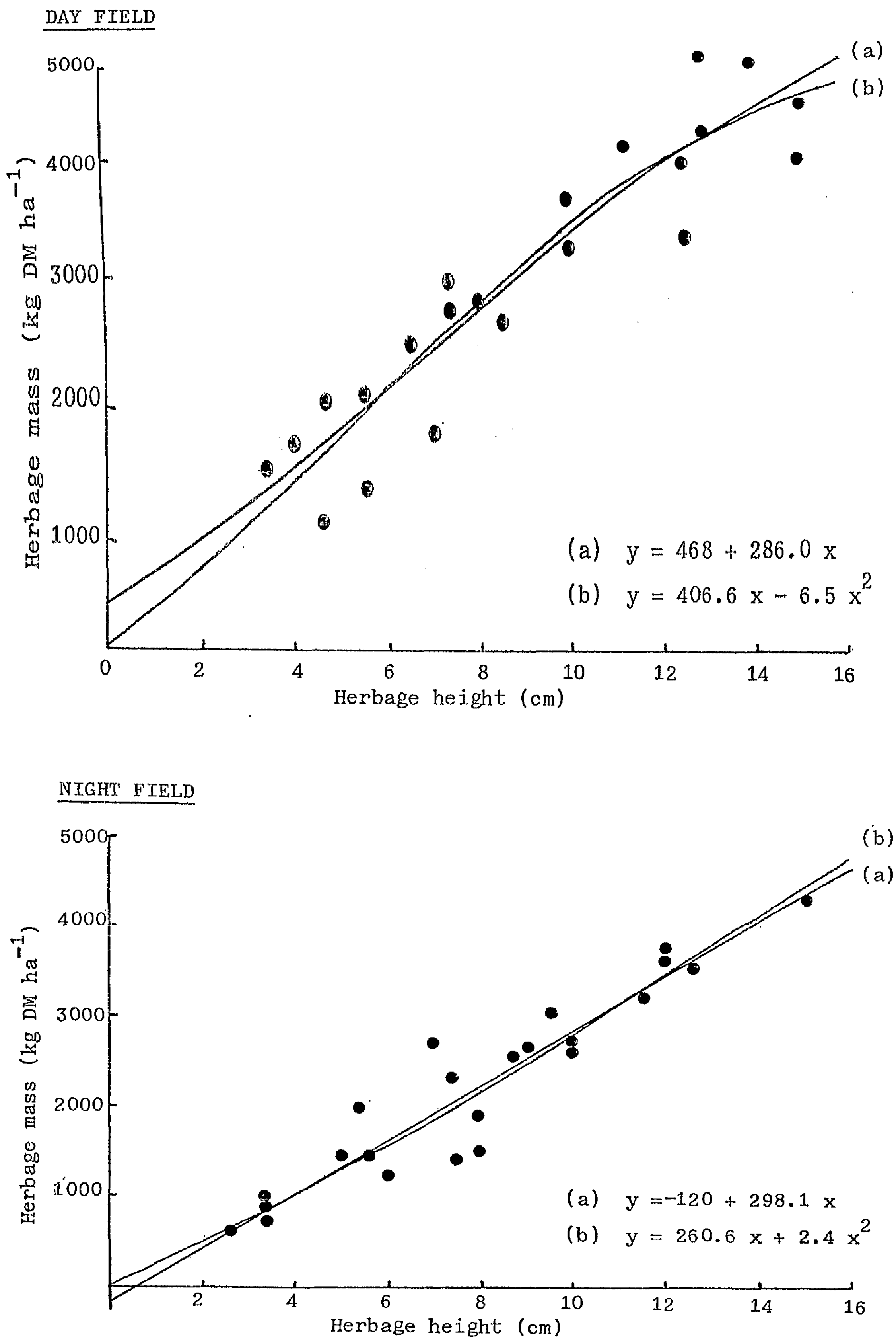


Table E1.8 The relationship between herbage mass (kg DM ha^{-1}) and herbage height (cm)

Field	Period	No of observations	Coefficients of regression equation			SE of estimate (±)
			Constant (± SE)	Linear (± SE)	Quadratic (± SE)	
	I	27	331 (204.2)	215.7 (23.50)	0	392.4
			0	311.3 (33.82)	-5.8 (3.17)	387.3
Day	II	20	1160 (246.0)	201.2 (26.80)	0	399.3
			0	514.8 (41.78	-18.2 (3.79)	394.7
	III	22	468 (261.7)	286.0 (26.88)	0	461.0
			0	406.6 (39.47)	-6.5 (3.28)	453.7
	I	27	502 (193.5)	172.5 (23.36)	0	391.1
			0	332.6 (30.13)	-10.3 (2.87)	357.6
Night	II	22	892 (323.9)	251.6 (34.39)	0	589.4
			0	487.0 (47.73)	-13.0 (4.03)	561.7
	III	23	-120 (206.2)	298.1 (23.99)	0	374.0
			0	260.6 (33.53)	2.4 (3.13)	372.0

r^2 = the percentage of variation explained by the regression explained by the quadratic regressions was always higher than for the linear regressions, however the quadratic regression produced from data from the day field in Period I and III and from the night field in Period III gave non-significant quadratic coefficients. The standard error (SE) of the estimates ranged from 357.6 to 589.4 kg DM ha^{-1}.

Herbage accumulation: The initial mean herbage height within the protected area on each treatment was converted to a measure of herbage mass using the linear and quadratic relationships in Table E1.8 . Similarly, the final mean herbage height after a fortnight was expressed as herbage mass. The difference between the two values gave an estimate of net herbage accumulation on each treatment area. This procedure was carried out every fortnight using the appropriate period equations, and the results were summed to give an estimate of herbage accumulation in each period, and total herbage accumulation over the grazing season for each treatment (Table E1.9).

Use of the linear regression gave higher values for net herbage accumulation than the quadratic regression. It also gave similar values across treatments whereas the quadratic regression gave much lower values on Treatment L than on Treatments M and H. With both regressions net herbage accumulation was greater on the night field than on the day field for Treatments L and M but not for Treatment H.

Herbage utilisation

Herbage utilisation was estimated in two ways. Firstly it was derived from pasture measurements and secondly pasture utilisation was calculated from animal performance.

(a) From pasture measurements: The estimation of herbage

Table E1.9 Period and total net herbage accumulation (kg DM ha^{-1})

Field	Period	Regression equation used	Treatment L	Treatment M	Treatment H
Day	I	Linear	7391	7197	7550
		Quadratic	6038	5939	6728
	II	Linear	6005	5197	6599
		Quadratic	-507	2908	5265
	III	Linear	2611	2853	4054
		Quadratic	2628	3021	3978
	TOTAL	Linear	16007	15247	18203
		Quadratic	8159	11868	15971
Night	I	Linear	7534	7415	6490
		Quadratic	2961	4147	4162
	II	Linear	7331	6344	6535
		Quadratic	4417	5268	6436
	III	Linear	3763	4955	4110
		Quadratic	3992	5259	4317
	TOTAL	Linear	18628	18714	17135
		Quadratic	11370	14674	14915
Weighted mean of both fields	TOTAL	Linear	17055	16634	17776
		Quadratic	9443	12990	15549

utilisation from herbage measurements was calculated per period for each treatment as follows:

$$\text{Herbage utilisation (per ha per period)} = \text{Net herbage accumulation (kg DM ha}^{-1}\text{)} + (HM_1 - HM_2), \quad \text{... Eqn E1.2}$$

where HM_1 = herbage mass at the beginning of the period, and HM_2 = herbage mass at the end of the period. Herbage accumulation data is presented in Table E1.9 and herbage mass was calculated from the mean herbage height on the treatment area using the regression coefficients in Table E1.8.

Results for herbage utilisation are presented for both the linear and the quadratic regressions in Table E1.10. A weighted mean for both fields was also calculated so that utilisation by the two methods, using pasture measurements or animal performance, could be compared.

Table E1.10 Period and total herbage utilisation (kg DM ha^{-1}) from pasture measurements

Field	Period	Regression equation used	Treatment L	Treatment M	Treatment H
Day	I	Linear	5838	6744	7421
		Quadratic	5574	5418	6573
	II	Linear	6508	5599	6076
		Quadratic	-289	3370	4504
	III	Linear	3326	2853	4025
		Quadratic	3357	3021	3947
	TOTAL	Linear	15672	15196	17522
		Quadratic	8642	11809	15024
Night	I	Linear	6999	7260	6594
		Quadratic	2316	3835	4310
	II	Linear	7708	6118	6283
		Quadratic	4771	4981	6092
	III	Linear	3972	4895	4080
		Quadratic	4199	5200	4287
	TOTAL	Linear	18679	18273	16957
		Quadratic	11286	14016	14689
Weighted mean of day and night field	TOTAL	Linear	16875	16427	17296
		Quadratic	9700	12692	14890

As with results for net herbage accumulation, use of the linear regression gave higher values for herbage utilisation and similar results across treatments. The quadratic regression gave results that were directly related to the stocking rate applied in Period I ie the higher the stocking rate in the early part of the season, the higher the total herbage utilisation for the whole of the grazing season. Herbage utilisation was higher on the night field on Treatments L and M but not on Treatment H.

(b) <u>From animal performance</u>: Utilisation was calculated from animal performance in the following way:

The utilised metabolisable energy (UME) per cow from herbage was estimated from the animal performance results in Table E1.11 using the following equation:

$$\text{Utilised ME per cow from herbage} = \text{Maintenance ME} + \text{Milk production ME} + \text{LW change ME} - \text{Concentrate intake ME} \quad \text{... Eqn E1.3}$$

(ME allowances were calculated from tables in Bulletin 33 (MAFF, 1975).)

The herbage dry matter intake DMI) per cow was then calculated:

$$\text{Herbage DMI (kg day}^{-1}) = \frac{\text{UME per cow from herbage (Eqn E1.3)}}{\text{ME concentration of herbage (Table E1.11)}} \quad \text{... Eqn E1.4}$$

Herbage utilisation per period for each treatment was estimated as follows:

$$\text{Herbage utilised (kg DM ha}^{-1}) = \text{Herbage DMI (Eqn E1.4)} \times \text{stocking rate (cows ha}^{-1}) \times \text{no. of grazing days} \quad \text{... Eqn E1.5}$$

Results are presented in Table E1.12.

Table E1.11 Animal performance

Period	Treatment L	M	H
Period I			
Liveweight (kg)	559	561	550
Liveweight gain (kg day^{-1})	0.48	0.52	0.38
Milk yield (kg day^{-1})	25.0	25.4	24.8
Milk fat (%)	3.73	3.48	3.74
Solids-not-fat (%)	8.75	8.99	8.83
Concentrate feed (kg DM day^{-1})	4.3	4.3	4.5
Metabolisable energy of conc (MJ kg^{-1} DM)	11.5	11.5	11.5
Metabolisable energy of herbage (MJ kg^{-1} DM)	12.2	12.2	12.0
Period II			
Liveweight (kg)	591	586	577
Liveweight gain (kg day^{-1})	0.52	0.12	0.36
Milk yield (kg day^{-1})	20.6	21.7	22.5
Milk fat (%)	3.92	3.86	3.90
Solids-not-fat (%)	8.69	8.95	8.83
Concentrate fed (kg DM day^{-1})	4.7	4.7	4.7
Metabolisable energy of conc (MJ kg^{-1} DM)	11.4	11.4	11.4
Metabolisable energy of herbage (MJ kg^{-1} DM)	11.0	11.0	11.3
Period III			
Liveweight (kg)	611	599	598
Liveweight gain (kg day^{-1})	0.48	0.38	0.74
Milk yield (kg day^{-1})	16.0	17.5	17.5
Milk fat (%)	4.25	3.92	3.99
Solids-not-fat (%)	8.75	9.06	8.94
Concentrate fed (kg DM day^{-1})	3.9	3.9	3.9
Metabolisable energy of conc (MJ kg^{-1} DM)	12.0	12.0	12.0
Metabolisable energy of herbage (MJ kg^{-1} DM)	10.2	10.8	11.1

Table E1.12 Period and total herbage utilisation (kg DM ha^{-1}) from animal performance data

Period	Treatment L	M	H
I	2886	3435	3803
II	2445	2315	2456
III	1743	1674	1792
Total	7074	7424	8051

When calculated from animal performance data, herbage utilisation (kg DM ha^{-1}) decreased on all treatments over the grazing season. For each period, and for the grazing season as a whole, herbage utilisation was directly related to the stocking rates imposed in Period I ie. as the stocking rate increased, herbage utilisation also increased.

Results for herbage utilisation using this method were more closely related to results using the quadratic regression from pasture measurements both in total for the grazing season and for the difference between treatments (see Table E1.10).

Sward density

Monthly tiller counts gave an indication of changes in sward density between treatments and over the grazing season. The main effects of treatment, sampling date and field on tiller numbers, tiller weights and the amount of litter in the base of the sward are presented in Table E1.13.

Treatment H had a higher tiller population than Treatments M and L but the difference was not significant. Dead tillers only accounted for 1-2 % of the total tiller population and the difference between treatments was not significant. Although F-test also indicated no significant effect of treatment on the amount of litter in the base of the sward, this decreased as stocking rate increased and when individual means were compared by t-test the dry weight of litter (kg ha^{-1}) was significantly lower ($P < 0.05$) on Treatment H than Treatment L. A summation of the dry weight of live and dead tillers, and litter, gave an estimate of total herbage dry weight (herbage mass) expressed in kg per hectare. This increased as stocking rate decreased and was significantly greater on Treatment L than on Treatment M ($P < 0.05$) and Treatment H ($P < 0.01$).

Sampling date had a significant effect on all components of the monthly tiller count (see Table E1.13). Tiller population rose from a mean value of approximately 13,000 per m^2 in May to 18,000 per m^2 in September and then began to decline (Fig E1.7). A similar pattern was observed for the number of live tillers. A large increase in dead tillers per m^2 was observed in May and July when they accounted for 2.5 % and 5.0 % of the total tiller population respectively. The dry weight of litter fell to a minimal value of 59 kg ha^{-1} in June and

Table E1.13 Main effects on the mean components of monthly tiller counts

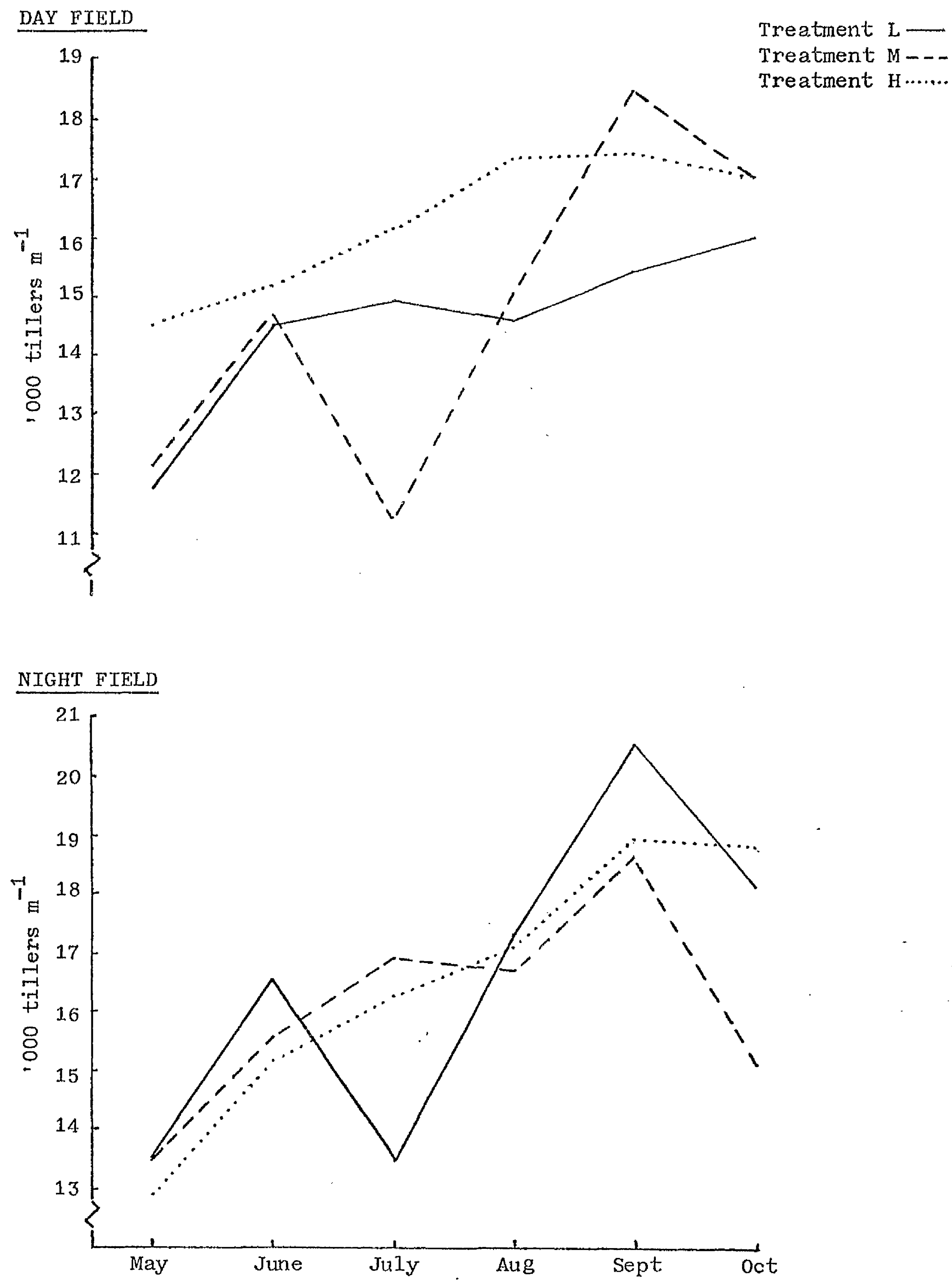
Treatment	L	M	H	SE of difference	Significance
Total tiller population (m^{-2})	15553	15525	16337	± 596.0	NS
Live tillers (m^{-2})	15343	15242	16103	± 572.2	NS
Dead tillers (m^{-2})	210	282	234	± 78.9	NS
Dry weight live tillers (kg ha^{-1})	3534	3087	3012	± 147.1	*
Dry weight dead tillers (kg ha^{-1})	25.7	30.8	25.7	± 10.03	NS
Dry weight litter (kg ha^{-1})	303	266	186	± 52.3	NS
* Total dry weight (kg ha^{-1})	3863	3359	3224	± 178.5	*

Date	May	June	July	Aug	Sept	Oct	SE of difference	Significance
Total tiller population (m^{-2})	13061	15270	15069	16272	18197	16959	± 842.9	**
Live tillers (m^{-2})	12736	15217	14327	16153	18103	16840	± 809.3	***
Dead tillers (m^{-2})	325	53	742	119	94	119	± 111.6	***
Dry weight live tillers (kg ha^{-1})	2517	3043	3855	3077	3293	3482	± 208.0	**
Dry weight dead tillers (kg ha^{-1})	52.5	5.7	74.9	11.3	6.1	13.9	± 14.18	**
Dry weight litter (kg ha^{-1})	154	59	329	342	322	304	± 73.9	*
* Total dry weight (kg ha^{-1})	2723	3107	4259	3382	3621	3799	± 252.5	**

Field	Day	Night	SE of difference	Significance
Total tiller population (m^{-2})	15220	16389	± 486.7	*
Live tillers (m^{-2})	14948	16177	± 467.2	*
Dead tillers (m^{-2})	272	212	± 64.4	NS
Dry weight live tillers (kg ha^{-1})	3332	3090	± 120.1	NS
Dry weight dead tillers (kg ha^{-1})	29.0	25.8	± 8.19	NS
Dry weight litter (kg ha^{-1})	336	167	± 42.7	**
* Total dry weight (kg ha^{-1})	3681	3283	± 145.8	*

* Total dry weight (kg ha^{-1}) = Dry weight live tillers (kg ha^{-1}) + dry weight dead tillers (kg ha^{-1}) + dry weight litter (kg ha^{-1}).

Figure E1.7 Total tiller population



then rose to an average of 324 kg ha^{-1} for the remainder of the season. Herbage mass (kg DM ha^{-1}) reached a peak in July, declined in August and then rose to reach a secondary peak in October.

The night field had a significantly higher live and total tiller population ($P < 0.05$) on all sampling dates with fewer dead tillers. The amount of litter was also lower ($P < 0.01$) averaging 50 % of that on the day field. From mid-July onwards the amount of litter in both fields was inversely related to the stocking rates imposed in Period I, but the difference between treatments was much greater in the day field (see Fig E1.8). It also increased on all treatments in the day field between July and October, but fell on the night field.

In addition to the main effects shown in Table E1.13, the field x date interaction was significant for dead tillers per m^2 ($P < 0.05$), dry weight of dead tillers ($P < 0.01$) and dry weight of debris ($P < 0.05$) (Appendix Table 9).

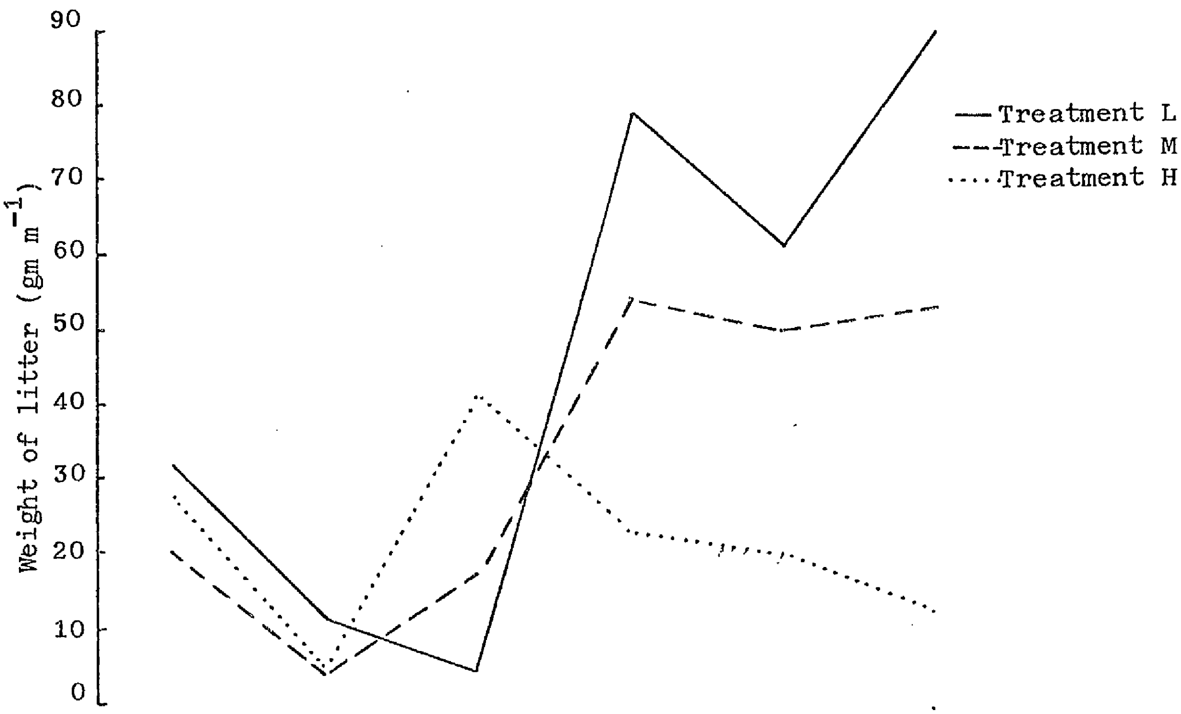
A separate count of aerial tillers was made at the October sampling which are expressed as a percentage of the total tiller population in Table E1.14. An aerial tiller was defined as one formed at nodes above ground level (see Plates 4 and 5). Fewer of these aerial tillers were produced in the night field but in both fields aerial tillering was inversely related to the stocking rates imposed in Period I ie. as stocking rate increased, the number of aerial tillers produced later in the season decreased.

Table E1.14 Number of aerial tillers at October sampling (% of total tiller population)

Field	Treatment L	Treatment M	Treatment H
Day	16	6	3
Night	9	1	1

Figure E1.8 Weight of litter

DAY FIELD



NIGHT FIELD

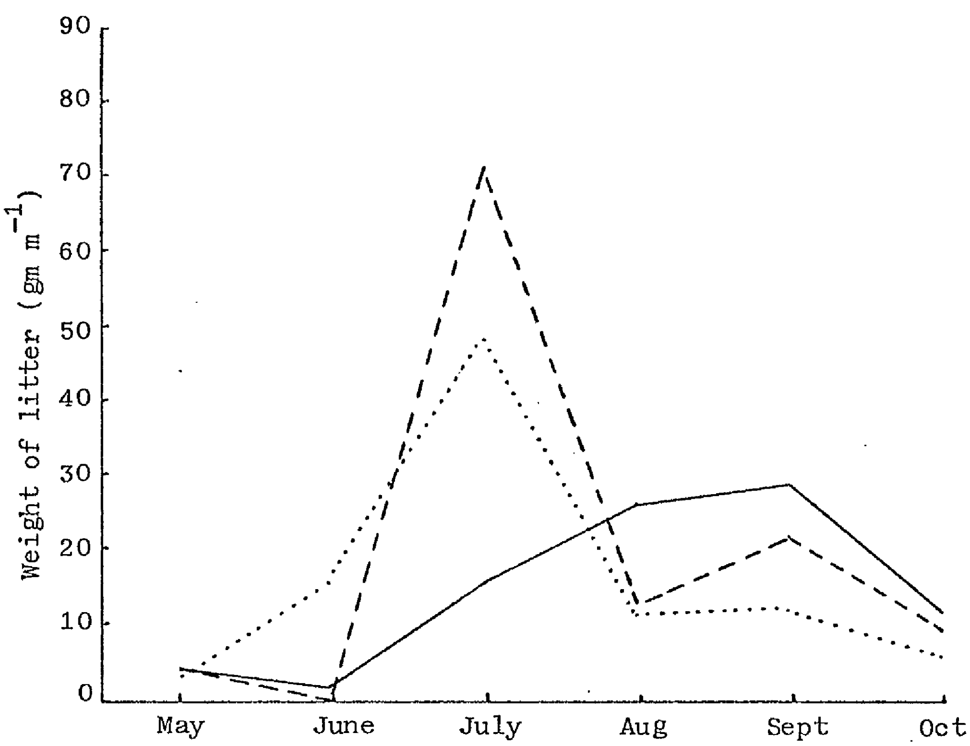


Plate 4 Aerial tillering *in situ*.

Plate 5 Details of aerial tillering.

Frequency of defoliation

The average height of the sward (cm) on the three treatments over the three observation periods is shown in Table E1.15.

Table E1.15 Mean herbage height (cm) in each observation period

Field	Period	Date	Treatment L	Treatment M	Treatment H
	I	20 June - 4 July	12.4	8.0	5.0
Day	II	2 - 16 August	11.3	6.8	6.4
	III	10 - 24 September	8.8	7.7	8.8
	I	20 June - 4 July	9.0	6.0	4.6
Night	II	2 - 16 August	7.7	6.0	5.4
	III	10 - 24 September	8.4	7.0	9.2

Treatment H swards were more closely grazed during the first and second periods of observation but there was less difference between their heights during the third period.

Table E1.16 shows the numbers of originally marked tillers lost in each observation period for each field. More tillers were always lost on the night field but there was no consistent interaction between treatment and number of lost tillers. The loss of tiller records was due to: failure to locate marked tillers; displacement of the identifying wires, and uprooting of tillers. Tillers obscured by dung pats were also considered lost to the experiment. Hodgson and Ollerenshaw (1969) included dead tillers and completely defoliated tillers (ie those having had all leaf material removed leaving only stem material) in their loss of records. These were not included in this study because on several occasions dead and completely defoliated tillers were grazed between observations.

Table E1.16 Losses of tiller records in each observation period

(a) Period I: 20 June - 4 July

Field Treatment	Day L	Day M	Day H	Night L	Night M	Night H
Total lost *	0	3	4	3	10	3
Uprooted	0	1	0	1	5	1
Obscured by dung	0	0	0	0	1	2
Failure to identify marked tiller	0	2	4	2	4	0

(b) Period II: 2 - 16 August

Field Treatment	Day L	Day M	Day H	Night L	Night M	Night H
Total lost *	0	1	3	4	6	4
Uprooted	0	1	0	3	1	2
Obscured by dung	0	0	1	0	2	1
Failure to identify marked tiller	0	0	2	1	3	1

(c) Period III: 20 - 24 September

Field Treatment	Day L	Day M	Day H	Night L	Night M	Night H
Total lost *	1	0	1	4	1	0
Uprooted	1	0	0	2	1	0
Obscured by dung	0	0	0	0	0	0
Failure to identify marked tiller	0	0	1	2	0	0

* Out of 50 marked per treatment at the beginning of each observation period.

In this study tillers from which all leaf material had been removed leaving only stem material were classified as completely defoliated. Tillers where 80 % of leaf and sheath components were brown or shrivelled were classified as dead. A tiller was considered uprooted if it was found lying on the sward with an identifying ring still attached. Displacement of identifying rings and failure to locate marked tillers are considered as one category in Table E1.16 because it is not possible to distinguish between them.

Losses were greater among tillers marked with blue and white striped wire than amongst those marked with orange, yellow, blue or turquoise wire. There were no significant differences between the frequencies of defoliation of tillers marked with different colours or of tillers in different transects on any one treatment.

In each observation period, six records were made on each treatment in each field. By comparing the recordings made on successive dates, individual tillers were assessed for defoliation between observations. A record was then made of the number of times each tiller had been defoliated in six observations over fifteen days. (Tillers lost before the end of an observation period were not included in the assessment). Results are summarized in Table E1.17.

The means were compared by simple "t" tests. Frequency of defoliation increased with stocking rate in Period I although similar results were obtained on Treatments M and H in the night field. No significant differences occurred between treatments in Period II in either field and only Treatment L in the night field was significantly different in Period III.

Table E1.17 Frequency of defoliation of individual tillers (defoliations per 15 days)

FIELD	PERIOD	TREATMENT						Significance of difference		
		L		M		H				
		No of tillers	mean ± SE	No of tillers	mean ± SE	No of tillers	mean ± SE	L v M	L v H	M v H
Day	I	50	1.06 ± 0.13	47	1.17 ± 0.09	46	1.67 ± 0.14	NS	**	**
	II	50	1.60 ± 0.19	49	1.43 ± 0.16	47	1.34 ± 0.15	NS	NS	NS
	III	49	1.12 ± 0.14	50	1.14 ± 0.12	49	1.41 ± 0.12	NS	NS	NS
Significance of difference	I v II		*		NS		NS			
	II v III		*		NS		NS			
	I v III		NS		NS		NS			
Night	I	47	1.23 ± 0.11	40	1.65 ± 0.15	47	1.64 ± 0.13	*	*	NS
	II	46	1.63 ± 0.15	44	1.66 ± 0.19	46	1.48 ± 0.16	NS	NS	NS
	III	46	1.93 ± 0.15	49	1.39 ± 0.15	50	1.38 ± 0.12	*	**	NS
Significance of difference	I v II		NS		NS		NS			
	II v III		NS		NS		NS			
	I v III		**		NS		NS			

A regression equation relating frequency of defoliation and herbage height was calculated for all values from all treatment areas and observation periods:

$y = 1.817 - 0.049\ x\ (r = -0.429)$ ... Eqn E1.6

(where 1.817 = intercept of y axis; 0.049 = slope of regression line; r = correlation coefficient).

Discussion

In the first seven weeks of the grazing season (Period I), differential stocking rates of 4.7 (Treatment L), 5.6 (Treatment M) and 6.4 (Treatment H) cows ha^{-1} applied on an all grass day field and a grass/clover night field supplying 60 % and 40 % respectively of the grazing area, had significant effects on herbage availability, herbage production and utilisation, aerial tillering, the amount of litter in the base of the sward and frequency of defoliation, a small effect on some components of chemical composition, and no significant effect on herbage digestibility or tiller density.

Herbage availability

Use of the grass disc to measure herbage height provided a simple and quick guide to the amount of herbage available to the grazing cattle over the season, and to the differences that occurred between treatments and fields.

An initial stocking rate of 4.7 cows ha^{-1} on Treatment L was not sufficient to prevent the grass from growing ahead of the cows. This excess in herbage availability was apparent for much of the grazing season although increases in herbage height in Period III on Treatments greater. Hancock (1950), after studying the grazing, defaecation and urination behaviour of three sets of identical twins, postulated that the night pasture should be two-thirds the area of the day pasture to avoid the transfer of fertility from the day to the night pasture. However, this area had to supply the grazing needs of the cows between the afternoon and morning milking; Castle and Watson (1978) observed that the proportion of the total time spent grazing by continuously stocked dairy cows in the periods between afternoon and morning milkings was 52-53 % over a 19-week grazing season.

The difference between treatments in herbage height was less pronounced on the night field which might suggest that the herbage available was similar on all treatments. But herbage height is only an indicator of herbage availability and sward density must also be taken into account. The tiller population was significantly higher on the night than on the day field and the calibration of height against weight was also higher in Periods II and III which also indicates that sward density was greater on the night field. Thus the smaller differences between treatments in herbage height on the night field would be equivalent to the greater differences on the day field in terms of herbage availability.

The variation in herbage height on each treatment area was expressed as the standard deviation of the mean and the coefficient uniform height of herbage. Standard deviations were not significantly different between fields reflecting similar levels of variation, but when expressed as the coefficient of variation, higher values were obtained for the night field. As the coefficient of variation expresses the sample standard deviation as a percentage of the sample mean, a lower mean herbage height, as in the case of the night field, would increase the coefficient of variation.

As stocking rate increases greater amounts of dung and urine are deposited on the sward (Marsh and Campling, 1970). Although cattle reject dung-affected herbage in and adjacent to areas contaminated by dung pats (MacLusky, 1960), the extent of the rejection depends on grazing intensity and the availability of alternative clean herbage (Greenhalgh and Reid, 1969). In Period I the amount of rejected herbage was inversely related to stocking rate (Table E1.4). Cows on Treatment L selectively grazed clean herbage and clumps of long rank herbage formed round dung pats which contributed to the difference in mean herbage height between Treatment L and the other more heavily stocked treatments. In contrast at higher stocking rates cows were forced to graze closer to dung pats so that little herbage was completely rejected. The amount of rejected herbage was generally greater on the night field possibly because proportionly more of it was affected by the deposition of dung and urine.

Herbage chemical composition

When a grass plant continues to grow past the ear emergence stage, digestibility can fall to quite low levels of 60 % or less (Smethan, 1973). However continuous grazing maintains the pasture components at a physiologically young stage of growth. Because of the effects of temperature and photo-period on plant growth, there is still some change of leaf-stem ratio, and of such plant constituents as fibre and protein and thus digestibility, but the decrease of digestibility and the increase of fibre are much less than in the case of plants allowed to grow uncut or ungrazed (Dent and Aldrich, 1968). The slow decline in herbage quality, as measured by the in vitro D-values, on all treatments from the start to the end of the grazing season is recorded in other experiments where swards were continuously stocked for the entire season (Castle and Watson, 1975, 1978). The mean D-value of 67.2 over the 21-week period compares favourably with estimated values from other grazing experiments (Leaver et al, 1969; Castle and Watson, 1975, 1978). Differences in mean D-values for early and late season of 71.0 and 64.5 are in accord with other published estimates (Greenhalgh and Runcie, 1962; Leaver et al, 1969) although the digestibility in these experiments was estimated from the N-content of the faeces.

The mean herbage digestibility increased with increasing stocking rate in Period I but the increases were small and non-signficant. Other work has shown little decline in nutritive value until defoliation intervals exceed 4-5 weeks (Woodman and Norman, 1932; Chestnutt et al, 1977) and only small and variable changes with different cutting heights (Binnie and Harrington, 1972; Binnie et al, 1974). As continuous stocking need not involve frequent or severe defoliation (Hodgson, 1966; Hodgson and Ollerenshaw, 1969), the lack of difference between treatments is perhaps not unexpected. However, the difference between treatments was pronounced on the day field from the end of July (see Fig E1.3) possibly due to the ratio of plant leaf to stem and sheath. Herbage rejected on low stocked pastures at the beginning of the season continues to grow more mature and may depress the overall digestibility of the herbage available later in the season (Tayler and Deriaz, 1963; Raymond, 1964). It has been shown that frequent but lenient defoliation of a perennial ryegrass sward can give rise to the development of an extended tube of dead sheath (Hunt and Brougham, 1967; Jackson, 1973) from which green leaf emerges. Investigations have shown that the digestibility of leaf, sheath and stem fractions of grasses is quite different. As the grass plant matures, the D-value of the stem falls off approximately six times as fast as the leaf, while that of the sheath declines about three times as fast (Terry and Tiley, 1964). A possible decrease in leaf:stem ratio on lower stocked pastures would explain the fall in digestibility from mid-season onwards. The digestibility was similar on all treatments in the night field possibly because the mean height of herbage available never showed the same difference between treatments as the day field ie. herbage was of similar maturity.

Protein content is also an indication of herbage quality. The mean crude protein content for the 21-week grazing season was 237 g kg^{-1} DM. This was considerably higher than results from other cutting (Reid, 1967; Binnie et al, 1974) and grazing (Marsh, 1977; Castle and Watson, 1978) experiments, although Thompson and Warren (1979) obtained a mean value of 230 g kg^{-1} DM for the herbage from five dairy farms they studied over a 2-year period. The reason for the high crude protein content of the herbage could have been the amount of fertilizer N applied over the grazing season which totalled 395 kg ha^{-1} and exceeded the amount generally used in the south west of Scotland and nationally. With 400 kg N ha^{-1}, Reith and Inkson (1964) obtained average seasonal CP contents of cocksfoot and brome-grass of 228 g kg^{-1} DM. The seasonal pattern of crude protein content agrees with the work of Dent and Aldrich (1968) although Thompson and Warren (1979) obtained increases in the crude protein content of the herbage as the season progressed. High levels in May could have been due to an accumulation of nitrogen from the nutrient return of sheep grazing over winter and the initial nitrogen dressing in April of 110 kg ha^{-1}. The decrease in crude protein in herbaceous plants with advancing maturity is a well established relationship (Heady, 1961) that could explain the fall obtained in June and July, together with the lower than average rainfall recorded from May to July. Increased recycling of nitrogen from dung and urine as the season progressed may have contributed to increases in the crude protein content of the herbage as the season progressed. The herbage was also probably grazed at a less mature stage of growth from mid-June onwards when the rate of grass regrowth declined.

The crude protein content of the herbage increased with increased stocking rate in Period I and this difference was maintained for much of the season although differences between treatments were smaller on the night field (Fig E1.2). Several factors may have contributed to increases in the crude protein content of the herbage with increasing stocking rate. Although cutting experiments have shown inconsistent effects of different cutting heights on CP content (Reid, 1959; Binnie et al, 1974), the interval between defoliations can have an effect. But as a decline only occurs when the interval exceeds 2-5 weeks (Ashford and Troelson, 1965), defoliation frequency is unlikely to explain the difference between treatments in this experiment. As CP content declines as herbage matures, the difference in herbage "age" between treatments offers a more likely explanation. It is also likely that the higher stocking rate on Treatment H in Period I would have led to a greater deposition of dung and urine which would be released and taken up by the herbage as the season progressed. A greater deposition of excreta per unit area and recycling of nutrients, primarily N, could also explain the higher CP content of herbage on the night field. A similar explanation may exist for the higher CP at high stocking rate and in the night field; both are associated with shorter and therefore less mature herbage. The different composition of the sward in the night field is unlikely to explain the higher levels of herbage CP; although legumes contain a higher CP level, grasses such as timothy are lower in CP than the ryegrasses (Lyttleton, 1973). Very little of the white clover originally sown in the night field was apparent which supports the observed repression and elimination of clover in mixed pastures by added nitrogen fertilizers (Reith and Inkson, 1964).

Contamination of herbage by soil will reduce the organic matter content and although precautions were taken by plucking rather than cutting the herbage for chemical analysis, soil contamination could explain the reduced OM content as the stocking rate increased on Treatments M and H, and on the night field compared to the day field.

Soil contamination results from the effects of trampling by grazing animals, rain splash or wind, and increases as grass gets shorter or the stocking rate increases.

The mineral content of the herbage followed the seasonal pattern of crude protein content in that all the elements studied fell in mid-season before rising again. Thompson and Warren (1979) also found that changes in Ca, P, K and Mg were parallel to changes in the crude protein content of the herbage as the season progressed. There are many references in the literature to seasonal changes in herbage mineral content (see Fleming, 1973) but results are diverse and it is difficult to separate the effects of stage of maturity per se and variables such as defoliation and fertilizer application, and advance in season. The efficiency of nutrient recycling in the soil-plant-animal grazing system depends upon the amounts of nutrients recycled (a function of herbage yield and grazing pressure), nutrient availability, rate of recycling and nutrient losses (Frame, 1976). The high level of fertilizer used in this experiment could be the cause of the higher mineral content recorded than for other published results (Pain et al, 1974; Thompson and Warren, 1979). The lower values for each element were more than the dietary concentrations required by the dairy cow producing 20 kg milk from grass alone (MAFF, 1975 b). A greater return of animal excreta would explain the marked increase in herbage P and K on treatments with a higher initial stocking rate, and the difference between the day and the night field. Differences due to species (Whitehead, 1966) might further explain the significant difference in mineral content between fields.

Herbage production and utilisation

Estimates of total production presented in Table E1.9 appear high especially when the estimates of herbage utilisation calculated from animal performance are considered (Table E1.11). Estimates of the amounts of dry matter produced under grazing vary widely between soil types and climatic regions, but Munro et al (1979) set a target figure of 11250 kg DM ha^{-1} for the south-west of Scotland using 375 kg N ha^{-1} on a grass sward under grazing management.

Errors could be associated with either the estimation of growth of herbage within the protected areas or the calibrations of the disc establishing a height/weight relationship for the herbage. No error could be found in the procedure used to weigh and dry samples associated with the calibrations, and although cutting consistently to 1 cm on uneven ground was sometimes difficult, soil contamination was not a problem. The linear results in Table E1.8 suggest that each 1 cm on the vertical scale measured a herbage mass of approximately 234 kg ha^{-1} DM on the pure grass day field and 241 kg ha^{-1} DM on the grass/clover night field. This compares with other calculated yields of 160 (Castle, 1976) and 174 kg ha^{-1} DM (Phillips and Clarke, 1971) per 1 cm on the vertical scale on grass swards and 230 kg ha^{-1} DM on clover swards (Phillips and Clarke, 1971), using a similar instrument. Differences have also been found in the regressions for different periods of the year (Phillips and Clarke, 1971; Powell, 1974; Castle, 1976; Leaver, 1978), as well as between species of grass (Castle, 1976) and grass and grass/clover swards (Phillips and Clarke, 1971).

Because the calibrations compare favourably with other published results, the overestimation of herbage production is probably due to the estimation of growth within protected areas as presented by cumulative increases in herbage height in Table E1.7. Exclosures of various types are known to affect the growth of herbage within them (t'Mannetje, 1978). by altering the microclimate of the sward, although electrical cages reduce this effect (Prendergast and Brady, 1955). Pasture regrowth is however affected by the characteristics of the sward after defoliation (King et al, 1979). One aspect of this is the height of the stubble (Brougham, 1956, 1960) because the longer the stubble, the greater the leaf area index and interception of light, and the faster the regrowth. The height of herbage within the protected area when erected may have been sufficient to account for the rapid increases in growth recorded. Several factors may have been responsible for the differences observed between treatments. Differences in tiller density as well as herbage height will affect light interception and hence regrowth, as will the amount of litter in the base of the sward (Hunt, 1965). The fortnightly positioning of the protected area could also introduce an error into the results because if the average herbage height within it differed from that outside, estimates of growth would not be representative of growth occurring on the grazed sward. Although the protected areas were positioned at random, the height of herbage within them was generally slightly lower than the weekly mean height of the grazed area, possibly because less of the long rank herbage that developed as the season progressed was enclosed within them. However both the weekly mean herbage height and the initial herbage height within the protected area were greater on treatment L in both fields for much of the grazing season.

than when the quadratic relationship was used (see Table E1.9). This was due to the curvilinear effect at high herbage heights which is apparent in Figs E1.4-E1.6. When this curvilinear effect was strongest eg. on the night field in Period I and the day field in Period II, the difference in net herbage accumulation as calculated by the two regression equations was greatest. The final height within each of the protected areas after a fortnights growth reached from 14-24 cm with an average of 18.6 cm for the later part of Period I and most of Period II. These heights were therefore outside the range of data used in the calibrations. These final heights were usually greater on Treatment L in both fields which explains the greatest difference in net herbage accumulation between the two regressions on this treatment especially when the quadratic relationship was strongly curvilinear. The lower herbage mass at each final height than at each initial height on Treatment L, day field, Period II, explains the negative value obtained by the quadratic regression.

Figures for growth as expressed by cumulative increases in herbage height and estimates of net herbage accumulation were generally greater on the night field. Differences in soil composition are unlikely to explain differing growth rates as the soils in both fields were similar. Higher tiller populations and lower amounts of litter may have increased the photosynthetic capacity of the sward, and as herbage height on the night field never reached the levels of the day field, the physiologically "younger" herbage may have been more efficient in intercepting and utilising light. The botanical in their susceptibility to the frequency and severity of defoliation (Brougham, 1959) and growth rates after defoliation (Agyare and Watkin, 1967). Erect species give good light penetration into the sward and will increase photosynthesis in dense canopies, while prostrate species will intercept light energy more efficiently when the sward is still open, and at reduced canopy heights a greater residual leaf area may remain after defoliation (Davies, 1977). Nitrogen availability is known to affect regrowth by influencing tiller numbers (Langer, 1959) and stem and leaf growth. Tillering is stimulated, leaves are longer, they appear more rapidly, but also senesce correspondingly faster (Jackson, 1973). The recirculation of N from dung and urine may have differed between fields but the daily distribution of excreta was not examined.

Both production and utilisation increased as the initial stocking rate applied in the early part of the grazing season increased. There appears to be some confusion in the literature with regards to the effect of stocking rate on the net production of grass dry matter as reviewed by Gordon (1978). A mean reduction in grass production with increasing stocking rate has been reported for growing heifers (Leaver, 1975) and lactating dairy cows (McFeely et al, 1977). Others have reported a curvilinear relationship between herbage production and stocking rate with little effect on herbage production over a fairly wide range of stocking rates (Birrell et al, 1974). Gordon (1973) and Greenhalgh (1970), obtained an increase in net herbage accumulation as stocking rate increased. In his review of published results from cattle experiments Hodgson (1978) cited small responses, herbage accumulation declining by 2.3 % ($\pm$ 0.64) for a 10 % increase in stocking rate. If the differences between treatments obtained in this experiment are valid, the reason is probably due to the different photosynthetic efficiencies of the swards. Because herbage height was kept comparatively low on Treatment H, mutual shading was reduced, and a lower accumulation of litter in the base of the sward would increase light penetration compensating for the reduction in photosynthetic area. Although leaf area was greater on Treatment L it may have been physiologically "older" and photosynthetically less efficient, and together with an increased rate of senescence and decay resulted in a decrease in net herbage production (Smethan, 1975).

Because of the high estimates obtained for herbage accumulation, herbage utilisation was equally high when derived from pasture measurements (Table E1.10) and also showed the variation when calculated using linear or quadratic relationships. Even the lower estimates derived from the quadratic regression were considerably higher than estimates of herbage utilisation calculated from animal performance data (Table E1.11). Calculations of the percentage utilisation of herbage by the cattle were not made in view of the inflated estimates of herbage production from the exclosure technique. Results in Tables E1.10 and E1.11 show that when cows were kept at a high stocking rate at the beginning of the grazing season their utilisation of herbage (kg DM ha^{-1}) increased over the season. Increased utilisation with increased stocking rate has been found by Gordon (1973). Leaver (1976) expresses the relationship graphically between herbage allowance, intake and the percentage utilised. At low grazing pressures, when herbage allowance is high (Treatment L), utilisation is low but as grazing pressure increases animal intakes decline very slowly but the percentage utilisation increases. Eventually a point is reached where the animals cannot utilise any more herbage available due to its inaccessibility in the base of the sward and intakes and percentage utilisation reach zero. At higher stocking rates in Period I, cows on Treatment H were able to overcome constraints imposed by increasing their frequency of defoliation. The total utilisation of herbage over the whole season may exceed 90 % of the net herbage production at high stocking rates (Gordon et al, 1966; Leaver, 1974, 1978), which illustrates the high ability of the grazing animal to utilise grass.

Sward density

The number of tillers per unit area gave a measure of herbage density which could be compared between treatments and fields. Cutting the samples in situ and transporting them to the field laboratory for separation, made for easier division into component parts, though care had to be taken when cutting to ensure that each tiller was cut only once at ground level. A circular quadrat was chosen to minimise 'edge effects' (t'Mannetje, 1978) from the often experienced difficulty of deciding whether a plant is in or out because it may or may not be rooted within the quadrat, what to do with lodged vegetation and the disturbance caused by the initial placing of the quadrat.

In an established sward the total number of tillers per unit area declines over the summer (Langer et al, 1964). The fall can be reduced by frequent defoliation but the effect of cutting and grazing on tiller numbers can be extremely variable depending on the treatment imposed and the environment (Langer, 1963). The gradual increase in tiller numbers over the grazing season observed in this experiment, confirms that under continuous stocking the tiller population is sustained throughout the season, whereas under rotational grazing it falls rapidly (see Hodgson, 1978). Results also confirm the relative insensitivity of tiller population to changes in grazing pressure under controlled continuous stocking (Morris, 1970; Hodgson, 1978). Compensating changes appear to occur over a range of treatments under continuous stocking, but this may not be the case when defoliation is particularly severe or frequent (Brougham, 1959). Periodic close grazing may stimulate tillering by preventing basal shading but persistent close grazing may have the opposite effect. Nitrogen is known to be effective in stimulating tillering (eg Campbell, 1961) and the high fertilizer N level together with the return of excreta may have caused the upward trend in tiller population as the season progressed.

The different botanical composition of the night field was probably responsible for the higher tiller population recorded at each sampling. Pasture species differ greatly in the amount and duration of tiller production (Langer, 1963). The initial sowing rate may also affect the number of plants per unit area and the number of tillers per plant which indirectly affect the tiller population per unit area (Langer, 1963). Although the original mixture in the night field contained Italian ryegrass and white clover, there was little evidence of these species in the sward. A considerable amount of Poa annua was noted, which is known to invade pastures if clover or productive grasses have been grazed out (Weeda, 1965), and which has a higher number of tillers/plant than the ryegrasses.

The number of dead tillers in the counts only averaged 1-2 % of the total but it is possible that many more may have decomposed between monthly counts.

The average dry weight of a dead tiller, calculated from results in Table E1.13 , was approximately 50 % of that of a live tiller. Tillers lose weight during senescence owing to redistribution of cell constituents and after death because of decomposition. Nevertheless on separation it was noted that the dead tillers were considerably smaller than live ones in the same sample. Ong (1978) provided the first direct experimental evidence that the smallest or youngest tiller, irrespective of tiller position, tends to die first when the whole plant is stressed because of nutrient or light shortages.

The amount of litter present in the base of the sward is of great importance because it represents a loss of potential production. Not only is this material probably of very low nutritive value, it is avoided by the grazing animal. Perhaps more correctly, being mainly in the base of the sward it is less accessible for grazing. Results suggest that the laxer the grazing the greater the weight of dead material there will be present which agrees with other published results (Campbell, 1961; Hunt and Brougham, 1967; Tainton, 1974). Campbell (1961) and Morris (1970) have shown that decay processes can account for as much as 50 % of the amount grown although it averaged only 7.8, 7.9 and 5.8 % of the total dry weight over the grazing season for Treatments L, M and H respectively (see Table E1.13).

The rate at which this material decomposed and was therefore lost to the pasture was not measured but senescence and decay at the base of the grass sward may have several deleterious effects photosynthetic capacity. A large volume of remaining on the pasture may also inhibit the development of new basal tillers and the development of short-lived aerial tillers provides an inadequate substitute. The problems associated with aerial tillering have been reviewed by Swift (1975). Few of them produce roots which can penetrate the soil, and the whole plant is thus poorly anchored and prone to uprooting. Once started aerial tillering spreads rapidly, probably because the shoots are unpalatable to stock. This abnormal growth is probably due to a light deficiency caused by a dense sward or excess litter which restricts the development of tiller buds at the base of the plant. Thus the greater litter on Treatment L was associated with more aerial tillering recorded at the October sampling. The accumulation of litter and the development of aerial tillers was greatly reduced on the night field because of the higher grazing pressure. The accumulation of litter may also contribute to the decline in herbage D-value as the season progresses (Thompson and Warren, 1979) and also the lower D-value of herbage that had been lightly stocked at the beginning of the season.

Frequency of defoliation

The marked effect of defoliation frequency on net herbage accumulation and sward quality is well known and widely documented (see Review Section I). Although Hodgson (1978) has concluded that severity and frequency of grazing have only small effects on herbage production in the U. K., detailed knowledge of these parameters is still needed for purposes of prediction of their effect on sward development.

end of the leaves of each tiller provided an easy method of determining whether tillers had been grazed between observations. The technique of tiller identification and recording was very time-consuming but simple.

Comparatively few marker wires were lost, but of those that were, more were blue/white striped than any other colour. It may be that this colour combination was more apparent than plain colours to the cows. More records were lost in the night field, especially rings lost from uprooted tillers. Records in the 'failure to identify marked tillers' category (Table E1.16) are likely to have been wires missed by recorders rather than displaced by the cows; herbage height never fell below 5 cm during periods of observation and the rings were anchored firmly by pushing the ends of the wire into the ground. There was no evidence that differences in the number of tillers lost were related to differences in the frequency of defoliation of the marked tillers between treatments, although both were higher on the night field.

Studies on the defoliation of individual tillers (Hodgson, 1966; Hodgson and Ollerenshaw, 1969; Wade and Baker, 1978), individual seedling plants (Greenwood and Arnold, 1968) and small areas of a sward (Morris, 1967) have been published. The intermittent grazing of small units of herbage within a sward, and the increased frequency of defoliation with increased grazing pressure in Period I of this

Hodgson and Ollerenshaw (1969) reported defoliation intervals of 14 to 5 days at stocking densities of 29 to 91 sheep per ha; Morris (1969) obtained values of 19, 24 and 36 days at 3000, 4200 and 5500 kg DM ha^{-1} respectively; Greenwood and Arnold (1968) obtained a 16-day interval at a stocking rate of 7.4 sheep per ha, while Wade and Baker (1978) reported defoliation intervals of 19 to 7 days at stocking densities from 15 to 45 sheep per ha. Using pooled data from two experiments with lactating dairy cows and calves, Wade and Baker (1978) obtained defoliation intervals of 19 to 4 days over the equivalent of 2 to 16 cows per ha. In Period I of this experiment each tiller on average was grazed every 14, 13 and 9 days, and every 12, 9 and 9 days at stocking rates of 4.7, 5.6 and 6.4 cows per ha in the day and night field respectively.

Factors other than stocking rate were responsible for the results obtained in Periods II and III when treatments were identical at 4.2 and 3.1 cows per ha respectively. Morris (1969) showed an association of the length of defoliation intervals with herbage mass, where stocking rates were effectively the same. Grazing severity was not measured but the amount taken in at each bite will directly affect defoliation frequency. Sward density or tiller number may also have an effect, and a comparatively sparse sward was the reason offered by Wade and Baker (1978) for the apparently low 16-day interval at 7.4 sheep per ha recorded by Greenwood and Arnold (1968). The amount of rejected herbage, accumulation of dead litter in the base of the sward, aerial tillering and the 'age' and growth habit of species per unit area as the dominant variable. Transects of marked tillers were established at random on treatment areas and it is possible that it would have been more accurate to choose areas that were representative of the sward as a whole. Tillers within a transect, and the transects themselves were widely spaced to minimize the effects of patchy grazing.

All the intervals measured were much less than 3 weeks, less than in an average rotational system (Wade and Baker, 1978). But the effect of increased frequency of defoliation in set-stocked swards is offset by the relative laxness of each defoliation in terms of amount removed per defoliation, and the greater number of tillers per unit area compared to swards rotationally grazed. Intervals of a week or less might reduce herbage production (Hodgson, 1978) and possibly the amount utilised but the lowest interval recorded in this experiment was 8 days.

The method described makes it possible to study individual plant units in a sward. Although the large number of factors contributing to variation of defoliation interval may make interpretation of results difficult, studies such as these are needed to evaluate systems of grazing management and for purposes of prediction of their effect on sward development.

EXPERIMENT 2 An investigation into the change in herbage height within protected areas of pasture

Introduction

In a previous trial (Experiment 1) herbage production was estimated by measuring the cumulative increases in herbage height within protected areas and ascribing to them a weight figure which had been determined for each period of the grazing season. The results appeared to be considerably higher than target production figures for the south-west of Scotland using similar fertilizer nitrogen levels (Munro et al, 1979), and also than the estimates of herbage utilisation calculated from animal performance in Experiment 1.

This overestimation of herbage production was thought to be due to the high values of herbage growth obtained within protected areas of the sward (see Table E1.7) rather than to a bias in the height/weight relationship established using the grass disc instrument. t'Mannetje (1978) has reviewed several studies made on the effects of various types of exclosures on herbage growth. Cages, fences and hurdles are known to affect the micro-environment of the enclosed areas (Williams, 1951; Dobb and Elliot, 1964) and the difference due to the absence of grazing animals also adds to the artificiality of exclosures.

The opportunity was taken in this experiment to examine the pattern of herbage growth within protected areas and then to study their effect on growth when left in position for varying periods of time. The experiment was carried out in these two stages between April and June, and June and August, 1980.

Experimental materials and methods

Design

Three rectangular areas of 25 m^2 were protected from cattle by an electric fence on a perennial ryegrass (Lolium perenne) ley set-stocked by dairy cows. The ley was that used for the day field in Experiment 1.

Procedure

The protected areas were set up on 11 April and the mean height within them established by taking 20 'height' readings from around the perimeter using a simple disc instrument (Castle, 1976). These areas were rectangular so that measurements could be taken without having to stand on the herbage being measured. A mean height was calculated twice weekly for four weeks (Period 1) and plotted to show the pattern of increase in herbage height within each of the protected areas. The electric fences were then moved to another part of the field and the procedure repeated for a further four weeks (Period 2).

From 11 June onwards, cumulative increases in herbage height were measured within the same three protected areas moving one of them twice weekly (A), a second weekly (B) and a third fortnightly (C) as in Experiment 1. The experiment ended on 8 August.

Results

The pattern of herbage growth within protected areas

The pattern of increase in herbage height in Period 1 and Period 2 is presented graphically in Fig E2.1.

Figure E2.1 Pattern of herbage growth within protected areas of the sward

PERIOD 1: 11 April-9 May; PERIOD 2: 16 May-13 June

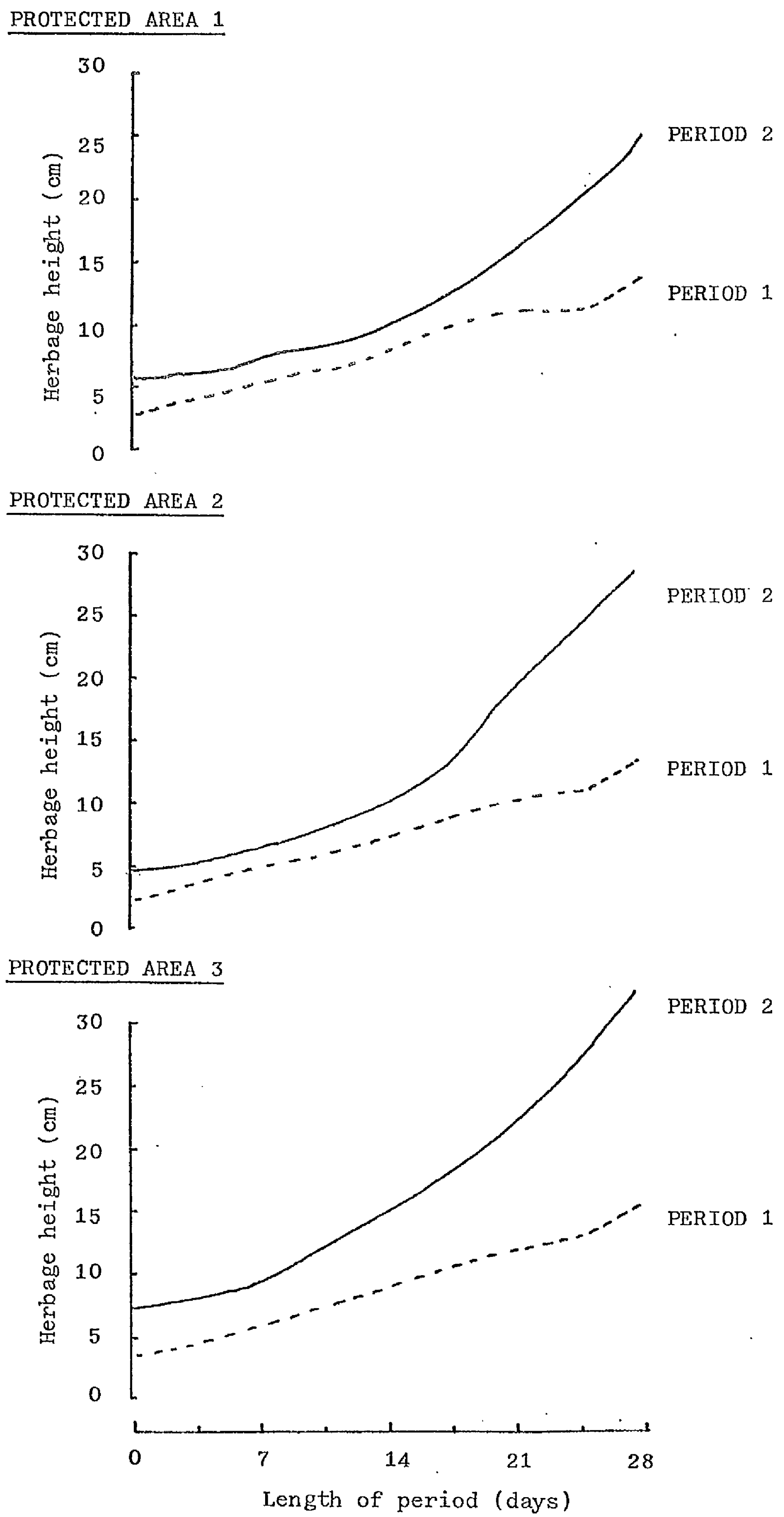


Table E2.1 Weekly increase in herbage height (cm) within protected areas (figures in parentheses express weekly increase as % of total increase)

Period	Week	Protected area 1	Protected area 2	Protected area 3
1	1	2.3 (24.7)	2.8 (29.5)	2.8 (24.3)
	2	3.0 (32.3)	2.2 (23.2)	2.8 (24.3)
	3	2.3 (24.7)	2.9 (30.5)	3.3 (28.8)
	4	1.7 (18.3)	1.6 (16.8)	2.6 (22.6)
TOTAL INCREASE (cm)		9.3	9.5	11.5
2	1	2.2 (10.7)	2.4 (9.9)	2.2 (8.7)
	2	3.1 (15.1)	4.5 (18.5)	6.0 (23.8)
	3	6.9 (33.7)	7.3 (30.0)	6.7 (26.6)
	4	8.3 (40.5)	10.1 (41.6)	10.3 (40.9)
TOTAL INCREASE (cm)		20.5	24.3	25.2

Results were similar for each of the protected areas but not for each period. In Period 1, the protected areas were set up before the grazing season started, growth was slow and the increase in herbage height with time was almost linear. In Period 2 the relationship was quadratic, herbage height increasing slowly for the first week or ten days and then increasing more rapidly. Weekly increases in height, expressed as a percentage of the total increase, are presented in Table E2.1.

The effect on herbage growth of protected areas moved after different lengths of time

Cumulative increases in herbage height over fortnightly periods using protected areas moved twice weekly (A), weekly (B) or fortnightly (C) are shown in Table E2.2. In each fortnight, the increase in herbage height was always greater within the stationary protected area (C) than the cumulative increase obtained by A and B. The increase in herbage height in each fortnight and the total increase over eight weeks was greater the longer the protected area remained in a given position.

Table E2.2 Cumulative increases in herbage height (cm) using protected areas moved after different periods of time

Date	Protected area		
	A	B	C
13 June-27 June	2.9	3.4	5.9
27 June-11 July	4.4	5.5	5.6
11 July-25 July	3.4	4.2	5.0
25 July- 8 August	6.1	6.5	7.8
TOTAL	16.8	19.6	24.3

Discussion

In April (Period 1) herbage growth was slow and herbage height increased almost linearly with time (Table E2.1) so that the increase in height between each observation was similar until the last few days of the period when it rose (Fig E2.1). But in Period 2, as the grazing season progressed, herbage grew faster and the regrowth curve was quadratic. This agrees with work by Brougham (1955) who established that the regrowth curve of closely grazed or mown swards is broadly sigmoid in form. The duration of the initial exponential phase depends on the closeness of defoliation because the amount of herbage residue affects the rate of regrowth of the sward. Brougham (1956) found it to last 20 days following defoliation to 2.5 cm height in spring, and about 12 days following defoliation to 7.5 cm, while swards defoliated to 12.5 cm had passed out of the exponential phase of regrowth within 4 days. Similarly in this experiment, the duration of the exponential growth phase depended on the initial height within the protected area; it lasted approximately 21 days with initial herbage heights of 2.5-3.5 cm in Period 1, while initial heights of 4.7, 5.7 and 7.3 cm in Period 2 led to exponential phases of approximately 15, 12 and 6 days respectively (see Fig E2.1).

Following the exponential phase of regrowth, swards entered a phase characterized by an approximately constant rate of increase in herbage height. This occurred when the herbage reached 10-13 cm. Brougham (1956) associated entry into this phase with absorption by the leaf canopy of about 95% of the incident light, so that growth rate is largely light-limited and highly correlated with seasonal trends in solar radiation (Brougham, 1959). Eventually growth rate

Table E2.2 suggests that protected areas affect the growth of herbage within them. Cowlishaw (1951) also using a fortnightly sampling period, and Owensby (1969) found that growth under cages was greater than outside in the absence of grazing. Heady (1957) recorded higher yields on Californian annual grassland under wire cages than outside during the cooler months, but no difference during periods of rapid growth. Jagtenburg and De Boer (1958) in the Netherlands found that yield under cages was 15% higher than outside on clay soils.

Cages, fences and hurdles reduce wind velocity and increase the temperature and relative humidity inside the structures (Williams, 1951; Dobb and Elliott, 1964) which can increase growth. These effects on the micro-environment within exclosures can be reduced by using wire or electrical cages (Prendergast and Brady, 1955) but differences can be expected between protected and grazed areas due to trampling and fouling, and yield also increases as the frequency of defoliation decreases (Stapledon, 1924; Wolton, 1972). t'Mannetje (1978) concluded that the magnitude of the effect of exclosures is directly related to the length of time they are in a given position and Table E2.2 appears to confirm this even though the difference was only between 3 and 14 days.

In Experiment 1, the change in herbage height within protected areas moved fortnightly gave an estimate of herbage growth which was used to calculate net accumulation once a height/weight relationship it. Free from the effects of trampling, fouling and defoliation, it is possible that herbage regrowth entered the linear phase discussed earlier. Brougham (1956, 1960) has shown that longer stubble leads to a faster regrowth, and this appears to be due to the greater leaf area giving an increase in light interception. Therefore the growth of herbage in these areas does not bear any exact relationship to the herbage growing outside them, whereas the lower values obtained by moving the protected areas twice weekly (Table E2.2) are likely to be more representative of the growth on the grazed area.

Using the linear and quadratic relationships between herbage height and herbage weight established for the day field, Period II in Experiment 1 (Table E1.8), the results in Table E2.2 can be converted to a measure of net herbage accumulation and summed to give an estimation of net herbage accumulation for the eight weeks of the study (Table E2.3). On average total net herbage accumulation using the linear and quadratic regression was estimated to be 45% and 10% higher respectively using protected areas moved fortnightly (C) compared to those moved twice weekly (A). As herbage height increases, the increase in herbage mass becomes progressively smaller using the quadratic regression (see Fig E1.5), so that the large increase in herbage height within protected area C did not lead to as great a difference in net accumulation as was obtained using the linear regression.

Table E2.3 Net herbage accumulation within each fortnight and for the eight weeks of the study

Date	Regression eqn used	Protected area A	Protected area B	Protected area C
13 June-27 June	Linear	584	684	1187
	Quadratic	1117	1233	1631
27 June-11 July	Linear	885	1107	1127
	Quadratic	1664	1891	1762
11 July-25 July	Linear	684	845	1006
	Quadratic	1235	1459	1591
25 July- 8 August	Linear	1227	1308	1569
	Quadratic	1947	1772	1602
TOTAL	Linear	3380	3944	4889
	Quadratic	5963	6355	6586

These results do not imply an optimum length of time for which such protected areas should be left in position, but they do suggest that protected areas directly affect herbage growth within them and that the length of time that they were left in position was probably the cause of the exceptionally high estimates of net herbage accumulation obtained in Experiment 1.

EXPERIMENT 3 A comparison of three methods of measuring herbage height for the estimation of herbage mass

Introduction

There are many occasions when it is desirable to obtain estimates of herbage mass without cutting the sward. Non-destructive methods of estimating herbage mass can involve the use of either the electrical capacitance type of meter or simple meters based on the measurement of the height of herbage as described previously (see Review, Section III). Height-measuring types of instrument have advantages over the electronic capacitance meters because of their simplicity of construction and use. Three such instruments used in the estimation of herbage mass are the simple disc instrument developed, tested and used at the Hannah Institute (Castle, 1976), the grass meter developed by the Milk Marketing Board (MMB - Notes for Users), and the metre rule used at the Grassland Research Institute (Hodgson *et al*, 1971).

The opportunity was taken in this experiment to evaluate and compare the performance of these three instruments when used to measure herbage height on a range of grazed and conserved swards. The position of the disc of the disc instrument and the plate of the grass meter is not solely determined by the height of the herbage, but for ease of expression, the measurements will be referred to as 'height'.

Experimental materials and methods

Design and use of instruments

The disc instrument consists of an aluminium shaft marked in divisions of 0.5 cm and two linked discs made of 20 gauge aluminium sheet and weighing approximately 211 g (Fig E3.1). In use, the shaft was held vertically with its base on the ground and the discs were

Fig E3.1 The Disc Instrument

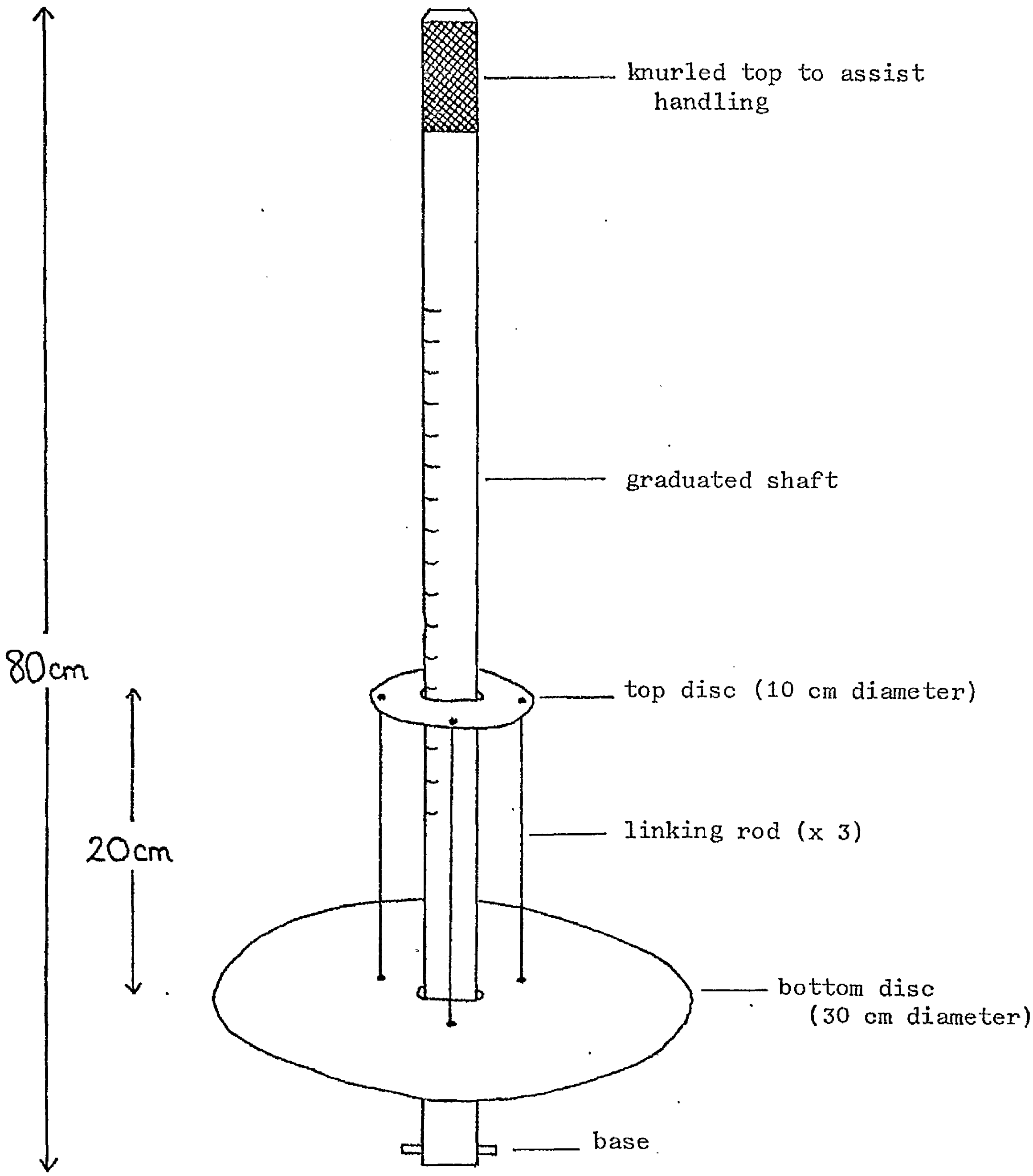


Fig E3.2 The Grassmeter

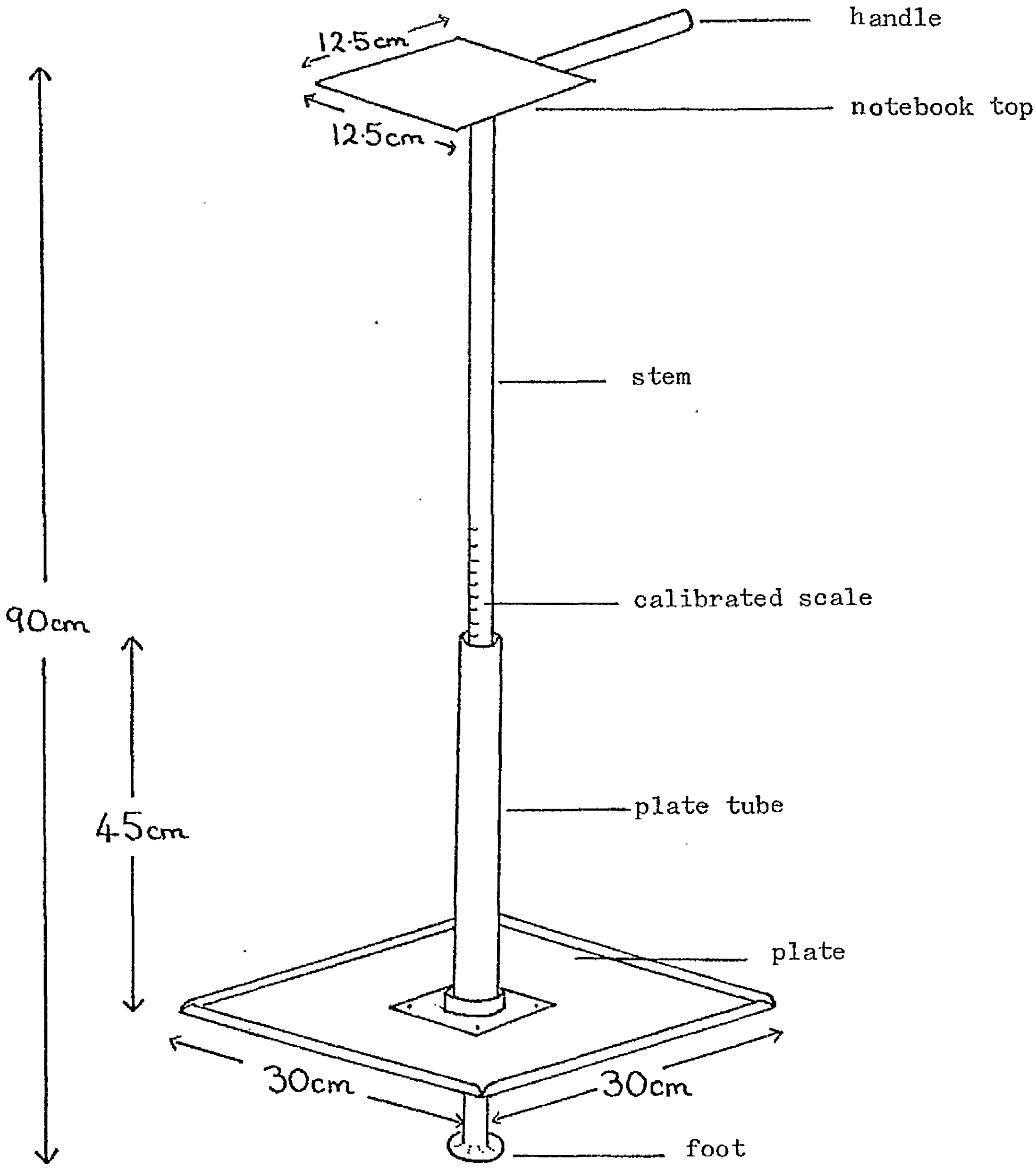


Plate 6 Use of the grass disc

Plate 7 Use of the grass meter

Plate 8 Use of the graduated ruler

placed over the shaft with the small disc uppermost. When the basal disc settled to a constant position on the herbage, the height was read from the position of the small top disc against the graduated shaft (Plate 6).

The grass meter consists of a metal plate attached to a vertical plate tube which slides smoothly over a calibrated stem. The plate and plate tube together weigh approximately 434 g. To take a reading, the grass meter was held by the handle so that the stem was vertical, and the foot lowered through the herbage until it rested securely on the ground. The plate was held up by the herbage beneath it and the height read off where the plate tube came to rest against the graduated scale (Plate 7). Although the stem is marked in 1 cm divisions, measurements were read to an accuracy of 0.5 cm.

In this experiment, an ordinary plastic half-metre ruler was used rather than the metre rule used at G.R.I. (Hodgson *et al*, 1971). The graduated ruler was held upright in the sward, its base on the ground, and the average height of a small number of adjacent leaves was measured to an accuracy of 1 cm after extending them fully up the ruler (Plate 8).

Fields

Height measurements were mainly taken on three perennial ryegrass (*Lolium perenne*) leys, varieties Hora, Perma and Talbot, conserved for silage, covering first and second growth.

Measurements were also made on three perennial ryegrass (*Lolium perenne*) leys and two permanent pastures set-stocked by dairy cows.

Procedure

Between May and August 1979 measurements were taken on the eight swards using the following procedure: on each occasion 25 height measurements were taken with the grass disc at 20-pace intervals in a W-pattern across each of the fields being studied. Results were recorded in a hand dictophone and the procedure repeated using the grass meter and the graduated ruler. A mean height was calculated for each field using each of the three instruments. Relationships were established between the methods by regression analysis(Appendix Table 10).

Results

The relationship between the graduated ruler and the grass disc, the graduated ruler and the grass meter, and the grass meter and the grass disc, are presented graphically in Figs E3.3, E3.4 and E3.5 respectively. Regression analyses were carried out separately on the data from the silage swards, the grazed swards and on all the data. Correlation coefficients and the coefficients of all regressions are given in Table E3.1.

The results show that highly significant relationships ($P < 0.001$) existed between herbage height as measured by each of the methods studied. The r^2 value for the data from grazed swards, silage swards and all swards, ie the percentage of variation explained by the regression, was similar for both relationships involving the grass disc (GD) and averaged 89.9, 93.4 and 95.2 % respectively. The r^2 values for the graduated ruler (GR) v grass meter (GM) relationship

Fig E3.3 The relationship between herbage height measured by the graduated ruler and the grass disc

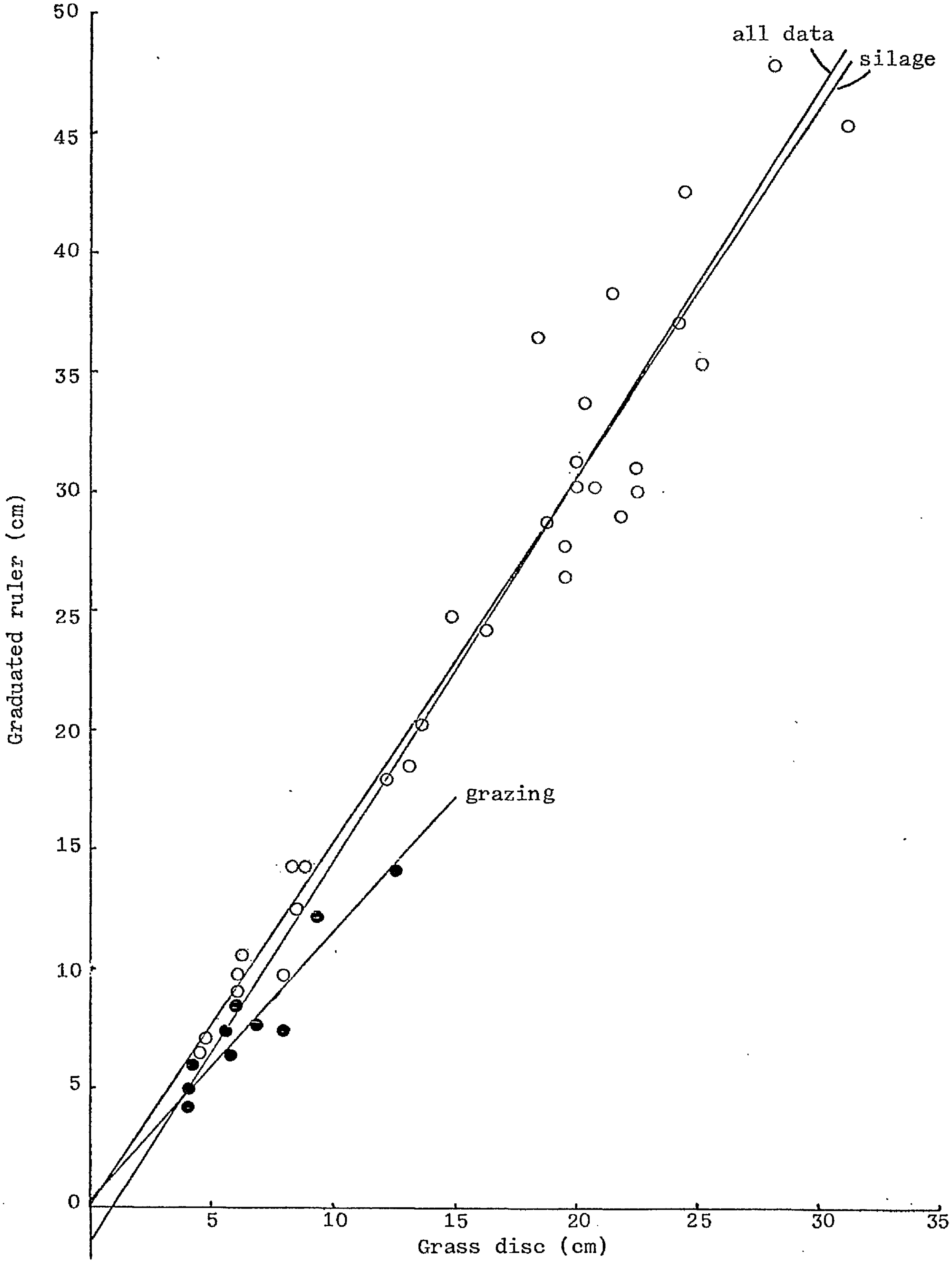


Fig E3.4 The relationship between herbage height measured by the graduated ruler and the grass meter

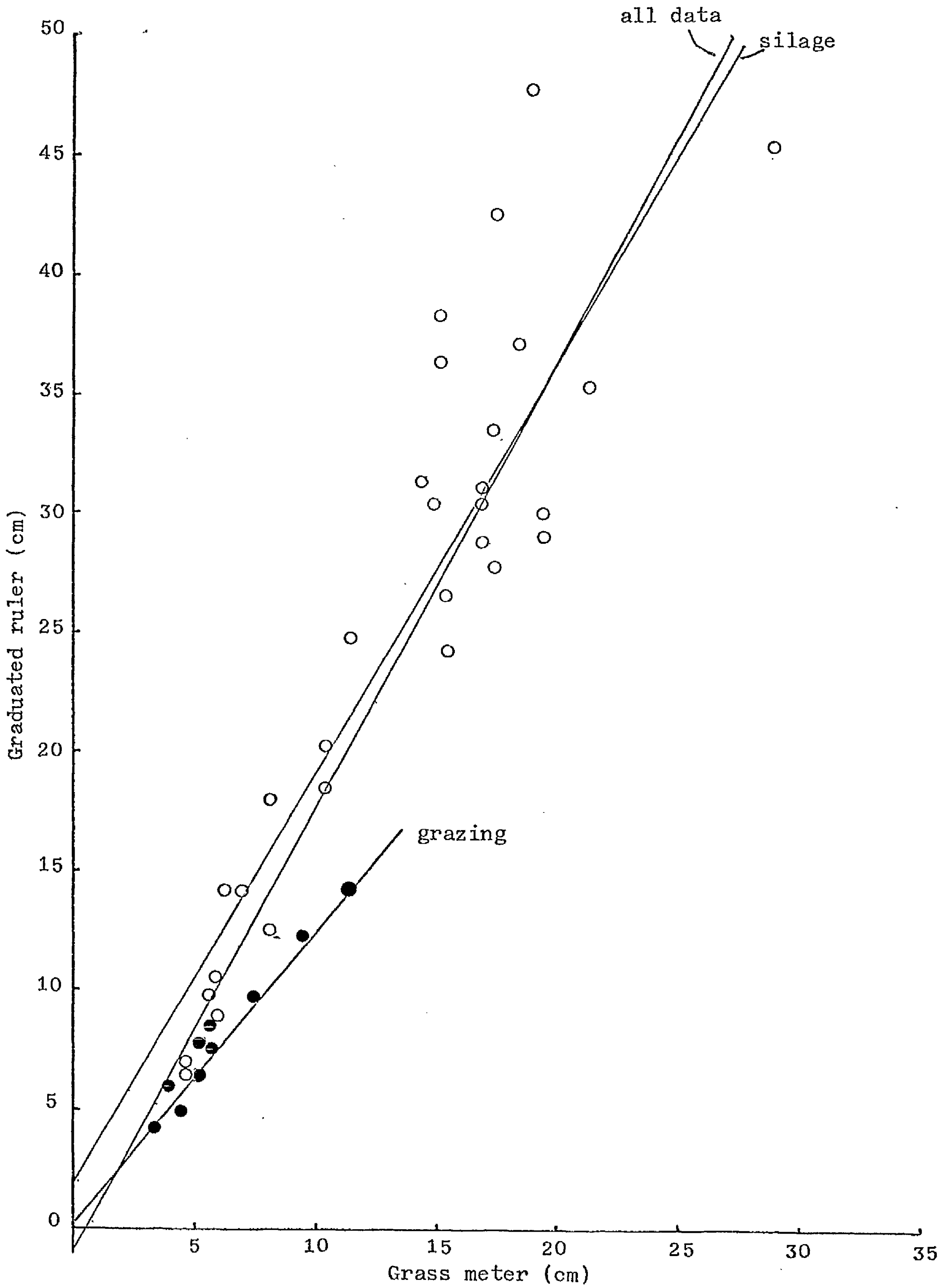


Fig E3.5 The relationship between herbage height measured by the grass meter and the grass disc

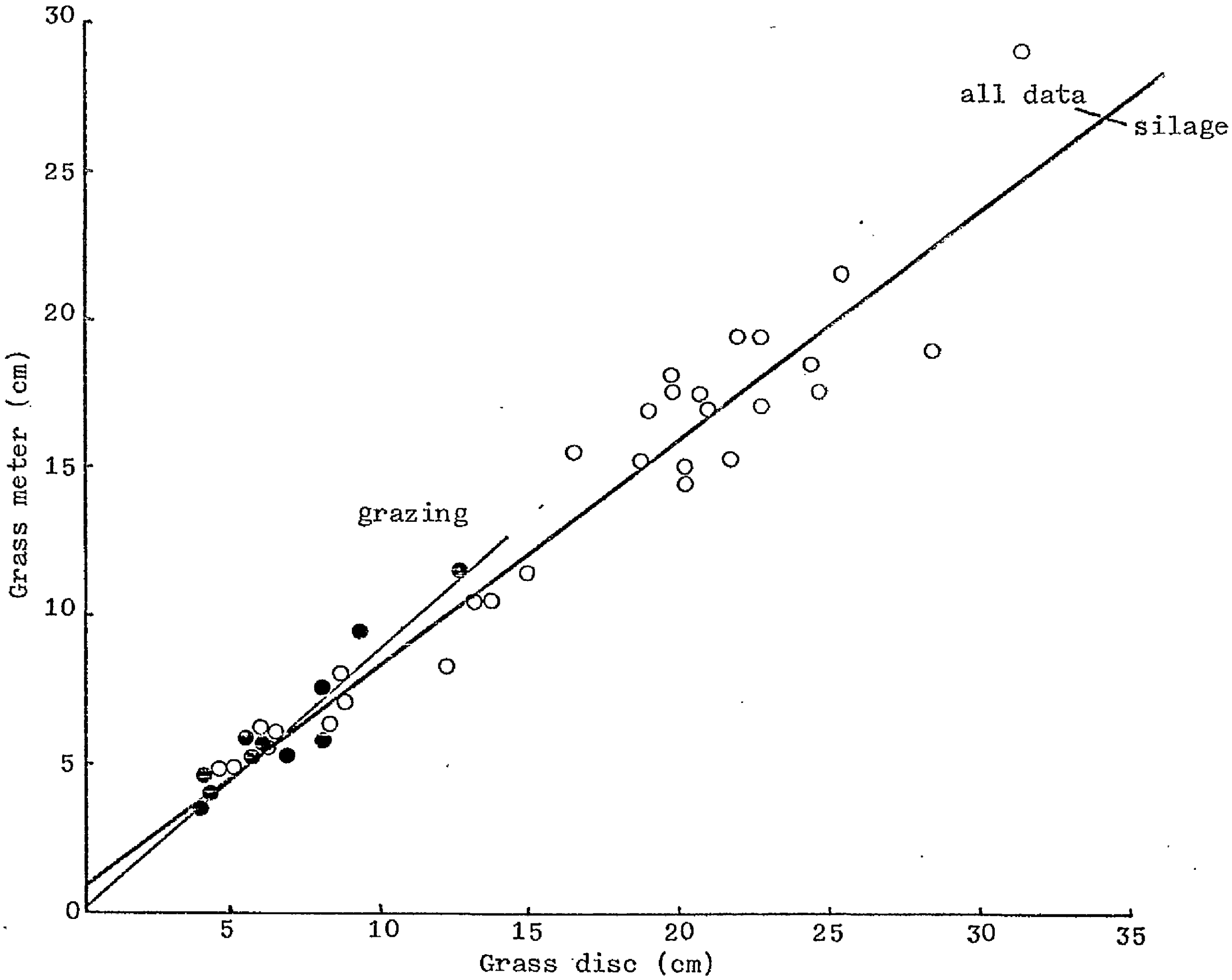


Table E3.1 The relationship between herbage height (cm) as measured by the grass disc (GD), grass meter (GM) and graduated ruler (GR)

Relationship	Data	No of observations	Coefficients of regression equation: Constant (± SE)	Coefficients of regression equation: Linear (± SE)	SE of estimate (±)	Correlation coefficient (r)	r^2
GR (y) v GD (x)	Grazed	11	0.61 (0.909)	1.11 (0.126)	1.03	+ 0.946 ***	89.5
	Silage	30	0.41 (1.337)	1.51 (0.073)	2.94	+ 0.969 ***	93.9
	Grazed + silage	41	-1.26 (0.896)	1.58 (0.056)	2.77	+ 0.977 ***	95.5
GR (y) v GM (x)	Grazed	11	0.48 (0.478)	1.23 (0.072)	0.55	+ 0.985 ***	97.0
	Silage	30	1.84 (2.434)	1.73 (0.162)	5.26	+ 0.895 ***	80.1
	Grazed + silage	41	-1.17 (1.622)	1.88 (0.122)	4.84	+ 0.927 ***	85.9
GM (y) v GD (x)	Grazed	11	0.17 (0.702)	0.89 (0.098)	0.79	+ 0.950 ***	90.3
	Silage	30	0.76 (0.744)	0.78 (0.041)	1.63	+ 0.964 ***	92.9
	Grazed + silage	41	0.85 (0.467)	0.78 (0.029)	1.45	+ 0.974 ***	94.9

showed that the regression explained 97.0, 80.1 and 85.9 % of the total variation for the grazed swards, silage swards and all swards.

When the graduated ruler was compared with the grass disc (Fig E3.3) and the grass meter (Fig E3.4) the slopes of all three regression lines (ie the linear value of the regression equations), were higher than those obtained when the grass disc and grass meter were compared. Lower slopes were also found for the grazed swards than for the silage swards which in turn were lower than those obtained for all swards, whereas the GM v GD (Fig E3.5) gave higher slopes for the grazed swards than for the silage swards and combined swards whose slopes were identical. However, the difference in the slopes of the regressions fitted to the data from silage and grazed swards within each of the relationships was not significant.

The SE of the estimates which ranged from 0.55 to 5.26 cm was always lower on the grazed swards, and was greatest for the silage swards and a combination of all swards when the graduated ruler and grass meter were compared.

Discussion

All three instruments are inexpensive to construct, easy to use, and only the grass disc needed minor repairs because of the loosening of one linking rod. There are major advantages compared with the complex electronic measuring types of equipment which require careful handling and maintenance. The grass disc and meter were quick to use eg 25 readings could be taken and recorded in about 5 mins. The 'extended height' method using the graduated ruler was slower eg 25 readings took about 7 mins to take and record, and this method was also far more subjective as the operator had to estimate the average height of the number of adjacent leaves when extended up the ruler.

Linear regressions were not fitted through the origin because zero readings did not correspond between the three instruments. The negative intercept obtained when the regression was fitted through all the data in Figs E3.3 and E3.4 was not significant. Results in Table E3.1 show that 1 cm on the disc and the meter was equivalent to a height of 1.58 and 1.88 cm respectively on the ruler when data was pooled from grazed and silage swards. Because the leaves were fully extended up the ruler when measurements were taken, a higher estimate of herbage height was given than with the other instruments. This was particularly apparent on laid silage swards. A height of 1 cm on the grass disc corresponded to 0.78 cm on the grass meter for pooled data. The lower values recorded with the grass meter were probably due to the way in which it was used and the weight of the plate and plate tube. Although both instruments were held up by the herbage beneath them,the grass disc was lowered gently onto the sward whereas the plate of the meter rested on the herbage as the foot was pushed through the sward. On less dense silage swards especially near cutting, the herbage tended to be flattened by the plate as the foot was pushed through it, and the extra weight of 434 g compared with the disc of 211 g would also compress the herbage giving lower readings. The addition of 1 kg to their weighted-disc grass meter gave Phillips and Clarke (1971) consistently lower estimates of herbage height than the disc and shaft alone. The comparatively higher results obtained by the graduated ruler and the lower results obtained by the grass meter when herbage is tall and maybe lain, would account for the higher SE of the estimates and lower correlation coefficient for the silage and pooled swards when these methods were compared.

Lower slopes were obtained when the data from grazed swards using the graduated ruler was plotted against data from grazed swards using the grass disc or grass meter. On shorter, denser grazed swards the higher values associated with the ruler on silage swards did not occur to such an extent, and 1 cm on the disc and meter corresponded to 1.11 and 1.23 cm on the ruler respectively. (Note that the difference was again greater between the ruler and the grass meter). The problem of the meter flattening tall herbage was reduced on the shorter grazed swards so that the slope of the regression line was increased when results were compared with the grass disc.

Although no relationship between height and weight was determined, this study shows that a highly significant relationship exists between measurements of herbage height using each of the three instruments described. Herbage height may be used to obtain estimates of herbage mass without cutting the sward (t'Mannetje, 1978) but these results suggest that herbage height measurements will differ according to the instrument used. Therefore care needs to be taken when comparing experiments where herbage height has been measured eg in the estimation of herbage height below which animal intake is depressed.

GENERAL DISCUSSION

The grazing process involves a two way interaction between plant and animal. The study of sward parameters in experiments of this kind give an indication of the effects of grazing management on herbage production and utilisation.

The major work in this thesis was designed to examine the effect of stocking rate in the early part of the season on herbage production and utilisation. Two smaller experiments examined aspects of the use of grass height in the measurement of herbage production and utilisation.

The effect of stocking rate in the early part of the grazing season on herbage production and utilisation

In Experiment 1, the imposition of three stocking rates of dairy cows for the first 7 weeks of the grazing season, led to significant effects on herbage production, quality and utilisation, and these effects were carried over into the later part of the season.

Undergrazing of swards in early season (Treatment L) led to the development of a mosaic of severely and laxly grazed areas with patches of long rank herbage forming because the cows selectively grazed herbage away from dung pats. These undergrazed areas were also characterised by increased aerial tillering and accumulation of litter in the base of the sward. The greater herbage DM production of Treatment H probably occurred because the high stocking rate in spring produced a sward of immature dense herbage capable of attaining high daily net accumulation rates even though sward height was comparatively low for most of the season. Plant growth did not appear to be depressed by an increase in stocking rate, but any depression that might have occurred would have been balanced by the decrease in decomposition losses as indicated by the amount of dead material in the base of the sward. Higher herbage production was also encouraged by a higher rate of return of nutrients from dung and urine as stocking rate increased.

A high stocking rate in spring produced herbage with a greater crude protein, potassium and phosphorus content and slightly higher digestibility.

Tiller populations increased over the season on all treatments in contrast to the observed fall in monthly cutting and rotational grazing studies. The difference between treatments in tiller population was small and non-significant.

Many of the differences in the results between the day field and the night field, eg in herbage height, chemical composition, tiller population and aerial tillering, amount of litter, herbage production, were attributed to a difference in grazing pressure rather than to the different sward composition in the two fields. It is possible that results would have been similar had the grazing area been divided on a more equal basis rather than on the 60:40 basis in favour of the day field.

Although animal performance data was mainly used to estimate herbage utilisation, results in Table E1.11 shows that cows on Treatment H produced on average 1 kg of milk more per day over the grazing season than cows at lower stocking rates in spring. Cows liveweight was lower on Treatment H in Periods I and II but their liveweight gain was greater in Period III so that at the end of the experiment there was very little difference in individual cow liveweight between treatments. At the highest stocking rate in the early season, cows were able to overcome the constraints imposed upon them by increasing their frequency of defoliation. As under rotational grazing, the herbage intake of animals continuously stocked is affected by the severity of grazing which can be related to herbage height. Although intakes may have been depressed on herbage of 4-5 cm, utilisation increased on Treatment H where a high stocking rate was imposed early in the season.

A high stocking rate in early season can thus lead to several practical benefits; improved sward quality and quantity, improved performance per animal and particularly per hectare, and the release of land from grazing for more conservation.

Experimental techniques

Measuring herbage height with the grass disc proved a useful guide to herbage availability on the treatment areas over the grazing season. This technique of measuring herbage mass was used because the study was carried out on a large scale (10 hectares). Although it overcame many of the disadvantages of more laborious herbage cutting techniques, some problems were experienced when it was calibrated to establish the relationship between herbage height and herbage mass. Different predictions of herbage mass were obtained depending on whether a linear or quadratic relationship was fitted to the data. However, the quadratic relationship was more precise (ie the correlation coefficient was higher and the S.E. of the estimate lower) than the corresponding linear relationship in each period. An additional problem was that in calibrating the disc, the herbage heights examined only covered the range up to 15 cm, but the heights within the protected areas were up to 24 cm. It is important particularly if curves are fitted to the data that the calibrations cover the range of data to be used for the prediction of herbage mass. The inclusions in the calibrations of samples taken in the longer herbage inside the protected areas at the end of each fortnight would have extended the range of calibrations and avoided extrapolating from limited data.

It is important that the exclosures used in the estimation of herbage production are positioned on an area representative of the grazed area as a whole. In Experiment 1 the protected areas were situated at random and on occasions the herbage within them differed in height from the grazed area. The greatest source of error attached to their use appeared to be the length of time they were left in position and the effect this had on herbage growth. Experiment 2 confirms that herbage of 5 cm or more is capable of entering the exponential phase of growth as defined by Brougham (1956), when protected from defoliation for 2 weeks. Herbage growth in exclosures should be representative of the growth on the grazed area around them. The results of Experiment 2 suggest that leaving them in place for 2 weeks can lead to an overestimation of net herbage accumulation, particularly when initial heights are over 5 cm.

Leaver (1978) used similar techniques to those used in Experiment 1 to measure herbage production and utilisation on a set-stocked system for dairy cows. No problems were experienced with the use of similar protected areas, reasonable estimates of herbage production were calculated, and the grass disc estimate of herbage utilisation was only 7.6 % greater than that estimated by the UME method. However rainfall during the 1977 grazing system when Leaver undertook his experiment was only 74 % of average and only 44 % of average in June and July. Herbage height averaged 3-4 cm for much of the grazing season, regrowth was slow and so the growth inside protected areas was similar over a fortnightly period to that of the grazed sward.

The height of either the residual herbage under rotational grazing or the whole sward under continuous stocking gives a simple estimate of the severity of grazing and can be related to herbage consumption and animal production. The results in Experiment 3 show how estimates of herbage height vary according to the technique used. It is therefore important that the technique is stated in published results so that comparisons between experiments can be made. The regression equations relating the three methods will be useful for this purpose.

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APPENDIX

Appendix Table 1 Allocation of 'marker' cows to treatments in Experiment 1

Treatment																	
L						M						H					
COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score	COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score	COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score
231	1	21.2	94	510	2	498	1	20.2	78	500	2¼	505	1	20.0	77	500	2¾
232	1	22.2	72	560	2¾	513	1	20.5	46	500	2¼	515	1	20.8	62	520	3¼
567	2	26.2	86	510	2	561	2	28.2	72	545	1	463	2	28.2	76	510	¾
459	2	28.4	89	605	3¼	467	2	24.6	84	565	2	483	2	25.0	97	600	2½
566	2	29.8	24	555	1¼	454	2	28.2	13	570	2¼	572	2	32.0	29	600	3
227	1	23.0	111	470	1¾	693	1	22.8	129	570	2¼	229	1	24.0	99	550	1¼
462	2	33.0	62	625	2½	565	2	32.8	60	620	2¼	685	2	31.4	47	585	2¾
237	3+	30.0	54	610	2½	291	6	31.4	54	590	2½	239	3+	28.0	48	590	2½
275	4	34.0	63	665	2¼	395	3	35.0	65	625	3¼	294	5	34.0	56	640	3¼
278	4	34.0	80	675	2¾	381	3	38.0	83	630	2½	268	4	38.0	79	580	2¼
316	5	31.0	90	600	2¾	374	3	31.2	86	585	1¾	390	3	31.0	76	575	1½
Mean	2.5	28.4	75	580	2¼	Mean	2.4	28.4	70	573	2¼	Mean	2.4	28.4	68	568	2¼

Appendix Table 2 Allocation of remaining cows to treatments in Experiment 1

Treatment

L

COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score
514	1	22.4	72	475	1¾
407	3	38.0	57	620	2
230	1	23.0	98	550	2
595	1	26.4	74	505	2½
Mean	1.5	26.2	77	539	2
235	1	26.2	58	555	2
238	3+	35.5	54	615	1¾
Mean	2	30.9	56	585	2

M

COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score
496	1	23.0	59	530	1¾
380	3	38.0	55	630	2½
518	1	25.5	78	485	2
526	1	27.6	85	490	1½
Mean	1.5	27.2	71	531	2
471	2	36.0	53	505	1
394	3	31.6	79	700	2¾
240	2	31.0	35	505	1
682	2	34.0	85	560	1¾
310	6	24.2	26	595	3¼
Mean	3	31.4	56	573	2

H

COW	Lact^n No	Yield (kg day^{-1})	Days from calving	Livewt (kg)	Cond^n score
508	1	26.0	69	490	2¾
236	3+	39.0	55	640	2¾
507	1	22.0	79	465	1¾
490	1	26.8	85	485	1¾
Mean	1.5	26.6	70	506	2¼
233	1	20.4	23	605	2¾
458	2	22.6	75	590	3¼
564	2	39.0	39	535	1¼
241	2	24.0	40	545	1
342	3	32.0	77	560	2½
302	5	23.0	64	550	2½
474	2	41.6	82	610	1¼
587	2	34.0	80	725	2½
Mean	2.4	29.6	60	590	2¼

Appendix Table 3 Level of concentrate supplementation used in Experiment 1

Mean Grass Height (cm)	SEASON Early (Period I)	Mid (Period II)	Late (Period II)
10	23	17	12
9	22	16	11
8	21	15	10
7	19	13	8
6	16	10	5
5	12	6	0
4	7	0	
3	0		
2			

The above figures refer to milk production (kg per day) supported by these grass heights.

Concentrates were fed at a rate of 0.45 kg/kg of milk above these levels of production.

eg in Mid Season at a mean grass height of 7 cm, concentrates were fed at 0.45 kg/kg above 13 kg of milk.

Appendix Table 4 Meteorological records at Crichton Royal: 1978, 1979 and mean for 1941-70

	March	April	May	June	July	Aug	Sept	Oct	TOTAL
				Monthly rainfall (mm)					
1978	91.0	25.8	6.9	57.6	49.3	81.7	69.6	21.5	403.4
1979	117.4	63.6	65.3	30.0	49.3	142.3	65.1	143.3	676.3
Mean 1941-70	67.0	64.0	77.0	68.0	85.0	99.0	112.0	106.0	678.0
				Duration of sunshine (hr)					
1978	90.2	113.7	201.2	178.6	151.2	113.5	101.2	78.3	1027.9
1979	90.6	146.1	155.0	176.4	114.2	159.9	141.0	70.4	1053.6
Mean 1941-70	101.4	142.3	180.8	179.7	152.1	146.5	108.1	86.3	1097.2
				Mean daily temperature (^{o}C)					
1978	5.8	6.4	12.2	12.8	13.8	14.3	13.1	10.8	
1979	3.8	6.8	8.1	13.4	14.0	13.6	11.9	10.7	
Mean 1941-70	5.1	7.5	10.3	13.3	14.5	14.4	12.6	9.7	

Appendix Table 5 Analyses of variance of herbage height (cm), and of the standard deviations and coefficients of variance (%) of herbage height

Source	df	Mean square		
		Herbage height	Standard deviation	Coefficient of variance
Treatments	2	40.70 ***	23.26 ***	413.56 *
Periods	2	25.00 ***	46.48 ***	3984.89 ***
Fields	1	26.15 ***	1.08 NS	3767.63 ***
Treatments x periods	4	11.08 ***	8.00 ***	0.61 NS
Treatments x fields	2	4.88 **	0.03 NS	1.09 NS
Fields x periods	2	3.78 *	0.24 NS	2.32 NS
Treatments x periods x fields	4	0.27 NS	0.19 NS	0.21 NS
Error	108	1.88	0.96	119.10
Total	125			
CV		19.3 %	27.6 %	22.0 %
RSD		± 1.371	± 0.980	± 10.913

Appendix Table 6 Analyses of variance of herbage dry matter (g kg^{-1}), organic matter (g kg^{-1} DM) crude protein (g kg^{-1} DM), D-value and metabolisable energy (MJ kg^{-1} DM)

Source	df	Mean square				
		Dry matter	Organic matter	Crude protein	D-value	Metabolisable energy
Treatments	2	748.25 NS	960.64 ***	4481.43 **	16.32 NS	0.97 NS
Periods	2	16044.30 ***	4250.31 ***	31516.66 ***	478.01 ***	21.24 ***
Fields	1	5117.60 ***	11314.57 ***	14528.64 ***	4.31 NS	0.26 NS
Treatments x periods	4	155.40 NS	116.10 NS	656.92 NS	17.23 NS	0.91 NS
Treatments x fields	2	472.00 NS	207.31 NS	1825.96 NS	23.18 *	1.32 *
Fields x periods	2	153.95 NS	238.03 NS	1597.24 NS	11.89 NS	0.66 NS
Treatments x periods x fields	4	171.00 NS	14.69 NS	450.65 NS	15.07 NS	0.81 NS
Error	108	482.01	108.85	892.92	6.81	0.38
Total	125					
CV		13.6 %	1.2 %	12.6 %	3.9 %	5.5 %
RSD		± 21.955	± 10.433	± 29.882	± 2.610	± 0.616

Appendix Table 7   Analyses of variance of herbage mineral content (g kg^{-1})

		Mean square			
Source	df	Calcium	Phosphorus	Magnesium	Potassium
Treatments	2	0.08 NS	1.70 ***	0.18 NS	116.83 ***
Periods	2	2.68 ***	16.77 ***	0.34 *	580.20 ***
Fields	1	0.17 NS	6.00 ***	14.00 ***	1634.40 ***
Treatments x periods	4	0.26 NS	0.11 NS	0.07 NS	12.44 NS
Treatments x fields	2	0.16 NS	0.66 *	0.10 NS	44.14 *
Fields x periods	2	0.41 NS	0.23 NS	0.03 NS	11.58 NS
Treatments x periods x fields	4	0.04 NS	0.09 NS	0.01 NS	12.48 NS
Error	108	0.27	0.21	0.08	11.14
Total	125				
CV		10.7 %	10.2 %	11.5 %	9.4 %
RSD		± 0.520	± 0.458	± 0.283	± 3.338

Appendix Table 8 (a) Linear regression analysis of herbage height (cm) (x) on herbage mass (kg DM ha^{-1}) (y)

Day field

Source	df	Period I Mean square	df	Period II Mean square	df	Period III Mean square
Regression	1	12975482	1	8984912	1	24072880
Residual	25	153989	18	159451	20	212553
Total	26		19		21	
RSD		± 392.414		± 399.313		± 461.035

Night field

Source	df	Period I Mean square	df	Period II Mean square	df	Period III Mean square
Regression	1	8340230	1	18601552	1	21584128
Residual	25	152993	20	347428	21	139864
Total	26		21		22	
RSD		± 391.143		± 589.430		± 373.984

(b) Quadratic regression analysis of herbage height (cm) (x) on herbage mass (kg DM ha^{-1}) (y)

Day field

Source	df	Period I Mean square	df	Period II Mean square	df	Period III Mean square
Regression	2	64557616	2	87491136	2	114300000
Residual	25	149972	18	155815	20	205800
Total	27		20		22	
RSD		± 387.262		± 394.734		± 453.652

Night field

Source	df	Period I Mean square	df	Period II Mean square	df	Period III Mean square
Regression	2	49103360	2	113700000	2	69086144
Residual	25	127987	20	315500	21	138355
Total	27		22		23	
RSD		± 357.627		± 561.694		± 371.961

Appendix Table 9 Analyses of variance of components of monthly tiller counts; total tiller population (m^{-2}), live tiller population (m^{-2}), dead tiller population (m^{-2}), dry weight live tillers ($kg\ ha^{-1}$), dry weight dead tillers ($kg\ ha^{-1}$), dry weight litter ($kg\ ha^{-1}$) and total dry weight ($kg\ ha^{-1}$)

Source	df	Mean square		
		Total tiller population	Live tiller population	Dead tiller population
Treatments	2	2550148 NS	2654910 NS	16416 NS
Dates	5	18753456 **	21681952 ***	413776 ***
Fields	1	12299197 *	13601131 *	32744 NS
Treatments x dates	10	584817 NS	553732 NS	20353 NS
Treatments x fields	2	2239012 NS	555388 NS	1244 NS
Fields x dates	5	625451 NS	2290360 NS	158824 *
Error	10	2131627	1964691	37373
Total	35			
CV		9.7 %	9.0 %	79.9 %
RSD		± 1460.009	± 1401.674	± 193.321

Appendix Table 9 ... continued

Source	df	Mean square			
		Dry weight live tillers	Dry weight dead tillers	Dry weight litter	Total dry weight
Treatments	2	955700 *	106.2 NS	42680 NS	1360000 *
Dates	5	1226900 **	5099.7 **	82160 *	1738700 **
Fields	1	529400 NS	93.2 NS	255140 **	1424200 *
Treatments x dates	10	201100 NS	493.1 NS	45810 NS	174600 NS
Treatments x fields	2	152600 NS	94.3 NS	53310 NS	363500 NS
Fields x dates	5	189400 NS	4743.3 **	90610 *	295800 NS
Error	10	129800	603.3	16390	191200
Total	35				
CV		11.2 %	89.6 %	50.9 %	12.6 %
RSD		± 360.278	± 24.562	± 128.023	± 437.264

Appendix Table 10 (a) Regression analysis of herbage height (cm) measured by the grass disc (x) on herbage height (cm) measured by the graduated ruler (y)

Source	df	Grazed swards Mean square	df	Silage swards Mean square	df	All swards Mean square
Regression	1	80.96	1	3666.24	1	6172.38
Residual	9	1.05	28	8.64	39	7.70
Total	10		29		40	
RSD		±1.025		±2.939		±2.775

(b) Regression analysis of herbage height (cm) measured by the grass meter (x) on herbage height (cm) measured by the graduated ruler (y)

Source	df	Grazed swards Mean square	df	Silage swards Mean square	df	All swards Mean square
Regression	1	87.69	1	3133.52	1	5558.62
Residual	9	0.30	28	27.66	39	23.43
Total	10		29		40	
RSD		±0.548		±5.259		±4.840

(c) Regression analysis of herbage height (cm) measured by the grass disc (x) on herbage height (cm) measured by the grass meter (y)

Source	df	Grazed swards Mean square	df	Silage swards Mean square	df	All swards Mean square
Regression	1	52.40	1	975.64	1	1488.39
Residual	9	0.63	28	2.67	39	2.09
Total	10		29		40	
RSD		±0.794		±1.634		±1.446