STUDIES ON DURATION OF GRAZING AND DEFOLIATION IN LUCERNE

a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Massey University New Zealand

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Alfalfa, whose luxuriant herbage feeds
The lab'ring ox, mild sheep, and fiery steeds:
Which ev'ry summer, ev'ry thirtieth morn,
Is six times re-produced, and six times shorn.

Old Andalusian Poem transcribed
by Rev. Harte, 1764

ABSTRACT

A project was conducted to study the influence of grazing duration (GD) on lucerne *Medicago sativa L.* 'Wairau'. GD was defined as the period of defoliation or grazing before regrowth to the early flowering stage was again permitted.

A field trial conducted for eight months from spring to autumn examined three grazing durations (GDs), 2-4, 15 and 30 days, using sheep as the grazing animal. Following this, three studies in controlled environment rooms using simulated grazing techniques allowed a more detailed study of the influence of GD and also provided an insight into the interaction of GD with climate.

In both the field and the controlled environments, total herbage production for the full duration of each of the studies was always greatest under the shortest GD (0-3 days) and least under the longest GD (30 days). In the field, total herbage production was reduced by 14% under the 15 day GD system and 29% under the 30 day GD system. However in all the studies the differences in total herbage production were generated almost entirely by differences in stem yield - there were generally no treatment differences in the total production of non-stem (leaf and new shoot) material.

The studies in the controlled environment rooms indicated that GD had less effect on lucerne herbage production under dry conditions than under moist conditions favouring rapid growth.

Detailed shoot population studies in which large numbers of shoots were individually tagged as they arose, demonstrated the impact of shoot decapitation, the relative contributions of the different shoot types and the importance of the time of shoot appearance in relation to grazing.

Differences in the immediate growth rate of the herbage following the different GDs were noted. Maximum herbage growth rates in this period followed the intermediate GDs (10-15 days) with lower growth rates after both the very short (0-3 days) and the very long (30 day) GDs. The initial regrowth inertia following the very short GD was attributed to the low number of basal shoots on this treatment at the start of the regrowth period.

However the initially reduced herbage growth rates following the 30 day GDs seemed to result from an 'earlier' partitioning of assimilate to the roots in the first half of the regrowth period following this treatment. It was postulated that this partitioning effect was generated by the 'sink' effect of the depleted root system (lowest root weight, and root TNC and starch concentrations) measured at the end of a 30 day GD.

The project has indicated that under active growth conditions, while GDs of 2-4 days will give maximum herbage production, GDs of 10-15 days will have little significant effect on the performance of mature sheep. Under dry conditions, or when grazing young lambs, even longer GDs of up to 30 days are unlikely to seriously affect stock production.

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Garth Janson

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CHAPTER 1 : INTRODUCTION

Lucerne is probably one of the oldest cultivated forage plants on this earth with a documented history of more than 2000 years.

Today it is recognised as a very valuable legume in many parts of the world because of its high yield, forage quality and wide climatic and soil adaptation. Its drought resistance has permitted substantial increases in forage production in many areas. It can provide a dependable and economical supply of good quality protein, independent of soil nitrogen. Lucerne is also an excellent source of calcium, magnesium, phosphorus and vitamins A and D.

There are two main species of lucerne, *Medicago sativa*, adapted to temperate climates, and *Medicago falcata*, a cold-hardy plant originating from northern Asia. *M. sativa* is very widely distributed. It is an upright plant, noted for its rapid growth, speedy recovery after cutting and drought resistance conferred by its deep taproot. By contrast, *M. falcata* is a more prostrate plant, winter dormant and slow to start growth in the spring. These two species have hybridised frequently so that lucerne strains cover a wide spectrum of genetic types.

Lucerne reached New Zealand about 1800 (Bolton 1962) and what became known as Marlborough lucerne owed its origin to Hunter River, Provence and Grimm. In 1950 Wairau was released in this country. It was produced from twenty foundation plants of Marlborough, and two each of Grimm, Ontario Variegated and American Commercial. Wairau is a highly productive lucerne, yielding good quality hay, but persisting and performing well under suitable grazing management. Currently it accounts for 90% of the lucerne sown in New Zealand.

Latest figures (1974) put the total area of lucerne in New Zealand at 191,000 hectares, a substantial increase from the 19,000 hectares of 1947. In the last decade the increases have been occurring in both the 'traditional' lucerne areas - Central and North Otago, Canterbury and Marlborough - and some of the regions which, until recently, were not generally associated with lucerne - West Otago, Wairarapa,

Hawkes Bay and the central North Island pumice country. This increasing use of lucerne is certainly not restricted to New Zealand. A similar trend is evident in parts of Australia, Canada and South America, and recently in some of the Middle Eastern countries, e.g. Iran, Iraq and Afghanistan.

1 : 1 PROJECT JUSTIFICATION

Associated with the expansion in the area of the crop has been an increase in its use for grazing purposes rather than simply cutting for later feeding in some conserved form. For example, in New Zealand, less than 10% of the area was used for grazing in 1947. This figure had risen to about 40% in 1966 and in 1974 was approximately 50%.

Research has been conducted on harvesting this crop for hundreds of years and a large amount of information has accumulated about it. However until recently, this research was concerned almost entirely with harvesting by cutting and very few studies were made on harvesting with the grazing animal. Fortunately, much of this work on cutting management is relevant to the grazing situation. For example, there is no reason to suggest that the importance of adequate spelling between harvesting would be materially affected by the manner in which the herbage was removed. Indeed, in all the grazing work cited below, where the stocking rate was reasonably high, lucerne plants quickly began to succumb if adequate spelling was not provided between each complete grazing.

However, replacement of the machine with the grazing animal introduces an entirely new factor into the physical process of harvesting herbage. This factor is the grazing period or grazing duration, i.e. the time taken to consume or harvest the herbage. Clearly, this is of no consequence when harvesting by machine as in practically every case the herbage is severed instantaneously near the base of the stems. In a grazing system, the grazing duration (GD) is a very important factor for it governs such things as subdivision, mob size, frequency of stock movement and water reticulation - all factors which can involve considerable labour or capital. The effects of GD have not been carefully studied as will be shown in the next section.

1 : 2 PREVIOUS WORK

1:2:1 GRAZING STUDIES

In the last decade or so, there have been a number of studies on rotational grazing systems for lucerne involving different grazing durations (GDs). However, many of these have given very little insight into the importance of GD, for the basis of comparison has confounded grazing and spelling durations. Examples of this approach are Smith (1970a, 1970b), Brownlee (1973) and Fitzgerald (1974). A consistent finding of these studies is for lucerne plant survival (often this is the only agronomic data collected) to improve as spelling duration increases and GD decreases, by increasing the number of paddocks in the rotation. In view of the importance of spelling duration, these findings, as stated, provide little understanding of GD. It is also interesting to note that the work of Smith (*loc.cit.*) demonstrated that stocking rate strongly influenced the importance of the grazing system. At very low stocking rates, the grazing system was relatively unimportant but, as stocking rate increased, the necessity for rotational grazing with an adequate number of paddocks in the cycle, rapidly increased. More recently the same principle was demonstrated again by Southwood and Robards (1975).

However, the recommendations from these trials, predictably enough, have encouraged subdivision with quick grazing and long spells. Others, with much less published evidence, have made similar recommendations (Iversen 1967, Clinton 1968, Clare 1971). However, implementation of these recommendations by the farming community has been very tardy and, under extensive farming conditions, negligible. This is not surprising in view of the considerable costs involved, combined possibly with a lack of conviction of worthwhile returns.

In reviewing this situation, Cameron (1973) says, "Recent developments in the management of lucerne-based grazing systems have revolved around the use of more and smaller paddocks and shorter grazing periods. However, because of the extensive nature of many livestock industries, these techniques are not widely applicable. What is required, rather, is a system using few paddocks and involving minimum handling of livestock."

The spelling requirements of lucerne can be met with two paddocks. Thus the necessity for increased subdivision with its associated costs

hinges on the importance of GD.

McKinney (1974) recently concluded a large study in New South Wales into the grazing management of lucerne in which he compared seven rotational grazing systems involving from two to 12 paddocks. Despite this relatively large number of treatments, the selection of the treatments and the paucity of agronomic data again did not greatly illuminate the question of GD. For example, in five of the seven rotational grazing treatments, GD varied by only five days and, as this was associated with spelling durations ranging from 20 to 55 days, the effect of spelling duration completely dominated the results. Grazing durations of 20 and 22 days during the growing period were chosen for the two remaining rotational grazing treatments but an extraneous factor (dog attacks) destroyed the reliability of one of these treatments and the other was associated with a spelling period too short for the lucerne. In his conclusions, McKinney *(loc.cit.)* stressed the importance of spelling duration. With reference to GD he stated that, "management of lucerne pastures should be based on two or four paddocks....." This recommendation involved GDs of 30 to 40 days. This conclusion appeared to be based principally on an 'objective function' for animal production (an integration of the costs of inputs and prices of outputs for each system) derived from very low flock numbers!

A more appropriate study of GD was that of Peart (1968, 1970) again in New South Wales. He compared two rotational grazing systems; 5 days on/35 days off (eight paddocks), with 12 on/36 off (four paddocks). Once again, little agronomic data was collected, but he did show that both the survival of the lucerne plants and the average liveweight of the wethers on the plots were higher on the system with the shorter GD.

O'Connor (1970) showed that GDs - varying from three to 18 days through the spring and summer - had no residual effect on lucerne yield or density six months later in the following spring. However, he also showed that herbage yield at the end of a 36 day regrowth period was considerably lower following an 18 or 24 day GD than a 12 day GD and stated that, "severe basal shoot grazing" on the 18 and 24 day treatments was the cause of this. No indication was given of the maturity stage of the lucerne when grazing commenced, or the severity of grazing when it ceased on the different treatments. The author simply noted herbage yield after 36 days following the different GDs.

The general pattern of lucerne herbage consumption by the grazing animal has been described by Arnold (1960) and McKinney *et al* (1970). A number of workers (Monson 1966, Othman 1972, Janson 1975, Constable *et al* 1977) have attempted to simulate this defoliatory effect of the grazing animal by progressively removing the herbage in small 'bites' with hand shears working down from the top of the stems. Othman (*loc.cit.*) and Janson (*loc.cit.*) were able to show that the removal of the apices and top third of the mature stems stimulated the development of new shoots at the base of the sward. In addition, if the progressive defoliation was very slow, i.e. extended over a prolonged period, the new shoots growing up from the base of the stems could be decapitated in the final 'bites' when the last of the mature herbage was removed. Surprisingly, Monson (1966) chose to leave these new shoots completely untouched and thus generated a quite unrealistic grazing simulation. Janson (1975) noted that herbage yield after 1-2 weeks regrowth was lower after both a very short and a long (21 days) defoliation duration (the time taken to progressively remove the herbage) than after an intermediate defoliation duration (DD). Othman (1972) recorded the same effect, while Constable *et al* (1977) recorded a depression in herbage regrowth following a long DD only.

Thus four reports (O'Connor 1970, Othman 1972, Janson 1975, Constable *et al* 1977) independently have demonstrated a depression in regrowth following a long grazing or DD and the first three have also indicated a lag in immediate regrowth following a very short or instantaneous DD. Janson (*loc.cit.*) suggested lack of development of the new shoot population caused the lag following a very short DD, but was less certain as to the reason for the effect of the long DD. Constable *et al* (1977) linked the reduced top weight increases following a long DD with reduced root weight and root total non-structural carbohydrate concentration. However, the design of their project, in common with that of O'Connor's and Othman's, confounded maturity stage and DD (Janson 1975) thus making it very difficult to accurately pinpoint the effect of DD *per se*.

Even this brief review of the work directly concerned with GD highlights the need for better understanding both of the plant's immediate response to GD and of its impact on total lucerne production in a grazing system.

1:2:2 MORPHOLOGICAL STUDIES

A brief summary is now given of certain morphological features of lucerne relevant to GD.

As the seed germinates, the young root and shoot appear through the seed coat. The shoot consists initially of the two cotyledons which unfold, and this is followed by the appearance of the first, simple leaf which is borne on a slender petiole. Next, the first trifoliate leaf emerges at the next node with later leaves appearing at successively higher nodes.

The most important aspect of early seedling growth concerns the buds which occur in the axil of each cotyledon, the simple leaf and the trifoliate leaves, because it is from these buds that the plant branches out and develops what subsequently will become the crown. Each bud grows out to form a shoot and ultimately a mature stem, from the base of which further buds arise and gradually the crown is formed.

The crown and stubble region of the mature lucerne plant is extremely important for it is from there that the new shoots develop at the start of each growth cycle. The crown has been variously defined by different workers but perhaps the simplest and most widely accepted is that of Stewart (1926): the crown consists of the perennial portions of the stem. This definition was adopted by Grove & Carlson (1972) in their recent review, but they also suggested that it makes little significant difference as to the exact morphological inclusions of the crown, for such things as summer drought, winter freezing, certain cultural practices and the general vigour of the plant all influence the amount and kinds of vegetative parts in the crown.

Arising from the crown is the stubble from the previous growth cycles (see Figure 1). In time, the extreme basal parts of this stubble will become part of the crown if the plant continues to grow actively and develop. Keoghan (1970) recognised this fact when he referred to these basal parts of the stems, characterised by extremely short internodes, as the region of 'crown capture'.

The growth of lucerne follows a cyclical pattern through the season with the number of cycles being determined principally by the length of the growing season. Following harvesting or winter dormancy new shoots arise from the crown and stubble region of the plant and steadily increase

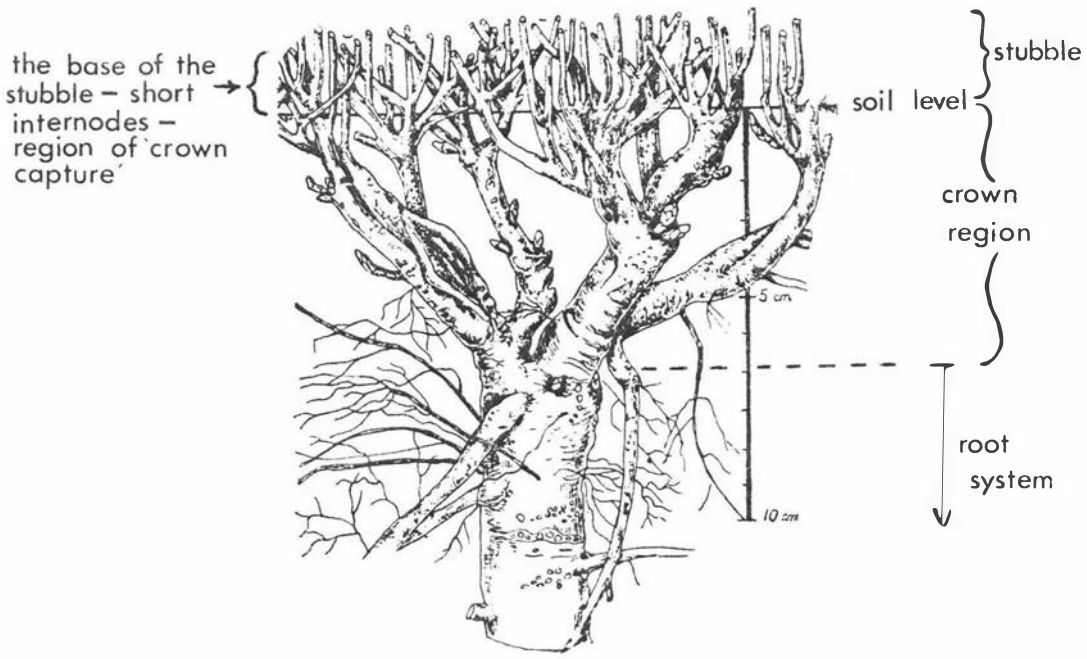


Figure 1. Stubble, crown and upper root of a mature lucerne plant.

in size and stature until, if temperature and day length are favourable, buds and flowers begin to appear at the apices of these now mature stems (Langer 1968). The time taken for the new shoots, which appear at the base of the plant, to develop into mature reproductive stems varies from three to eight weeks or more, depending on temperature and day length (Thomas 1967). Although varietal differences occur, the new shoots for the next cycle of growth are generally just beginning to appear at the base of the plant when the flowers start to appear at the stem apices of the current growth. If the herbage, or even the upper fraction (Othman 1972) is removed at this stage, development of these new shoots accelerates and a new growth cycle commences (Singh & Winch 1974).

1:2:2(a) Shoot Origin

The precise origin of the main regrowth shoots has been studied by several workers, generally to clarify the importance of cutting height. Leach (1968) working with Hunter River showed that where stubble was left, nearly all the shoots developed on it but, if this stubble was removed, shoots would develop on the crown but in smaller numbers and later. Later work with Totana (Leach 1970) showed that nearly all the regrowth shoots arose on the stubble within two centimetres of the crown. These shoots arose earlier and grew larger than those appearing higher up on the stubble. In a simulated sward of Wairau lucerne, Langer & Keoghan (1970) were also able to show that the major part of regrowth came from shoots arising very near the crown. Shoot origin was clarified further by a field study on Vernal and Saranac (Singh & Winch 1974) in which it was found that shoots originated mainly on the stubble of the most recently harvested stems.

Langer & Keoghan (1970) drew attention to the fact that shoot origin differed between spaced plant and sward conditions. Under spaced plant conditions, shoots arising from sites relatively high on the stubble (5-10 cm zone) made a significant contribution (44%) to final regrowth yield whereas, under sward conditions, their contribution was negligible. This difference between spaced plant and sward conditions has been, and still is, the cause of some confusion regarding the relative importance of the shoots arising some distance above the crown.

Keoghan (1970) divided these regrowth shoots into :

basal : shoots arising from the crown and the lower nodes where internode length did not exceed 0.5 cm

intermediate : shoots arising from nodes where internode length was 0.5 - 0.6 cm

stubble : shoots arising from upper nodes where internode length exceeds 0.6 cm

This classification appears to be superior to that of Leach (1968) who divided the shoots into crown (shoots arising directly on the crown) and stubble (shoots arising in the axils of stubble leaves) because :

a) it is often difficult to define the precise limits of the crown (Grove & Carlson 1972)
b) very few shoots arise on the crown when stubble is present (Leach 1968)
c) shoots at the extreme base of the stem in this zone of short internodes as a group are both the most numerous and the heaviest (Langer & Keoghan 1970), and
d) this zone of short internodes (0.5 cm or less) generally becomes a perennating part of the plant while sites on the stubble above this zone are generally only transitory due to stubble senescence (Keoghan 1970).

Some very detailed studies by Leach (1968) have provided valuable information on the time of shoot appearance following cutting and the significance of this to final yield. He showed that the majority of shoots appeared in the first 14 days following cutting at the early flowering stage and the earlier a shoot arose the greater its final weight. The ratio of shoot weights on Day 28 for shoots arising on Day 0, 7, 14 and 28 of the regrowth period was 100 : 44 : 12 : 3 respectively. As a consequence , shoots emerging in the first week of regrowth contributed well over 80% of the total shoot weight at Day 28. The contribution of shoots arising on Day 14 or later declined to 5% or less as the stage of cutting was delayed from late vegetative to late flowering. This work was done with Hunter River but the general principles were later shown to be also applicable to Rhizoma and Totana (Leach 1969).

1:2:2(b) Shoot decapitation

Early this century, it was thought that a lucerne stand would be severely and permanently damaged if harvested when crown shoots were tall enough to be cut by the mower (Wing 1916). However, a number of field studies on lucerne hay production (Moore & Graber 1922, 1925; Salmon *et al* 1925, Willard *et al* 1934, Tysdal & Westover 1949) showed that permanent damage to the lucerne stand did not occur although Meyer & Jones (1962) found that, if long basal shoots were cut during harvesting, it resulted in uneven hay quality at the following cut.

To examine shoot decapitation more closely, Keoghan (1970) constructed small simulated swards and contrasted a high and a low cut taken at a very advanced stage of maturity (full bloom-seedpod). He noted higher regrowth yields if the large population of new etiolated shoots at the base of the plant was not removed. This result is not surprising for very few intact shoots remained after the low cut and this resulted in initial regrowth inertia while new shoots developed.

As already mentioned, O'Connor (1970), Othman (1972), Janson (1975) and Constable *et al* (1977) all imposed treatments which caused varying degrees of basal shoot decapitation as a result of the extended grazing or cutting durations employed and recorded a depression in total regrowth yield. This depression followed the treatment which involved the greatest interference with the new shoots. Various suggestions were made as to why this should occur but no detailed study has been made on the response of the new shoot population to decapitation and the relevance of this to regrowth effects.

A study of grazing duration will necessarily involve degrees of basal shoot decapitation and it is clear that a better understanding of the plants' response to this is needed.

1:2:3 CLIMATIC INFLUENCES

The effect of harvesting on the lucerne plant, whether by cutting or grazing, is influenced by climatic factors. For instance, it is well known that a cutting or grazing system which can be sustained in one area will cause heavy losses in another. In the Yakima Valley (Washington) an area of low rainfall and high light intensities, cutting every 24 days for two seasons had little effect on irrigated lucerne vigour, while less drastic cutting schedules in the more humid Midwest seriously reduced

production after only one season (Jackobs 1950). Turpin (1931), Dawson *et al* (1940) and Staten *et al* (1945) to name but a few, have all demonstrated the same effect: lucerne grown in dry regions, with or without irrigation, can be cut at much earlier stages without damaging the stand than in humid regions.

A similar effect has been demonstrated between wet and dry seasons in the same area. Davies & Tyler (1962) showed that three cuts/annum could usually be sustained in Britain, but that it proved disastrous in years of high rainfall and low sunshine hours when no more than two cuts/annum could be taken with impunity. Whitear *et al* (1962) demonstrated a similar effect in a grazing experiment.

The physiological reason for the increased resilience of lucerne in dry seasons and climates is not clear. The results with irrigated lucerne in dry climates prove that it cannot be due to water shortages *per se*. Willard (1951) has suggested it may be due to both the higher light intensities or cooler nights generally associated with dry areas. Support for both these suggestions has been provided in later work. Lucerne has been shown to be a light responsive species. The herbage yield of both spaced plants and seedlings declined if light intensity fell below about 3-4000 foot candles (Bula *et al* 1959, Garza *et al* 1965) and responses to higher light intensities have been noted in situations where mutual shading is greater (Brown *et al* 1966, Wilfong *et al* 1967). Reductions in light intensity have been shown to reduce root weight, root:top ratio, root carbohydrate levels and nodule numbers (Pritchett & Nelson 1951, Gist & Mott 1957, Garza *et al* 1965).

The influence of temperature on lucerne has been studied by a number of workers (Field *et al* 1976). Of particular interest to this discussion is the finding that high mean temperatures (above about 20-25°C) consistently and markedly reduced both root weights and root carbohydrate concentrations at the early flowering stage (Jensen *et al* 1967, Dale Smith 1969, 1970; Marten 1970, Lee & Smith 1972). These workers generally recorded maximum herbage growth rates at about 20-25°C. It was to be expected that these effects of high temperature on lucerne would interact with its management and, in Arizona, Feltner & Massengale (1965) and Robison & Massengale (1968) showed quite clearly that irrigated lucerne was more susceptible to frequent cutting during periods of high temperature (consistent daily maxima of 38°C or more) than during cooler periods.

In all these studies where climate has been shown to interact with lucerne management, the ability of the lucerne to withstand the stress of frequent harvesting has been affected. In view of the stress which long GDs appear to impose on lucerne (Peart 1968, 1970; O'Connor 1970, Othman 1972, Janson 1975, Constable *et al* 1977), it seemed reasonable to suggest that climatic factors may also interact with lucerne's response to GD. Indeed, O'Connor (1970), with no supportive experimental evidence, has already suggested that GD should be shortened during the winter period and the summer drought in Canterbury.

1 : 3 PROJECT OBJECTIVE AND OUTLINE

Two decisions were made at the outset of the project :

1. all the studies would be conducted on New Zealand Certified 'Wairau' lucerne;
2. all the grazing treatments - actual and simulated - would be applied only to lucerne which had reached the early flowering or basal shoot appearance stage. The concept of spelling to this stage is internationally accepted for maximum herbage production and is readily integrated into a grazing system.

The objective of the project was to conduct a detailed study into the effect of grazing duration on lucerne in terms of both immediate effects on the plant and the total overall effect on production through one season. A secondary objective was to investigate the possible interaction of certain climatic factors with GD effects.

A field trial was conducted through one full growth season under actual grazing conditions. Then the studies moved indoors into large controlled environment conditions to monitor treatment effects on the plant more closely than had been possible in the field. Simulated grazing was employed in this part of the project. Three different climatic combinations were imposed in the controlled environments to investigate the interaction of climate with GD.

CHAPTER 2 : FIELD TRIAL - EXPERIMENTAL

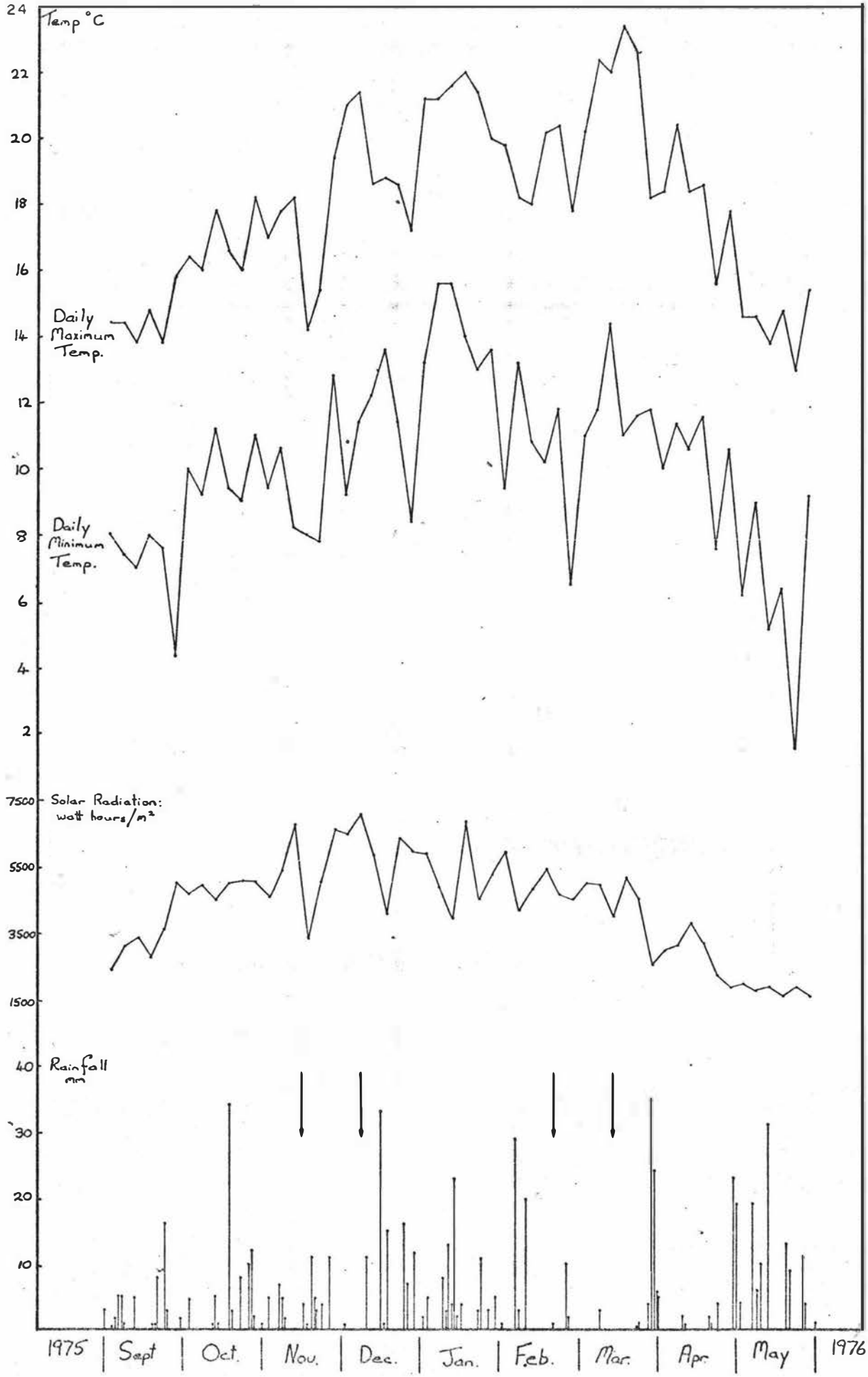
2 : 1 SITE AND STAND DESCRIPTION

A field trial was conducted through the 1975/76 spring/summer/autumn period on a three hectare field of lucerne (*Medicago sativa* L. cv 'Wairau') at Massey University, Palmerston North, New Zealand (latitude 40°23′S, longitude 175°37′E, 30 m A.S.L.).

Palmerston North, in the southern half of the North Island, has a cool temperate climate with an average annual rainfall of 1000 mm well spread through the year (30 year average). Mean daily maximum/minimum temperatures for the spring/summer/autumn period rise from 14.7°/6.4°C in September to 22.2°/12.6°C in February, falling again to 14.9°/6.7°C in May (40 year averages). Brief climatic data for the trial period are given in Figure 2. It was in all respects a very typical season. The temperatures followed the trend of the 40 year averages (above) and the rainfall was both well spread and in absolute amounts very close to the 30 year monthly averages.

The soil on the trial site was a Manawatu fine sandy loam, underlain by gravels at a depth of 0.55 to 1.00 metre.

In the winter of 1974, the permanent pasture on the trial site was ploughed and then 2500 kg/ha lime and 450 kg/ha potassic superphosphate applied and cultivated into the top 15 cm of soil. In October 1974, 10 kg/ha of Certified 'Wairau' lucerne seed was sown into a well-prepared seed-bed. The lucerne was given long spells to the flowering stage between each of the three quick hard grazings it received over the first summer and autumn period. It was irrigated three times in this establishment season and a further 450 kg/ha potassic superphosphate applied in the autumn. A mixture of paraquat and atrazine was applied in the winter to control some annual grasses and broadleaf weeds.


Temp °C
24
22
20
18
16
14
12
10
8
6
4
2
Daily Maximum Temp.
Daily Minimum Temp.
7500
5500
3500
1500
Solar Radiation: watt hours/m²
40
30
20
10
Rainfall mm
1975
Sept
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
1976

When growth began to accelerate in the early spring of the second year, it was apparent that the management applied in the first year had been successful in establishing a good stand of vigorous, relatively weed-free lucerne. Counts taken at this time showed a lucerne plant density of 90/m^2 and a chemical analysis of the lucerne herbage showed adequate levels of the major and trace elements. The stand was ready for the trial to begin.

2 : 2 TREATMENT DESCRIPTION AND EXPERIMENTAL DESIGN

Commencing in the spring of this second year, three treatments were imposed :

Treatment 1 : 2-4 day grazing duration, i.e. as quickly as possible
Treatment 2 : 15 day " "
Treatment 3 : 30 day " "

each grazing commencing when the new basal shoots started appearing.

The design was a randomised block with four replicates.

2 : 3 CALENDAR OF EVENTS

The trial period began on September 20, 1975 following a quick, hard grazing to improve the uniformity of the trial area after the trampling involved in the erection of the fencing. The first 'treatment' grazings commenced on November 9, 1975. Figure 3 depicts the timing of the grazing and regrowth periods on the three treatments through the eight month period from September 20, 1975 to May 13, 1976. The length of the regrowth period changed through the season with temperature and daylength but each new grazing on the three treatments always commenced when new shoots were just beginning to appear at the base of the mature stems. In the spring and autumn this preceded flowering by a few days and coincided with it in the summer.

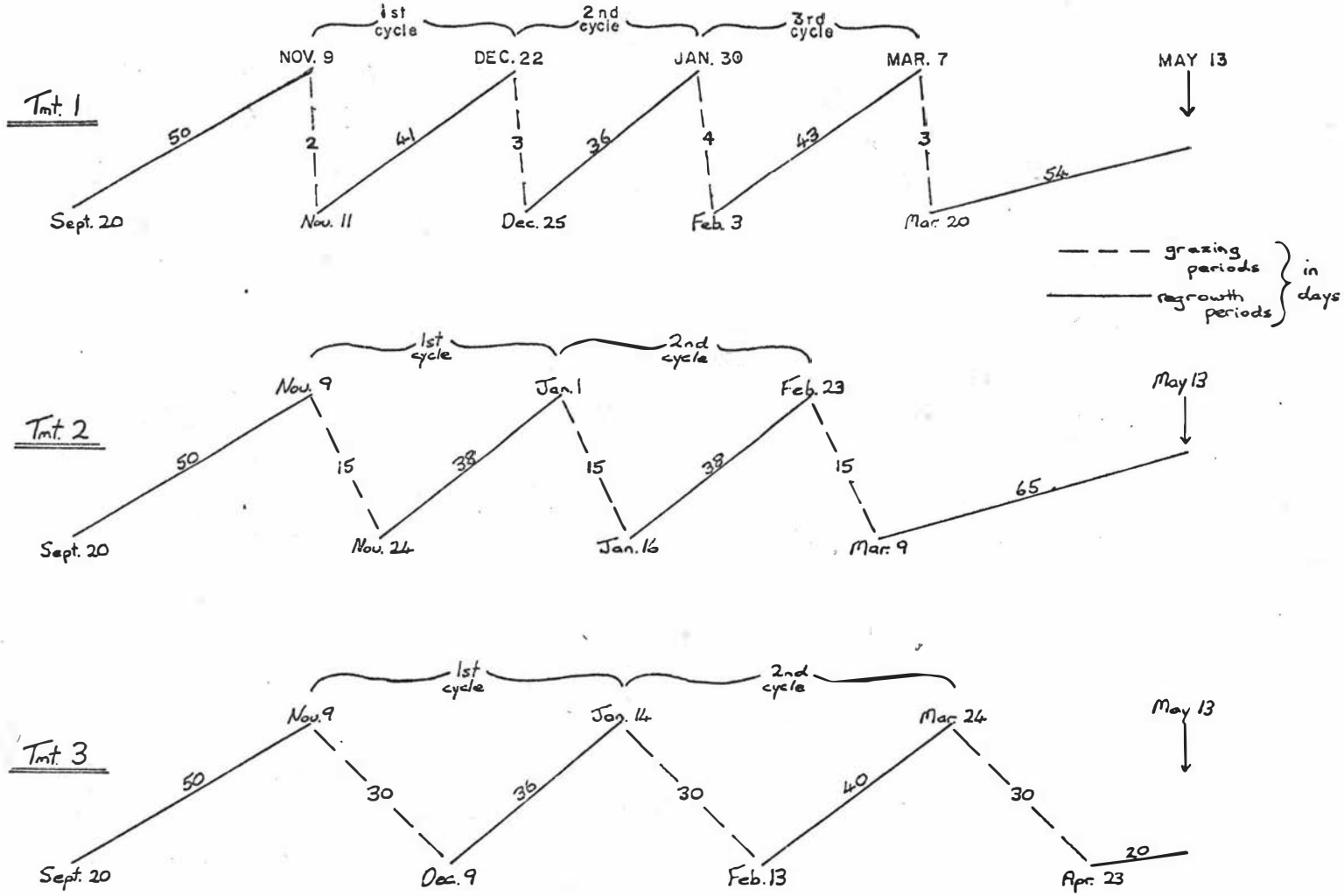


FIGURE 3. Timing of grazing & regrowth periods on the three GD treatments through the full trial duration.

By the beginning of May, herbage growth rate had become very slow on all three treatments and consequently the final harvest was taken on May 13 to prevent any frosting of the lucerne.

2 : 4 GRAZING MANAGEMENT

At the start of each grazing period, Romney hoggets were allocated to the treatments at a grazing pressure calculated to remove the herbage to a mature stem stubble height of 10-12 cm in 2-4, 15 and 30 days. For example, at the first grazing this required a concentration of approximately 1400, 180 and 80 hoggets per hectare respectively for Treatments 1, 2 and 3. Small alterations were made to sheep numbers during a grazing if it was apparent the herbage was being consumed either too quickly or too slowly.

The size of the small fenced paddocks used in this grazing experiment were: Treatment 1 - 210m^2; Treatment 2 - 300 m^2; Treatment 3 - 540 m^2. The paddock size was purposely increased with GD to ensure flock size on any of the paddocks did not fall below a minimum of 4-5 hoggets.

2 : 5 IRRIGATION

Irrigation scheduling was based on the evapotranspiration model developed by Clothier *et al* (1975). Their investigations were conducted on an area of Manawatu fine sandy loam less than one kilometre from the field trial site. Sampling showed the average soil depth to be virtually identical on the two sites and consequently the soil moisture characteristics given by Clothier *et al (loc.cit.)* were also used in the calculation of irrigation scheduling for the field trial. Lucerne roots on the field trial site at the start of the second season were found to be exploiting the full soil depth of approximately 0.7 metre.

Irrigation commenced when the calculations indicated 40% of the available water in the root zone had been lost through evapotranspiration (soil moisture tension at this point was -1 to -2 bars - B.E. Clothier *pers.comm.*). Sufficient water was then applied to restore the soil to Field Capacity.

PLATE 1. General view of the trial area : November 1975.

PLATE 2. Closer view of some of the small paddocks.

Under this policy, four irrigations were given during the course of the trial, each supplying approximately 45 mm of water by sprinklers.

2 : 6 COLLECTION OF HERBAGE DATA

Herbage samples were cut from the paddocks immediately prior to each grazing, at intervals during each grazing on Treatments 2 and 3, at the end of each grazing, at intervals during each regrowth period and at the final harvest on May 13, 1976. The sampling dates during grazing on Treatment 2 were Day 6, 9 and 12, and during grazing on Treatment 3 were Day 6, 12, 18 and 24. No samples were cut during the 2-4 day grazings on Treatment 1. The sampling dates during the regrowth period on all treatments were Day 3, 8 and 18 and then, of course, immediately prior to the next grazing.

Growth during grazing on Treatments 2 and 3 was measured by the Australian difference technique (Lynch 1960) using two large cages per paddock. The cages were shifted randomly within the paddocks on the sampling dates during grazing and removed at the end of each grazing. They were replaced on the paddocks at the next grazing after the sheep had been on the paddocks for two days. This delay of two days allowed sufficient time for stem apex removal over most of the paddock and thus avoided recording growth for the first six days of grazing under the rather unrealistic situation of completely undamaged lucerne.

All the herbage sampling mentioned above involved the harvesting of two randomly selected 0.2 m^2 quadrats per paddock. Hand shears were used to sever the tap-root of each lucerne plant in the quadrat, about 2-3 cm below the crown, thus ensuring none of the basal shoots were lost during harvesting. In the laboratory, the green weight of the two herbage samples from each paddock was determined, the two samples were then bulked and thoroughly mixed and a 100 g subsample weighed out.

From this subsample all the basal and stubble shoots were plucked off at their site of origin, the length of the 20 tallest was measured and then the number of shoots in each class and the leaf area of each class was determined. All the mature herbage was then severed from the crown and root segment and, if tall enough, divided into top and bottom

half mature herbage (based on stem height immediately prior to start of each grazing) after any dead stubble was removed. The leaves were stripped from the stems of the two halves and leaf area measured. All the herbage fractions were then dried overnight at 80°C and weighed.

Leaf area was measured with a Hayashi Denkoh Automatic Area Meter, Model AAM-7.

The following definitions for herbage components were adopted throughout this project, i.e. in both the field trial and the controlled environment studies :

- the crown consists of the perennial portions of the stem
- the stubble was the remaining mature stems after completion of grazing or cutting
- a bud became a shoot immediately the first leaf emerged and began to expand
- shoots remained shoots for the whole of a regrowth cycle. However, once the next cycle began, the shoots of the previous cycle became 'mature herbage' or 'mature stems'. At the end of a regrowth period the first shoots for the next cycle were just beginning to emerge at the base of the sward, but these tiny shoots were never harvested with the very large shoots of the concluding cycle. It was considered that this terminology assisted the understanding of regrowth rather than the alternative, e.g. Othman (1972) in which the shoots became stems part way through the regrowth period.
- shoots were subdivided into
    - basal shoots : shoots arising from the crown and the lower nodes of the stubble and mature stems where internode length did not exceed 0.5 cm
    - stubble shoots : shoots arising from upper nodes where internode length exceeded 0.5 cm
    - basal shoots were subdivided into
        - independent : a shoot which was neither subtended on another shoot nor was subtending another shoot
        - subtending : a decapitated shoot which was subtending another
        - subtended : a shoot which was subtended on another (see Figure 4 and Plates 3 & 4.)

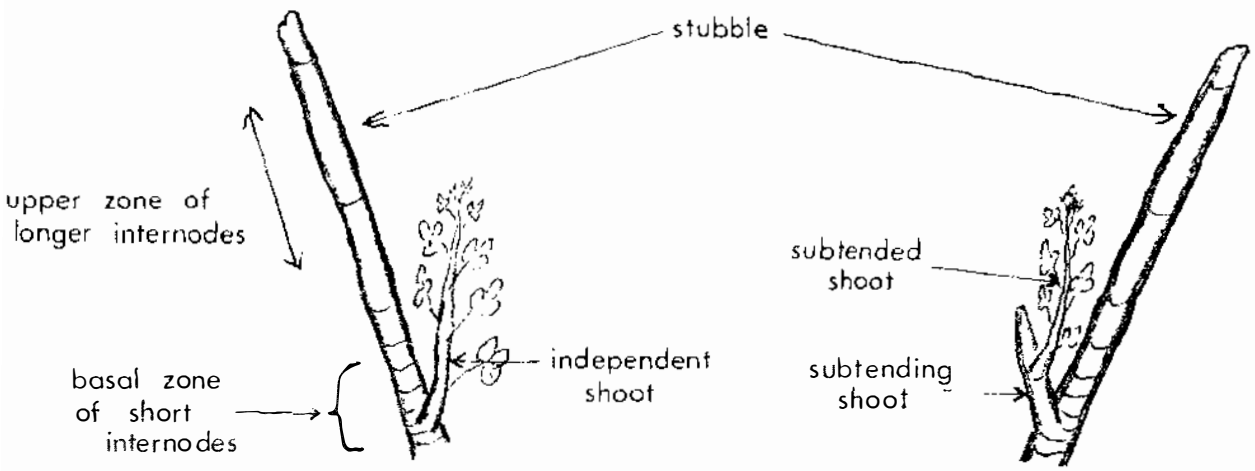


Figure 4. Diagrammatic presentation of the three types of basal shoot.

PLATE 3. Early development of an independent shoot.

PLATE 4. Early development of a subtended shoot. The decapitated independent (far left) gives rise to the new subtended shoot & in so doing becomes a subtending shoot.

This classification of basal shoots was decided on following preliminary glasshouse investigations into the morphological effect of decapitation of new shoots (shoot less than 10 cm long). These studies showed that about 10 days after an independent shoot was decapitated a new shoot appeared at one of its lower nodes. Thus what was originally an independent shoot became a subtending shoot and the new shoot was of course a subtended shoot.

Stubble shoots were not separated into the three subdivisons employed for basal shoots because the preliminary glasshouse studies indicated the yield contribution from stubble shoots under sward conditions and infrequent harvesting was so small that separation into three classes was neither practical nor warranted.

Light penetration through the mature herbage to the new shoots at the base of the sward was measured during the grazing period at the time of herbage sampling with a Lambda LI-185 light meter with a quantum sensor. Twenty readings were taken randomly per paddock, i.e. 80 per treatment, between 1100 and 1300 hours and the results expressed in terms of light at the new shoot level as a percentage of light just above the mature herbage canopy.

2 : 7 SHOOT POPULATION STUDIES

To monitor the shoot population closely through the grazing and regrowth periods, it was necessary to identify individual shoots as they arose.

Four lucerne plants per paddock were chosen at random for shoot marking. Immediately prior to the start of grazing, any new shoots present at the base of the four selected plants on each paddock were marked with a small coloured plastic ring. Thereafter, at five day intervals through the grazing period on Treatments 2 and 3 and at five day intervals through the regrowth period on all three treatments, the selected plants on each paddock were relocated and any new shoots which had arisen on these plants in the five days since the last tagging were marked with a ring (Plate 5). Different coloured rings were used for each five day period.

PLATE 5. One of the Treatment 3 plants on which the new shoots were individually tagged as they arose - red, blue & green rings can be seen on this plant. The photograph was taken at the end of grazing.

On Day 18 of the regrowth period, two of the tagged plants on each paddock of the appropriate treatment were carefully dug up. Each shoot was plucked off and allocated to its appropriate class according to its position and the colour of the tag at its base. The shoots in each class were then counted, dried and weighed. This was termed the preliminary harvest. At the end of the regrowth period, i.e. immediately prior to the start of the next grazing, the remaining two tagged plants on each paddock were dug up and the same procedure followed. This was termed the final harvest. (At this final harvest of the tagged plants, the tiny new shoots for the next growth cycle which were just appearing at the base of the sward were not included in the shoot population analysis of the current growth cycle.)

The techniques of this shoot tagging were investigated under glasshouse conditions but still required perfecting under grazing. This was done during the first cycle. Thus the results given in Chapter 4 relate to the second cycle.

The rings used in this tagging exercise were cut from split P.V.C. tubing of 4-5 mm diameter. The split rings permitted easy application at the base of the shoots with a pair of tweezers and also accommodated increases in shoot diameter without constriction.

2 : 8 ANALYSIS OF RESULTS

The design of this trial was a randomised block. It had four replicates and there were very few complicating factors. Analysis of variance was performed both on the results of different treatments at comparable sampling times and on the results of different sampling times within a treatment. The statistical parameters given in the tables are the Coefficient of Variation and the Least Significant Differences at the 5% and 1% significance level. On the graphs just the 5% LSD is shown.

Herbage growth rates during regrowth exhibited a definite seasonal effect which necessitated adjustment of the paddock or plot values before analysis of variance could be applied. The details of this are given later.

CHAPTER 3 : FIELD TRIAL - HERBAGE COMPONENTS AND YIELD

RESULTS

On November 9, 1975 grazing started on all three treatments. Appendix 1 provides details of the herbage harvested at this time and demonstrates the uniformity of the treatments. The appearance of the lucerne at the start of grazing is shown in Plate 6 and the herbage characteristics are summarised in Figure 5. The concentration of leaf weight and area in the top half (approximately 20-40 cm height) and the corresponding dominance of stem in the bottom half (approximately 0-20 cm height) is evident. Similar distributions were recorded by Warren Wilson (1965) and Keoghan (1966).

For much of the first grazing cycle, which commenced November 9, shoot classification and labelling techniques were being perfected. Thus, while the pattern of herbage consumption and regrowth were measured, a complete record of the number and types of shoots was not obtained until the second cycle. Since only two full cycles were completed on Treatment 3, the principal treatment comparisons from here on are made with results from the second cycle. Nevertheless, agreement or otherwise of first cycle results with second cycle figures is presented where possible.

3 : 1 THE PATTERN OF MATURE HERBAGE REMOVAL DURING GRAZING

The general pattern of mature herbage removal was very similar on Treatments 2 and 3; only the rate of consumption was different. The top half leaf was consumed very quickly; top half stem a little more slowly (Figure 6 and Plate 7).

The small amount of leaf in the bottom half of the profile disappeared quickly once leaf availability in the top half fell (Plate 8). Stem material in the bottom half however was left untouched until all this leaf material, and of course, the top half stem, was removed.

PLATE 6. Appearance of lucerne at start of grazing (basal shoot appearance / early flowering stage).

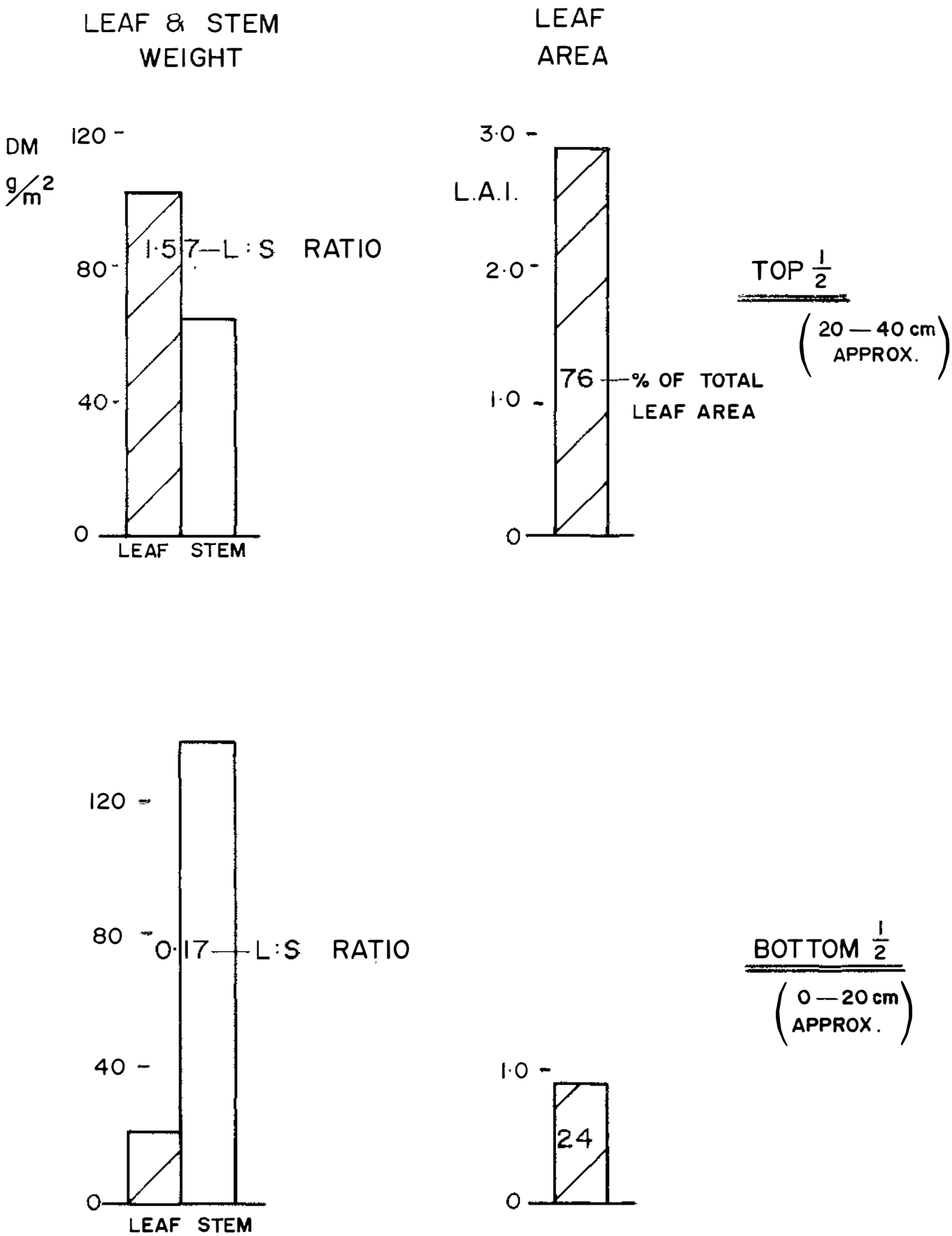


FIGURE 5. Mature herbage leaf & stem weights & leaf areas at first harvest (Nov.9) - average of all three GD treatments.

(Whole profile leaf:stem ratio was 0.63 & specific leaf areas in cm^2/mg were: whole profile - 0.30, top ½ - 0.28 & bottom ½ - 0.38.)

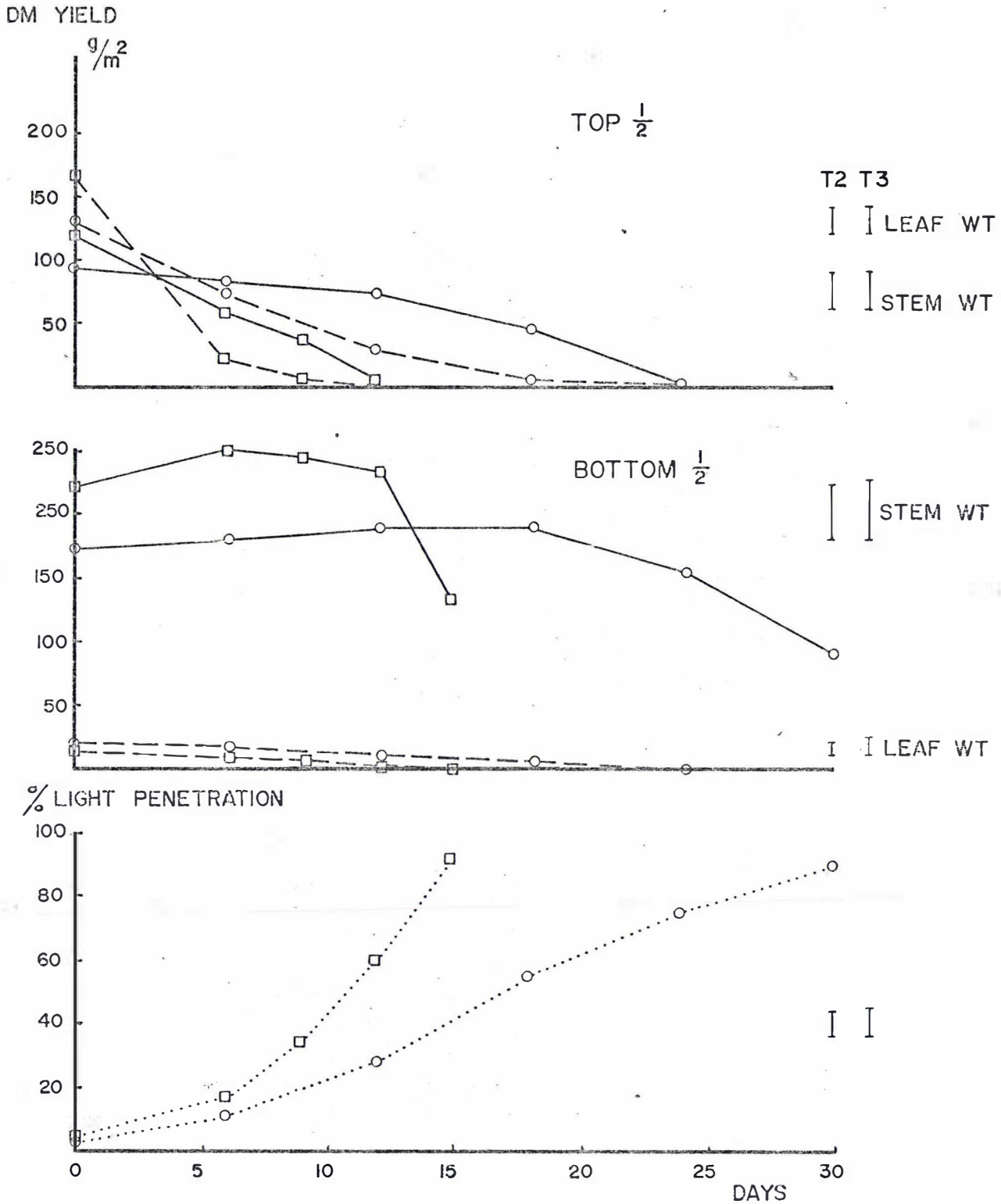


FIGURE 6. The pattern of mature herbage removal during grazing - plus light penetration to the new shoots.

——— stem yield □ Tmt 2 I LSD--5%

— — — — leaf yield O Tmt 3

(see Appendix 27 for actual numbers)

PLATE 7. General view of Treatment 2 lucerne after five days of grazing.

N.B. It was often difficult to photograph certain features of lucerne's development in the field. To overcome this a plant was dug from the field & photographed in a pot of soil. The suffix F.T. will always be attached to Plate descriptions of field trial plants photographed in pots.

PLATE 8. Treatment 3 lucerne plant after 18 days of grazing - new shoot development evident at base of mature stems. (F.T.)

PLATE 9. General view of Treatment 2 lucerne at end of grazing period (15 days).

Bottom half stem plus the new shoots emerging at the base of these stems were all that was available to the stock for the last quarter of the grazing period. About half of this stem material remained uneaten when the stock were removed at the end of grazing (Plate 9).

Light penetration to the basal shoots increased steadily as the mature herbage was consumed (Figure 6). Figure 7 depicts the changes in total leaf area during grazing. The development of new shoot leaf area is shown on the same scale to illustrate the size of the contribution from this source.

The pattern of herbage removal, leaf area decline and light penetration during the first grazing cycle was very similar to that of the second cycle.

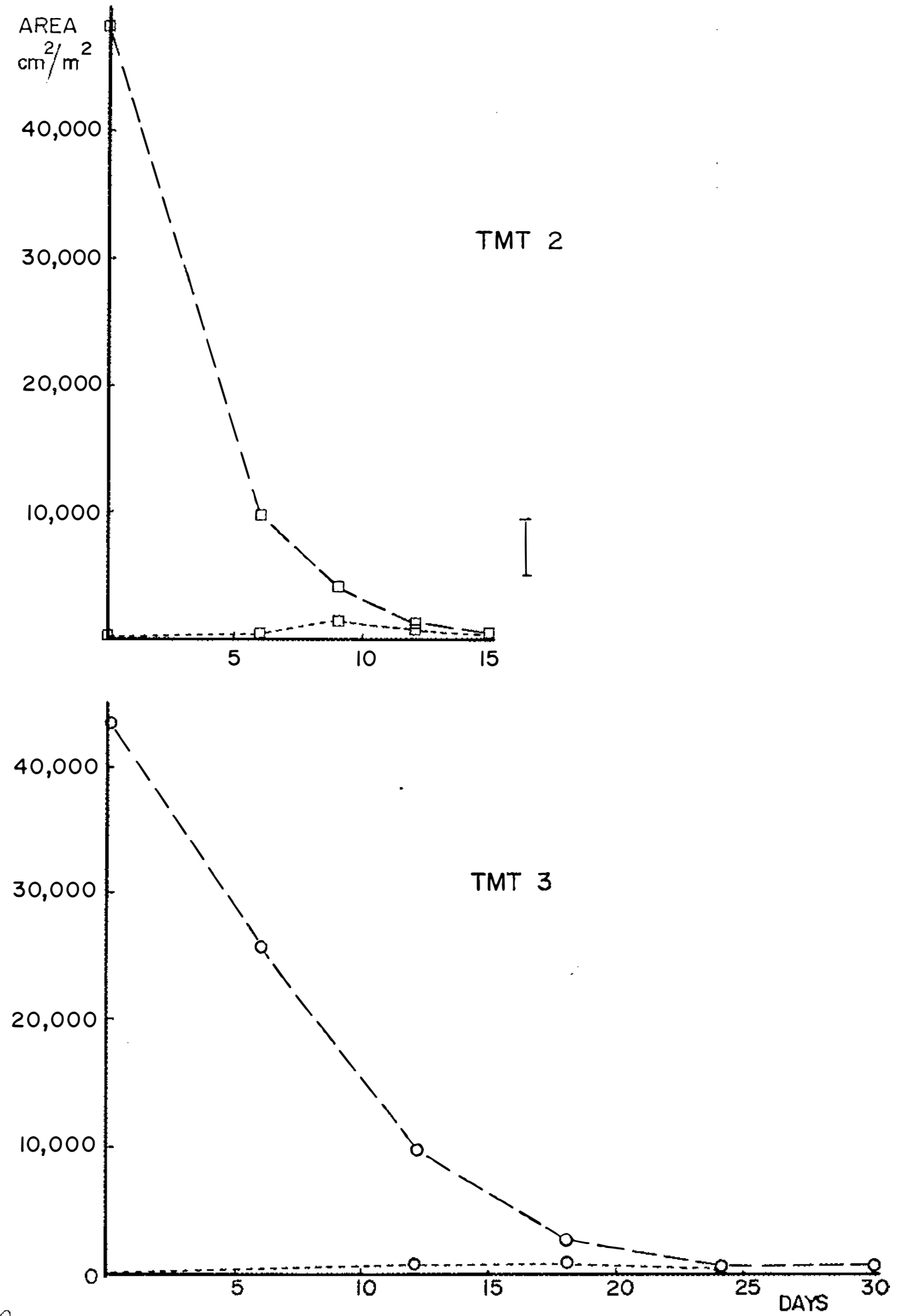
3 : 2 NEW SHOOT DEVELOPMENT DURING GRAZING

3:2:1 SHOOT NUMBERS

At the start of grazing, there were very few new shoots present (Figure 8). No increase was recorded three days later on Treatment 1 when grazing on this treatment finished. However, a significant increase had occurred on Treatments 2 and 3 after six days of grazing and a further substantial increase was recorded at the next count. For the rest of the grazing period, independent shoot numbers did not change significantly on either treatment.

By Day 24 of the 30 day grazing period, a small number of subtended and subtending shoots had appeared as a result of decapitation of some of the independents. This effect had increased by the next count at the end of the 30 day grazing period. Thus differentiation of the basal shoot population into the three classes was more advanced on Treatment 3 than Treatment 2 at the end of grazing.

Stubble shoot numbers were very low throughout grazing on both Treatments 2 and 3; for most of the time they comprised only about 2-4% of basal shoot numbers.



(see Appendix 28 for actual numbers)

FIGURE 7. Leaf area changes during the grazing period.

— — — — — total leaf area (mature herbage & new shoots)

. . . . . new shoot leaf area

I LSD-5%: total leaf area

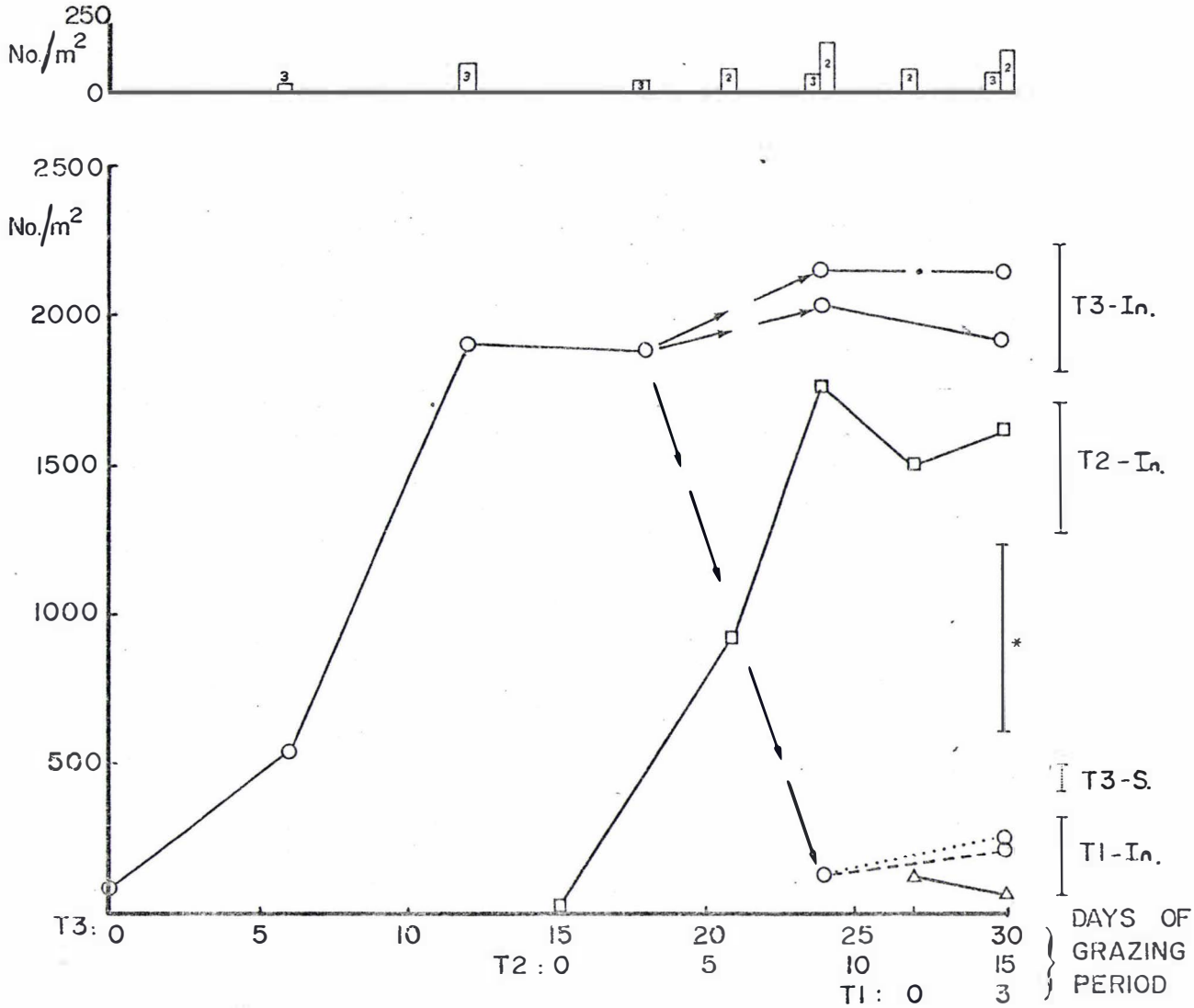


FIGURE 8. Shoot numbers during the grazing period.

△ Tmt 1
□ Tmt 2
○ Tmt 3

——— independent (In)
····· subtended (S)
——— · ——— independent & subtended
- - - - - - - - subtending

} basal shoots

[3] Tmt 2 } stubble shoots
[3] Tmt 3 }

——→ arrows emanating from Tmt 3 Day 18 value indicate the division of independent shoot numbers into independent, subtended & subtending shoot numbers

| LSD-5%

* treatment comparison at end of grazing : independent shoots on Tmts 1 & 2, & total of independent & subtended shoots on Tmt 3

3:2:2 SHOOT SIZE, LEAF AREA AND YIELD

The following results on shoot size, leaf area and yield relate to the total new basal shoot population.

At the start of grazing, the few basal shoots present were very small and consequently basal shoot yield and leaf area were practically negligible at this time. As grazing progressed on Treatments 2 and 3, the shoots increased in weight and length and, with the concurrent increase in shoot numbers (Figure 8), basal shoot yield and leaf area also rose steadily (Figure 9).

However, about halfway through the grazing period, the increase in basal shoot leaf area was halted and shortly after, the increase in shoot length and average weight was also stopped. None of these parameters increased again, but remained fairly stable for the remaining 5 and 12 days of grazing respectively on Treatments 2 and 3 - a trend that was also reflected in basal shoot yield.

Stubble shoot yield throughout the grazing period was minimal. The average stubble shoot contribution to total shoot yield was about 2%.

At the end of grazing the length, average weight, leaf area and yield of the basal shoots was higher on Treatment 3 than Treatment 2 (Table 1). These values were, of course, very low on Treatment 1 at this time for there had been no change in any of these components during the three day grazing period of this treatment.

Plates 10 and 11 contrast the above-ground appearance of Treatments 1 and 3 at the end of grazing while Plate 12 shows some of the below ground parts of a Treatment 2 plant at the end of grazing.

The pattern of basal shoot development under grazing in the first cycle was very similar to that of the second cycle.

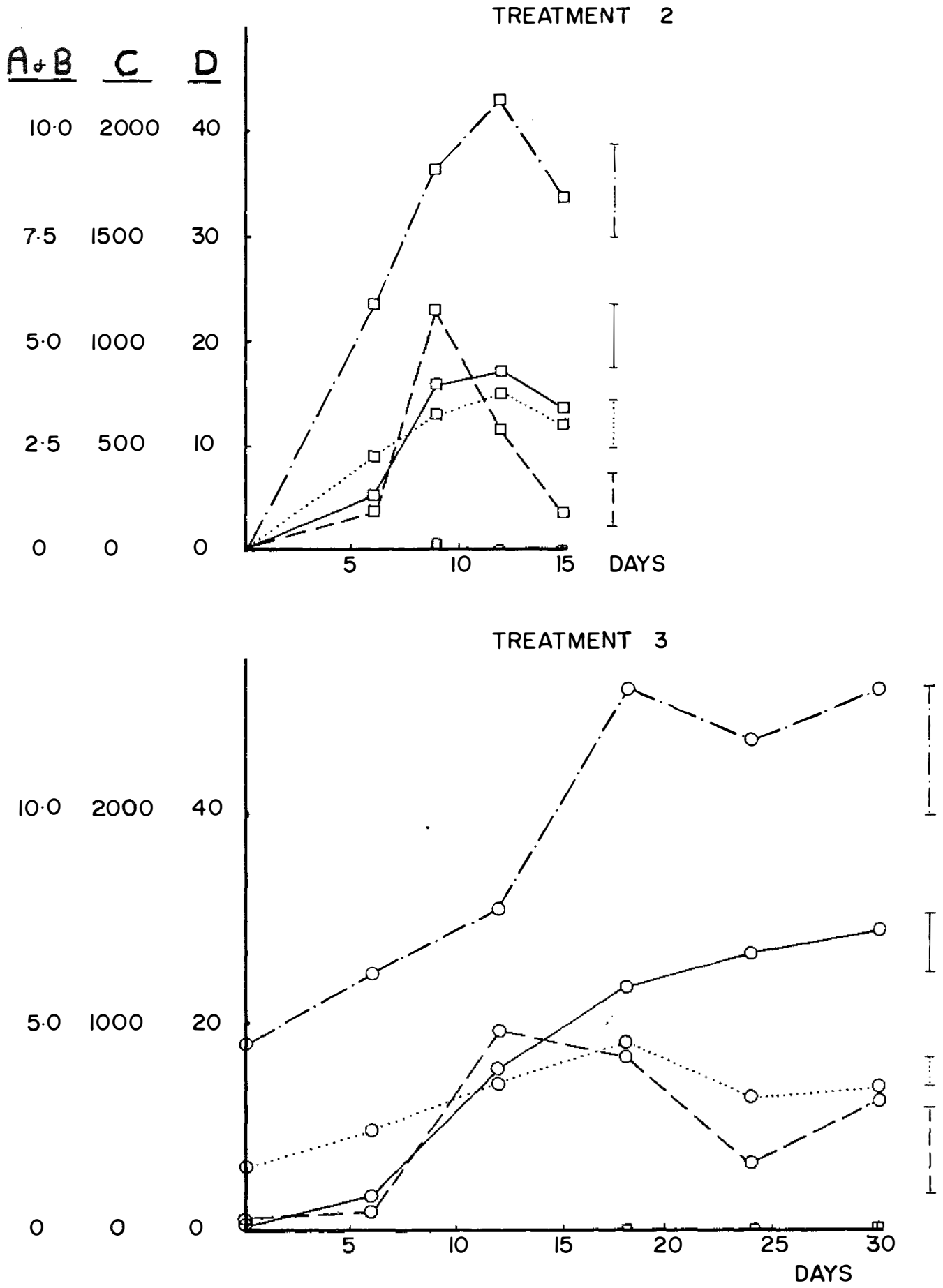


FIGURE 9. Yield, leaf area & size of new shoots during grazing.

- wt/shoot (A : mg)
- length (B : cm)
- leaf area (C : cm^2/m^2)
- yield (D : g/m^2)

} basal shoots

- yield of stubble shoots
- LSD-5%
- Tmt 2
- Tmt 3

(see Appendix x 29 for actual numbers)

TABLE 1. Treatment comparisons of yield, leaf area & size of new shoots at end of grazing.

	Basal shoots				Stubble shts.
	Yield (g/m^2)	Leaf area (cm^2/m^2)	Wt/ shoot (mg)	Length (cm)	Yield (g/m^2)
Tmt 1	0.22	-	4.65	1.13	-
Tmt 2	13.81	178	8.54	2.99	0.55
Tmt 3	31.10	645	13.10	3.50	0.56
CV%	32.3	43.2	16.3	7.0	94.7
LSD 5%	16.34*	400*	2.48	0.31	1.18
1%	29.99 #	734 #	4.52**	0.47**	2.16 #

* differences exist that are statistically significant at the 5% level
** " " " " " " " " 1% "
\# analysis performed on Tmts 2 & 3 only

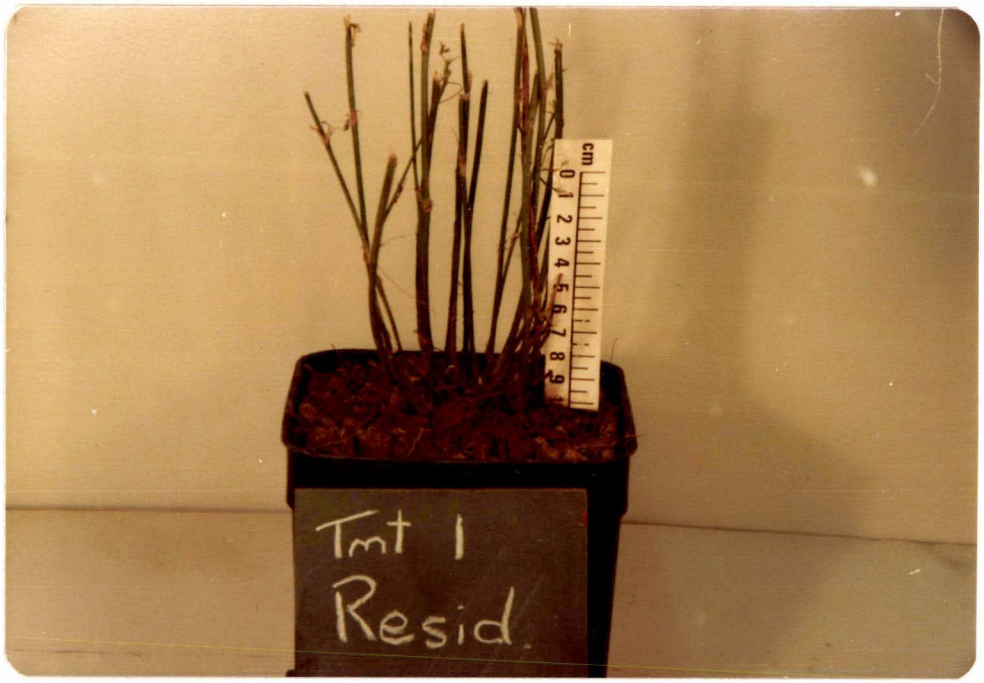


PLATE 10. Treatment 1 lucerne plant at end of grazing period (3 days). No new shoot development occurred during this grazing period. (F.T.)

PLATE 11. Treatment 3 lucerne plant at end of grazing period (30 days) - new shoot development evident at base of mature stems. (F.T.)

PLATE 12. Close-up of Treatment 2 lucerne plant at end of grazing period, showing part of the crown region, some dead stubble material, the base of several mature stems, several new white buds, & some new shoots both undamaged & decapitated.

3 : 3 REGROWTH

3:3:1 SHOOT NUMBERS

The differentiation of the basal shoot population into three classes, which was just commencing on Treatment 2, but was more advanced on Treatment 3 at the end of grazing, continued strongly in the first eight days of the regrowth period on these two treatments (Figure 10). Independent shoot numbers declined as, following the decapitation experienced by so many of them towards the end of grazing, they became subtending shoots with the development of a subtended shoot(s) on the decapitated 'stump'. Thus, independent shoot numbers declined while subtending and subtended shoot numbers increased.

This substitution of subtending and subtended shoots for independent shoots had apparently finished by Day 8 of the regrowth period for shoot numbers in the three classes stabilised thereafter on both treatments.

Despite the substantial changes in shoot numbers within the three classes during the early stages of regrowth, the total of independent and subtended shoots did not change throughout the first half of the regrowth period on Treatments 2 and 3.

Figure 11 compares shoot numbers (the total of independents and subtendeds only) on all three treatments through the first half of the regrowth period. The number of subtending shoots on Treatments 2 and 3 is not very relevant to regrowth as their contribution to yield was minimal at all times due to their very small size (see Chapter 4).

At the start of the regrowth period, there were very few basal shoots on Treatment 1 and a large number on Treatments 2 and 3. However, this difference had virtually disappeared after eight days for shoot numbers on Treatment 1 increased very rapidly to reach an apparently stable level by Day 8.

Treatments 2 and 3 only differed significantly at one count for the total of independent and subtended shoots. At the final count of the regrowth period no significant treatment differences were recorded.

Stubble shoot numbers were very low on all three treatments at all times. Only once did they reach 7% of the independent and subtended shoot total; for much of the time they comprised only 3-5% of this total. There

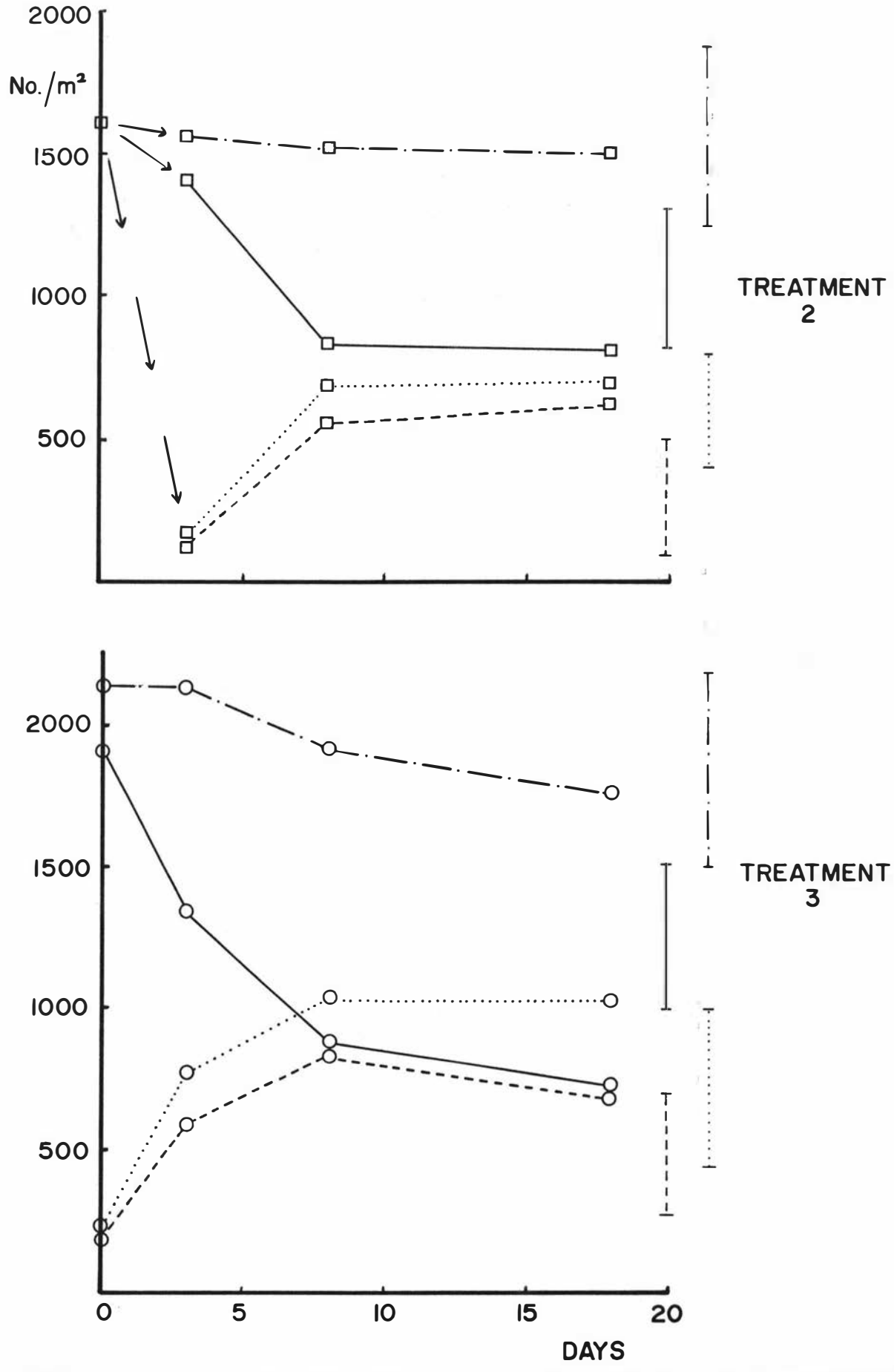


FIGURE 10. Shoot numbers during regrowth period : differentiation of basal shoots on Treatments 2 & 3.

independent shoots

independent & subtended shoots

subtended shoots

subtending shoots

□ Tmt 2. ○ Tmt 3. LSD-5%

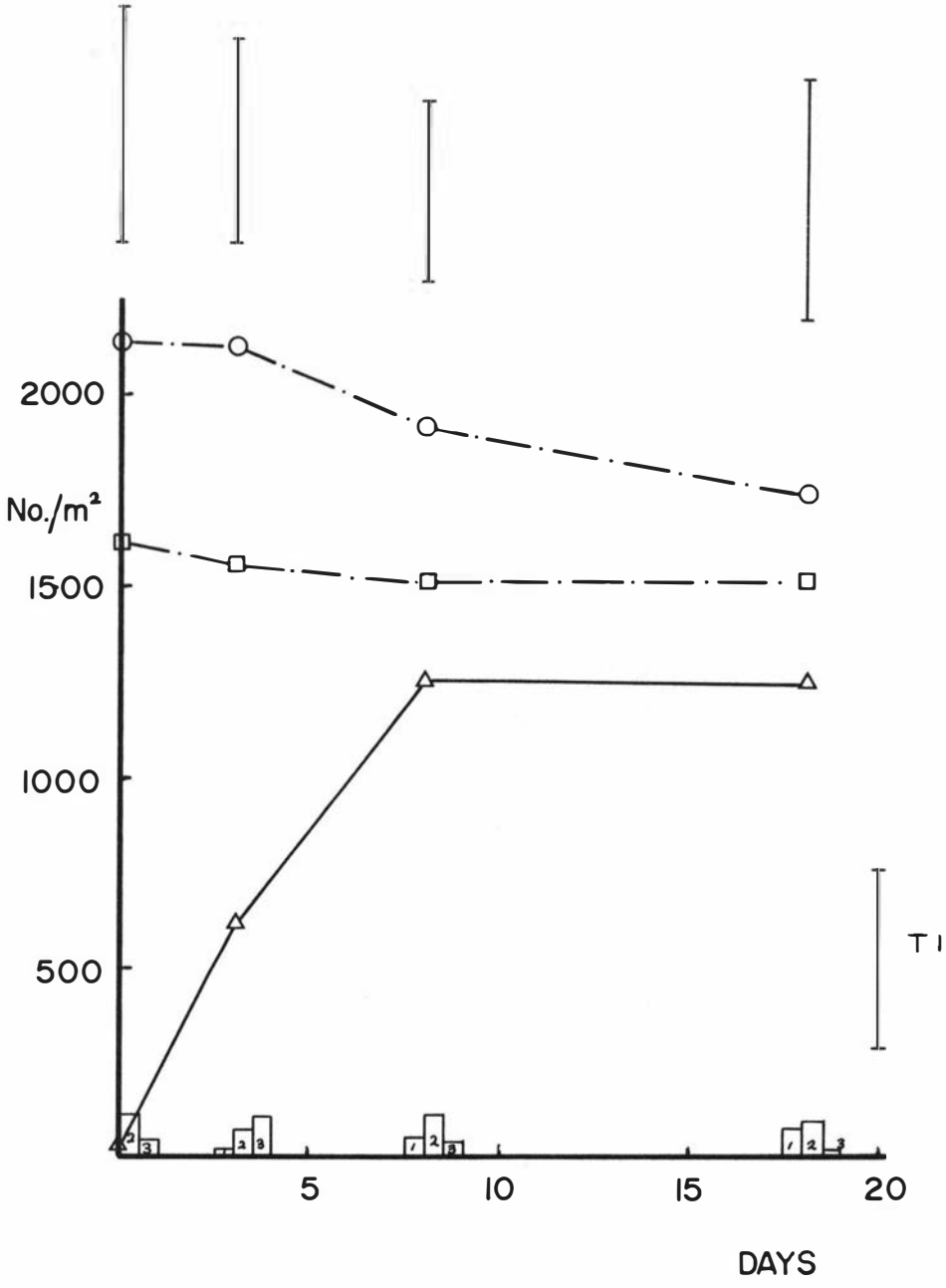


FIGURE 11. Shoot numbers during regrowth period : Treatments 1,2 & 3.

independent shoots
independent & subtended shoots
} basal shoots

△ Tmt 1
□ " 2
○ " 3

stubble shoot nos. on Tmts 1,2 & 3.

LSD-5%

were no significant differences between the three treatments at any harvest in either the number or percentage contribution of stubble shoots.

During the first grazing cycle, separation of the basal shoot classes was incomplete, but counts taken during the third cycle on Treatments 1 and 2 showed a very similar pattern to that depicted above for these treatments.

3:3:2 HERBAGE YIELD AND GROWTH RATES

Figure 12 gives a general picture of the regrowth curves for the first two cycles and their distribution through the season. The small differences in percentage bud/flower at the final harvests through the season are a reminder that, in this trial, the indicator for the start of each new grazing cycle was the development of new shoots at the bottom of the stems rather than the development of flowers and buds at the top of the stems. In most parts of New Zealand under sward conditions, new shoot development generally precedes flowering by a few days in the spring and autumn and coincides with it in the summer (C.G. Janson, personal observation).

It is fairly clear, even from this rather imprecise type of presentation, that both seasonal and treatment effects were influencing regrowth. For instance, there was a marked decline in herbage yield at the final harvest as the season progressed. This has been noted by others (Smith *et al* 1966, Daigger *et al* 1970, Singh & Winch 1974) and is a result of changes in such things as air temperature, daylength or evaporative demand which either accelerate reproductive development in the plant thereby inhibiting vegetative development earlier, or else simply reduce herbage growth rate *per se*.

Clearly, if the seasonal effect was significant, its influence would have to be removed before the treatment effects could be tested. The following procedure was adopted to remove the seasonal effect from the herbage growth rate data so that valid treatment comparisons could be made.

The 'residual' (residual = plot value - replicate effect - treatment effect - overall mean) was calculated for each plot, i.e. paddock, value of the particular growth rate under consideration in the first two cycles and then regressed with the number of days since the beginning of November. If the regression was significant, each plot value was adjusted using the derived regression equation. Analysis of variance was then performed on

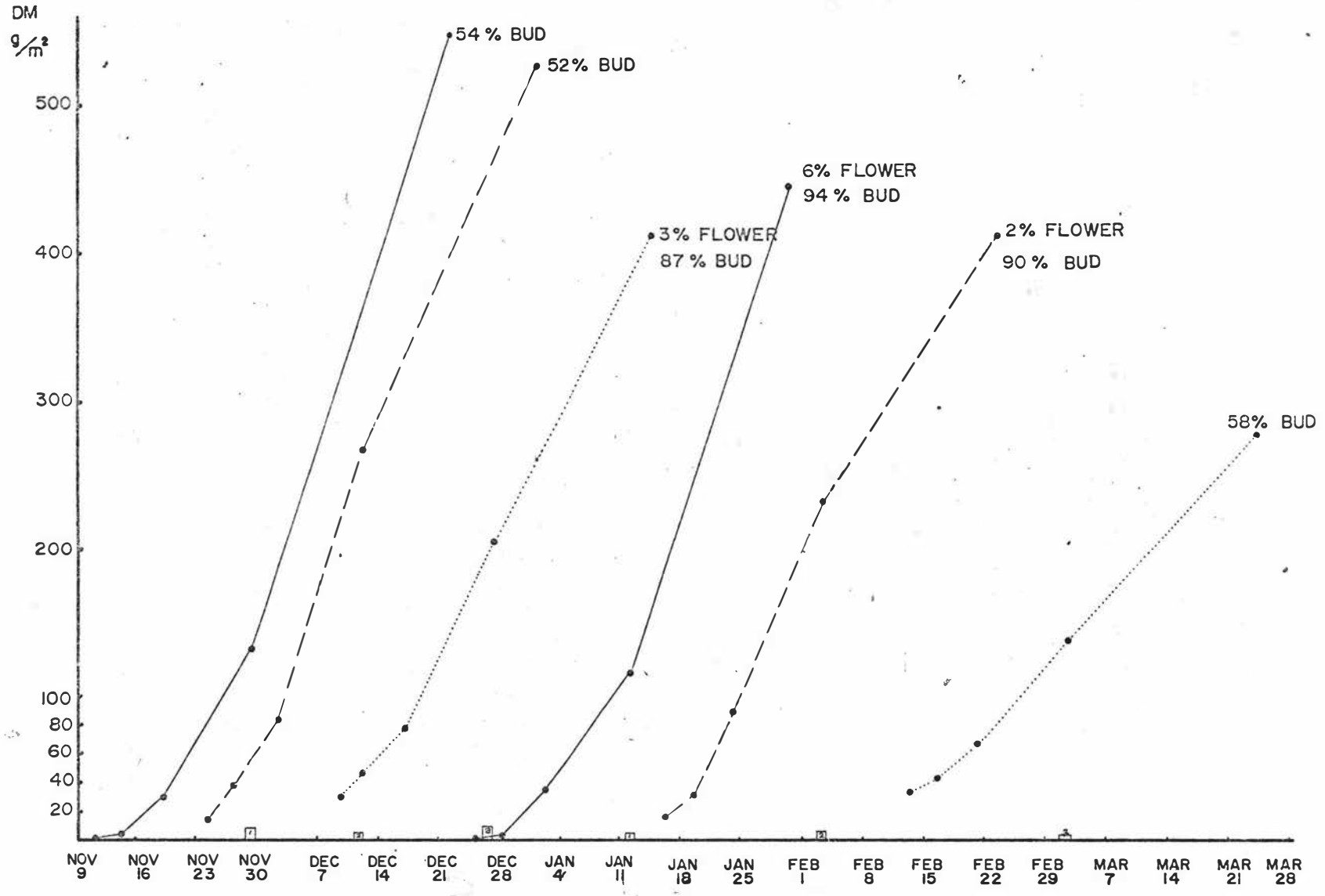


FIGURE 12. Herbage yield during the regrowth period - first two cycles.
(sum of basal & stubble shoots)

Tmt 1

Tmt 2

Tmt 3

stubble shoot yield at Day 18 for Treatments 1,2 or 3 as labelled

(See Appendix 30 for actual numbers)

these adjusted plot values to test for treatment differences unconfounded by the seasonal effect. One example of this procedure is given in Appendix 2 for absolute growth rates in the first half of the regrowth period. If the regression of 'residual' on day number was not significant, i.e. the seasonal effect was not significant, analysis of variance was performed on unadjusted plot values.

Figure 13 presents the herbage growth rates, absolute and relative, measured over the first half, Day 0-18, and the second half, Day 18 - x, of the regrowth period in the first two cycles.

During the first half of the regrowth period Treatment 2 was superior to the other two treatments in terms of absolute growth rates but, in terms of relative growth rates, Treatment 1 had the highest values (and incidentally Treatment 3 had the lowest).

In the second half of the regrowth period, Treatment 1 had the highest absolute and relative growth rates and no significant differences existed between the other two treatments in terms of either absolute or relative growth rates.

This whole section on yields and growth rates through the regrowth period has been expressed in terms of total herbage yield, i.e. the sum of basal and stubble shoots. It should be emphasised that the majority of this yield came from basal shoots. Stubble shoot yield as a percentage of total shoot yield exceeded 6% on only two occasions and at most of the harvests fluctuated around 2-3% (Appendix 3).

3 : 4 TOTAL HERBAGE PRODUCTION FOR TRIAL DURATION

Figure 14 compares the total herbage production under the three grazing systems for the full trial duration - September 20, 1975 to May 13, 1976. There are two main points in this figure. Firstly, the 15 and 30 day GDs did not result in massive reductions in total lucerne yield - they were 14% and 29% lower respectively than total lucerne yield on Treatment 1. Secondly, the differences between treatments in total lucerne yield were generated almost entirely by differences in stem yield. There

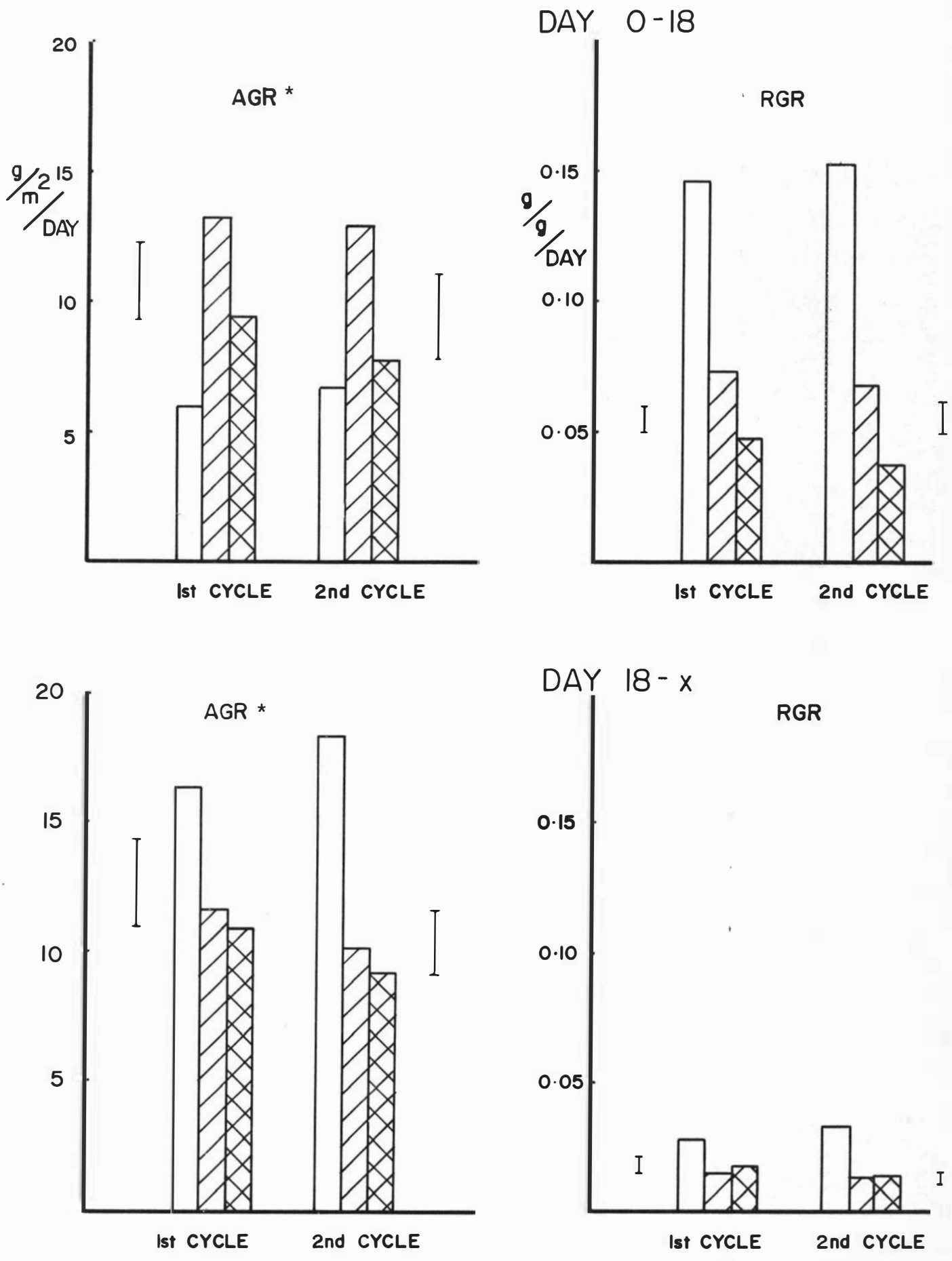


FIGURE 13. Herbage growth rates, absolute(AGR) & relative(RGR), for the first half (Day 0-18) & the second half (Day 18-X ie. Day 18 to basal shoot appearance stage) of the regrowth period for the first two cycles.

* adjusted values for seasonal effect

Tmt 1 Tmt 2 Tmt 3 LSD-5%

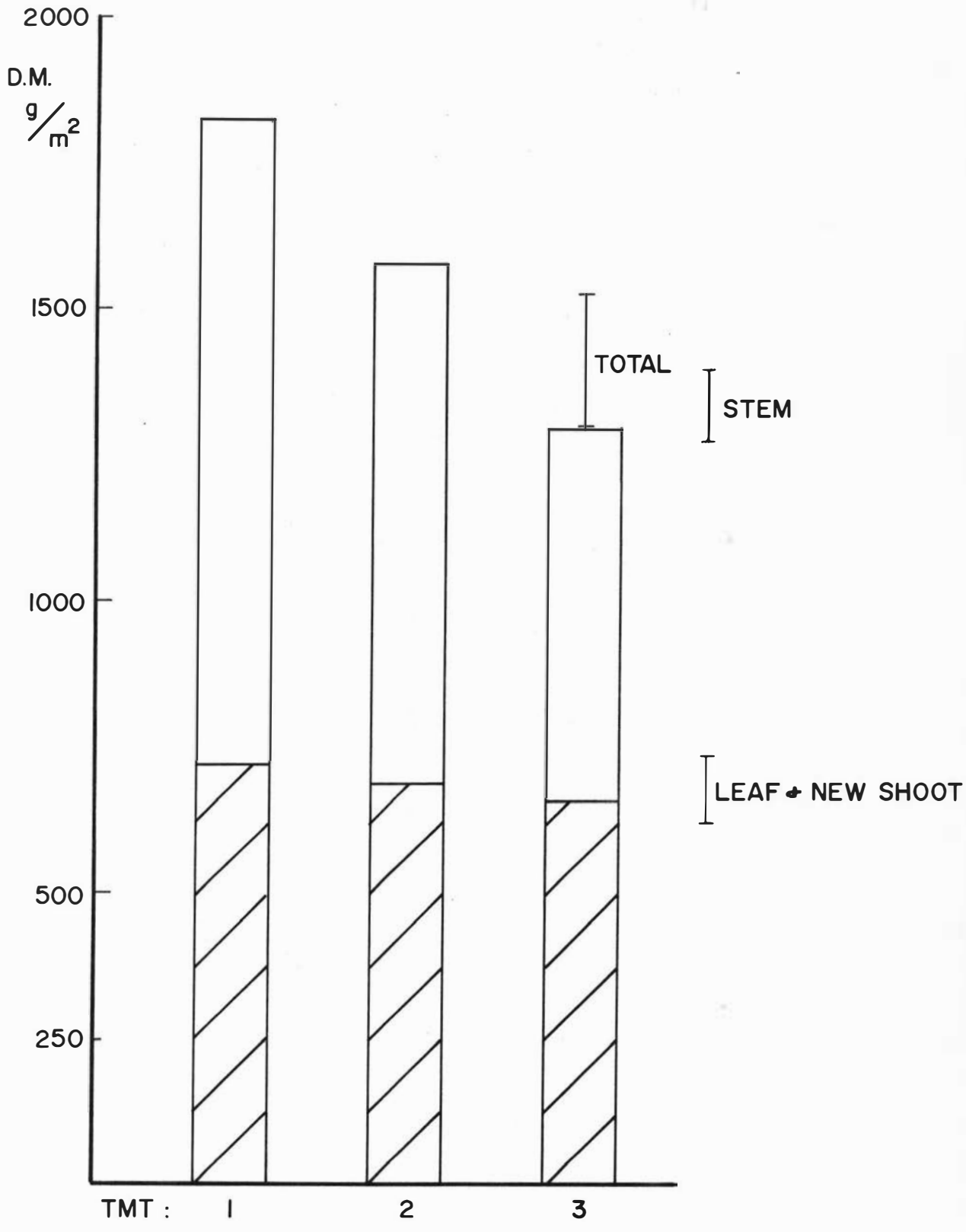
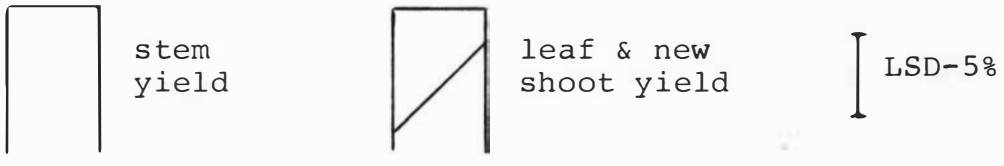


FIGURE 14. Total herbage production for trial duration.



were no significant differences between the three treatments in the total production of leaf and new shoot.

The average growth rate of the herbage during the regrowth periods, i.e. end of one grazing to start of the next, for all three treatments was 7.63 g/m²/day. The average growth rate of the herbage during the grazing periods for Treatments 2 and 3 was 2.78 g/m²/day, i.e. approximately 36% of the growth rate during the regrowth periods.

Of the 236 day total trial period, Treatments 2 and 3 spent 45 and 90 days respectively under grazing - i.e. 19% and 38% of the total trial duration. Thus, while treatment differences in growth rate during the regrowth period did occur (see Figure 13), it seems that an important cause of treatment differences in total production was the percentage of the trial duration that Treatment 2, but especially Treatment 3, spent under grazing; a period when herbage growth rates were slower.

Although production during the grazing periods was relatively small (123 and 255 g/m² for the 45 and 90 days of grazing on Treatments 2 and 3 respectively), 100% of it was leaf and new shoot and it appears this was largely responsible for the lack of any significant treatment differences in the total production of this valuable herbage component.

DISCUSSION

Consumption of the mature herbage in this trial followed the pattern described by Arnold (1960) and McKinney *et al* (1970) with the leaf and upper stem material being eaten first and the lower stem material last. The consequence of this of course was that the plants were left virtually bereft of leaf area for the last third of the grazing period.

The difficulty experienced in this trial in persuading stock to eat the lower half stem fraction is not uncommon when fairly mature herbage is being grazed, (see McKinney *et al* 1970), but was probably accentuated in this case because all the grazing was done with hoggets.

Development of the new shoot population was rapid following removal of the mature stem apices. Shoots quickly increased both in number and size

and thus it was inevitable that, under the 15 and 30 day grazing periods, the sheep would start 'topping' the tallest of these shoots once the leaf and upper stem fractions of the mature herbage had been consumed. As a result of this, the increases in the leaf area, length and average weight of the new shoots on Treatments 2 and 3 were stopped about two thirds of the way through the grazing period. Nevertheless, in view of the differences in regrowth which followed, it is important to note that all these parameters of the shoot population, plus the total yield of the shoot population, were higher on Treatment 3 than Treatment 2 when grazing finished 5-10 days later.

At the start of the regrowth period, shoot numbers on Treatment 1 were negligible and the few that were present were very small. Thus, although the population increased very rapidly in the first eight days of regrowth and the relative growth rate (RGR) of these new shoots was much higher than that of Treatment 2, the absolute growth rate (AGR) of Treatment 1 was substantially lower than that of Treatment 2 through the first half of the regrowth period.

Treatment 2 had, of course, developed a large population of undamaged independent, decapitated independent and emerging subtended shoots by the time the regrowth period started. In addition, a small but nonetheless significant and probably very efficient leaf area (specific leaf area: 0.15 cm^2/mg - see also Langer & Keoghan 1970) remained on this treatment at the end of the grazing period, down amongst the new shoots just below grazing height. Thus the morphological factors which prevented a rapid AGR early in the regrowth period of Treatment 1 were much less evident on Treatment 2 at the start of this period.

Treatment 3 had also developed a large population of undamaged independent and subtended shoots, subtending and decapitated independent shoots by the time the regrowth period started. Moreover, as noted above, the total yield, leaf area and average weight of the shoots in this population were all significantly greater than that of the basal shoot population on Treatment 2 at this time.

It was therefore surprising to find that both the AGR and RGR of Treatment 3 was lower than that of Treatment 2 through the first half of the regrowth period. It would seem that this could be caused by either one or both of the following two main factors :

a) the morphological composition of the shoot population from which regrowth occurred and/or
b) some other morphological or physiological aspect of the plants in Treatment 3 that was not monitored in this field trial.

With regard to the first suggestion, Figures 10 and 11 indicate that the principal difference between the shoot populations of Treatments 2 and 3 in the early part of the regrowth period is the greater importance of subtended shoots on Treatment 3. (The total of independent and subtended shoots on Treatment 3 exceeds that of Treatment 2 at only one harvest of the four in the first half of regrowth and then only marginally at the 5% significance level, as shown in Figure 11.) One of the objectives of the shoot population studies was to provide some detailed information on the relative performance of the different shoot classes through regrowth. Accordingly, the importance of any treatment differences in the morphological composition of the shoot populations is discussed in the following chapter.

With regard to the second suggestion, leaf area during regrowth would be of interest for it permits the calculation of Leaf Area Ratio (LAR). Leaf area was measured only for the first eight days of the regrowth period in the field trial so the following comments relate just to these first eight days. Table 2 shows there were no treatment differences in LAR at either cycle over this period. This indicates that differences between Treatments 2 and 3, at least for the first eight days of regrowth, are not attributable to differences in the partitioning of assimilates to leaf and non-leaf above-ground organs.

The Net Assimilation Rate (NAR) was also calculated for each treatment for this same period, but since no figures on root weight changes were collected in the field trial, only top weight changes could be included in the NAR calculation. Obviously, NAR based only on top weight changes is not a good indicator of leaf efficiency because root weight changes can influence NAR quite independently of any change in leaf efficiency. It is for this reason that the NAR figures are given (Table 2). It is most unlikely that leaf efficiency would differ greatly between treatments as leaves on all three treatments were small and relatively young at this stage - specific leaf area at Day 8 of the regrowth period being 0.22, 0.24 and 0.24 for Treatments 1, 2 and 3 respectively. Therefore the NAR figures suggest that treatment differences could exist in the reaction of root weight during this early part of the

TABLE 2. Leaf Area Ratio (LAR) & Net Assimilation Rate (NAR) for first eight days of regrowth period.

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% 1%
		LAR			
1st cycle	68.68	66.65	70.40	14.6	17.32 26.23
2nd cycle	65.79	71.98	65.09	12.9	15.07 22.82
		NAR			
1st cycle	0.0035	0.0015	0.0008	19.3	0.0006 0.0009**
2nd cycle	0.0037	0.0014	0.0007	18.8	0.0006 0.0009**

regrowth period - i.e. partitioning in the plant between tops and roots could be implicated in the differences in herbage growth rate between Treatments 2 and 3 recorded in the first half of the regrowth period in this field trial.

By the second half of the regrowth period, the AGR of Treatment 1 which had been so low in the first half exceeded that of the other two treatments. The reason for this is not clear, but is probably related to the stage of growth of the three treatments half way through the regrowth period. Consider firstly just Treatments 1 and 2. Treatment 1, with no shoots at the end of the grazing period, spent much of the early part of the regrowth period developing a shoot population. In contrast to Treatment 1, Treatment 2 started the regrowth period some distance along the regrowth curve for it had already developed a sizeable shoot population by the end of grazing. Thus, half way through the regrowth period, the herbage yield of Treatment 2 was higher than that of Treatment 1 (see Figure 12, Day 18 yields) and thus was closer to the stage when canopy factors (leaf:non-leaf ratio, self-shading etc.) start to reduce growth rate. In comparison, Treatment 1 was really just entering the steepest part of the sigmoidal growth curve by Day 18.

This same argument can still be used to explain the differences in growth rate between Treatments 3 and 1 in the second half of the regrowth period, but less convincingly for the herbage yield of Treatment 3 half way through this period was less than that of Treatment 2 at the same stage. On the basis of this argument, the growth rate of Treatment 3 should have been a little higher than that of Treatment 2 in the second half of regrowth, but in fact there was no significant difference between the growth rate of these two treatments in the second half. If anything, Treatment 3 tended to be a little lower than Treatment 2. This suggests that, for some part of the second half of the regrowth period, there may still have been some vestige of the factors which inhibited the growth rate of Treatment 3 in the first half.

The effect of grazing duration on the total lucerne produced through one full growth season was shown in Figure 14. The impact of the 15 day GD, in particular, on total lucerne production was sufficiently small to make the adoption of longer GDs than the 2-4 days which have been recommended (Iversen 1967) an attractive proposition in many circumstances. A 14% reduction in total lucerne yield may well be considered a reasonable price to pay for a less intensive system involving 15 day GDs rather than the idealistic one involving 2-4 day GDs.

The principal factor responsible for these differences in total lucerne yield was, of course, the slow growth rate during grazing. Unfortunately, this will always be a feature of lucerne, for the morphology of the plant and the grazing pattern of stock preclude high growth rates under grazing. Growth was generated principally from the stem apices and, once these were removed by the stock at the start of grazing, further growth could only occur from axillary leaf development on the stems and from new shoot development at the base of the stems. Axillary leaf development was minimal and also vulnerable to immediate removal by the stock while growth from new shoots at the base of the stems not only had to develop from very small initials, but was continually being interrupted - constant decapitation of these new shoots was maintained as long as grazing continued.

The fact that treatment differences in total yield were generated entirely by differences in stem yield has some important practical implications. While the stem is undoubtedly the least digestible fraction of the herbage (Christian, Jones and Freer; 1970), mature animals can use most of it. However, to young stock (especially lambs), much of the stem is virtually indigestible and, as a consequence, they graze principally just the leaf and new shoot material (Jagusch *et al* 1970, 1971). It is obvious therefore that extending the grazing duration up to 30 days is unlikely to significantly affect the capacity of the lucerne to feed young stock, but may reduce its production of feed utilisable by mature animals. Fortunately, it is the mature animals which adapt most readily to the high stock concentrations and frequent shifting associated with short grazing durations, and young stock (e.g. weaned lambs) which benefit most from the low stock concentrations and infrequent shifting of long grazing periods. For once, plant and animal requirements are not entirely in conflict.

* * * *

In the next chapter, the results of the shoot population studies are presented and discussed. The objective of this exercise was to provide a detailed insight into shoot development under grazing and the subsequent effects through the regrowth period. It should therefore provide a better understanding of the treatment differences in regrowth recorded in this chapter.

CHAPTER 4 : FIELD TRIAL - SHOOT POPULATION STUDIES

RESULTS

The following tables present details of the number and weight of the different classes of basal shoots that were present at the start of grazing (Prior), or arose either during grazing or after grazing in any of the specifed five day intervals. Data on the stubble shoots follow the basal shoot results for each harvest.

All the data are expressed on a per plant basis and as the average of eight plants.

In any statistical analyses of individual basal shoot classes, subtending shoots plus any classes with fewer than 0.5 shoot/plant were not included because their contribution to total yield was so small. Nevertheless, their contribution was recognised and when any analyses were performed on the three main basal shoot classes - independent, subtending and subtended - all the individual basal shoot classes were included.

When comparing individual basal shoot classes between the preliminary and final harvests, statistical analysis was only performed on those classes where the number of shoots as a percentage of the total had fallen at the final harvest.

Comparisons between treatments and between harvests were made on the percentage figures (number as percentage of total basals, weight as percentage of total basal shoot weight) rather than the absolute numbers and weights because of the relatively small sample size in these shoot population studies (eight randomly chosen plants/treatment/harvest).

4 : 1 TREATMENT ONE

All the shoots on Treatment 1 were independents.

4:1:1 PRELIMINARY HARVEST* (Table 3)

4:1:1(a) Basal Shoots

Eighty five percent of the shoots present at the preliminary harvest had appeared by the end of the first five days post-grazing. The remaining 15% of the shoots appeared in the next five day period.

The earlier a shoot arose on this treatment, the heavier its weight at the preliminary harvest; this resulted from both a longer growth period and a higher absolute growth rate. Consequently the early developing shoots ('Prior' and 1st 5) contributed over 90% of the total basal shoot weight (t.b.s.wt.).

4:1:1(b) Stubble Shoots

Stubble shoots were few in number and light in weight so contributed only 2% to total shoot weight (t.s.wt.) They appeared later than basal shoots, e.g. only 17% of the stubble shoots were present five days after the end of grazing.

4:1:2 FINAL HARVEST (Table 3)

4:1:2(a) Basal Shoots

In the second half of regrowth mortalities occurred principally amongst the late developing shoots, so that at the final harvest they contributed only 2% of t.b.s.wt. This of course accentuated both the numerical dominance and the yield contribution of the early developing shoots.

4:1:2(b) Stubble Shoots

The contribution of stubble shoots to t.s.wt. had decreased by the final harvest apparently due to both shoot mortality and limited weight increase of the survivors.

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* Day 18 of the regrowth period

TABLE 3. Shoot population studies.
Treatment 1 - Preliminary harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)	Shoot growth rate (mg/day) ##
	Prior	0.9	6%	0.25	14%	0.28	13.3
During the regrowth period	1st 5	12.5	79%	1.43	78%	0.13	10.0
	2nd 5	2.4	15%	0.16	9%	0.06	7.5
	3rd 5	-	-	-	-	-	-
Basal shoot totals		15.8		1.84			
	CV%	75.8		59.9		43.4	
	LSD 5%	4.26		0.39		0.07	
	1%	5.92		0.55		0.10	

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots #	0.8	5%	0.04	2%	0.05

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	-	0.1	0.6	-
%	-	17%	83%	-

Treatment 1 - Final harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	1.0	8%	0.70	10%	0.70
During the regrowth period	1st 5	10.8	86%	6.17	88%	0.57
	2nd 5	0.7	6%	0.17	2%	0.24
	3rd 5	-	-	-	-	-
Basal shoot totals		12.5		7.04		
	CV%	62.0		51.3		25.8
	LSD 5%	2.8		1.29		0.14
	1%	3.8		1.79		0.19

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	0.4	3%	0.06	0.8%	0.15

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	-	0.1	0.3	-
%	-	33%	67%	-

Comparison of Preliminary & Final Harvest Data

	CV%	LSD 5%	
Basal shoots - individual classes			
no. as % of total basals: during regrowth - 2nd 5	45.7	5.7	**
Stubble shoots			
no. as % of total shoots	75.0	3.5	ns
wt. as % of t.s.wt.	71.4	1.1	*

NOTES:
t.b.s.wt. - total basal shoot weight
t.s.wt. - total shoot weight
\# - the time of appearance of each stubble shoot was noted at harvest but because there were so few of them they were bulked for weighing
- shoot growth rate is taken as average weight divided by number of days from labelling to Preliminary harvest. There are a number of inaccuracies in this method but they are of little consequence since (a) they apply equally to all 3 shoot classes & (b) it is the treatment comparisons which are of interest rather than the absolute figures.
ns - not significant
* - significant at 5% level
** - " " 1% "

4 : 2 TREATMENT TWO

4:2:1 PRELIMINARY HARVEST (Table 4)

4:2:1(a) Basal Shoots

Under the 15 day grazing period of Treatment 2, most of the early developing shoots ('Prior' and 1st 5) were decapitated and ultimately developed into subtending shoots. Consequently, independent shoots were concentrated towards the end of the grazing period - where they had an increasing chance of avoiding decapitation - and in the immediate post-grazing period.

Because shoot decapitation only started about half way through the grazing period, subtended shoots were only just beginning to appear by the end of grazing and consequently the majority arose immediately post-grazing.

Of the independent and subtended shoots which arose during the grazing period, the later they arose the greater the average shoot weight of their age class at the preliminary harvest. Clearly, of the shoots which arose early in the 15 day grazing period, all the large, rapidly growing shoots were decapitated leaving only the small, slower-growing ones. This effect decreased in the shoot classes arising towards the end of grazing, presumbly because the large, rapidly growing shoots in these classes increasingly escaped decapitation and thus continued their development uninterrupted.

Shoots arising after the grazing period were lighter at the preliminary harvest than those appearing towards the end of grazing, for most of the latter escaped decapitation and thus were able to continue development without damage following an earlier time of appearance.

As a result of these combined effects, 86% of t.b.s.wt. at the preliminary harvest came from shoots appearing in the last five days of grazing and the first five days post-grazing.

Subtending shoots were always small irrespective of when they appeared and thus, while they contributed 30% to t.b.s.no., their contribution to t.b.s.wt. was only 5%.

TABLE 4. Shoot population studies.
Treatment 2 - Preliminary harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep#	-	-	-	-	-
		- subt'g	1.0	3%	0.03	1%	0.03
During the grazing period	1st 5	- indep	-	-	-	-	-
		- subt'g	3.8	13%	0.07	2%	0.02
	2nd 5	- indep	1.8	6%	0.29	9%	0.16
		- subt'g	4.0	14%	0.07	2%	0.02
		- subtd'd	-	-	-	-	-
	3rd 5	- indep	4.4	15%	1.18	35%	0.26
		- subt'g	-	-	-	-	-
		- subtd'd	1.5	5%	0.42	12%	0.28
During the regrowth period	1st 5	- indep	3.6	12%	0.40	12%	0.11
		- subtd'd	9.0	31%	0.91	27%	0.10
	2nd 5	- indep	-	-	-	-	-
		- subtd'd	-	-	-	-	-
	Basal shoot totals		29.2		3.37		
		CV%	63.3		75.1		46.1
		LSD 5%	2.6		0.49		0.08
		1%	3.5		0.66		0.11
Relative contributions from the 3 main basal shoot classes		Indep	9.9	34%	1.87	56%	0.19
		Subt'g	8.8	30%	0.17	5%	0.02
		Subtd'd	10.5	36%	1.33	39%	0.13
		CV%	29.4		32.3		25.8
		LSD 5%	3.1		0.39		0.03
		1%	4.3		0.54		0.04

	No.	No. as % of total I&S shts. ##	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	1.4	6%	0.11	3%	0.08

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5:	1st 5	2nd 5
No.	-	-	0.1	0.4	0.8	0.1
%	-	-	9%	27%	55%	9%

- indep - independent, subt'g - subtending, subtd'd - subtended
- I&S - independent & subtended shoots

Independent and subtended shoots comprised approximately equal proportions (34% and 36% respectively) of the basal shoot populations at the preliminary harvest, but independents made a greater contribution than subtendeds to t.b.s.wt. at this time (56% and 39% respectively). This was not due to any inherent difference in the growth potential of independent and subtended shoots, for independent and subtended shoots of the same age grew to the same average weight at the preliminary harvest. It was the result of a shoot size effect (see average weight of independent and subtended shoots) arising from a difference in the age composition of the two classes. Most of the independent shoots present at the preliminary harvest arose towards the end of grazing and thus appeared 5-10 days earlier than most of the subtendeds which arose mainly in the first five days post-grazing.

4:2:1(b) Stubble Shoots

As on Treatment 1, stubble shoots were few in number and light in weight and thus contributed only 3% to t.s.wt. Also, once again, it seemed that stubble shoots were appearing a little later than basal shoots.

4:2:2 FINAL HARVEST (Table 5)

4:2:2(a) Basal Shoots

In the second half of regrowth, it seems that, if mortalities occurred amongst the independent and subtended shoots, they occurred amongst the latest developing ones. Only in these classes did the percentage of t.b.s.no. decline, albeit non-significantly. There did not appear to be any difference in the survival of independent and subtended shoots of the same age during the second half of regrowth.

The relative contribution of independent and subtended shoots to both t.b.s.no. and wt. diverged during the second half of regrowth, a factor which is probably attributable to the different age composition of the two classes and the influence this has on survival.

4:2:2(b) Stubble Shoots

Once again the contribution of stubble shoots to t.s.wt. decreased in the second half of regrowth due to both shoot mortality and negligible weight increase of the survivors.

TABLE 5. Shoot population studies.
Treatment 2 - Final harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	0.1	< 1%	0.01	< 1%	0.10
		- subt'g	0.3	1%	0.02	< 1%	0.05
During the grazing period	1st 5	- indep	0.1	< 1%	0.01	< 1%	0.01
		- subt'g	2.4	12%	0.05	1%	0.02
	2nd 5	- indep	2.0	10%	1.09	17%	0.54
		- subt'g	2.4	12%	0.07	1%	0.03
		- subtd'd	-	-	-	-	-
	3rd 5	- indep	4.6	23%	2.68	41%	0.59
		- subt'g	-	-	-	-	-
		- subtd'd	1.1	5%	0.58	9%	0.52
During the regrowth period	1st 5	- indep	1.5	7%	0.38	6%	0.24
		- subtd'd	5.7	28%	1.58	24%	0.28
	2nd 5	- indep	-	-	-	-	-
		- subtd'd	-	-	-	-	-
	Basal shoot totals		20.2		6.47		
		CV%	73.6		84.5		43.5
		LSD 5%	2.2		1.09		0.19
		1%	3.0		1.47		0.26
Relative contributions from the 3 main basal shoot classes		Indep	8.3	41%	4.17	64%	0.50
		Subt'g	5.1	25%	0.14	2%	0.03
		Subtd'd	6.8	34%	2.16	33%	0.32
		CV%	31.7		34.1		26.1
		LSD 5%	2.3		0.79		0.08
		1%	3.2		1.09		0.11

	No.	No. as % of total I&S shts.	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	0.5	3%	0.05	0.8%	0.10

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5:	1st 5	2nd 5
No.	-	-	0.1	0.1	0.3	-
%	-	-	25%	25%	50%	-

Comparison of Preliminary & Final Harvest Data

		CV%	LSD 5%	
Basal shoots - main classes				
no. as % of total basals:	Indep	18.7	8.3	ns (as)
	Subt'g	20.2	6.6	ns "
	Subtd'd	15.5	6.4	ns
tot. wt. as % of t.b.s.wt.:	Indep	12.2	8.6	ns "
	Subt'g	18.2	0.8	**
	Subtd'd	19.4	8.2	ns
Basal shoots - individual classes				
no. as % of total basals: 1st 5 (regrowth)	-indep	49.3	5.5	ns "
" " "	-subtd'd	26.3	9.2	ns
Stubble shoots				
no. as % of total I&S shoots		55.6	2.9	*
wt. " " " t.s.wt.		61.7	1.4	**

(as) = approaching significance

4 : 3 TREATMENT THREE

4:3:1 PRELIMINARY HARVEST (Table 6)

4:3:1(a) Basal Shoots

Most of the independent shoots present at the preliminary harvest once again arose around the end of the grazing period for the same reasons as on Treatment 2. However, Treatments 2 and 3 differed in the development of subtended shoots. On Treatment 2, most of the subtended shoots arose after the end of grazing while on Treatment 3 nearly 50% arose before the end of grazing. Clearly, with shoot decapitation commencing on both treatments approximately half way to two thirds of the way through grazing (Figure 9), there was a greater opportunity for subtended shoot development during grazing on Treatment 3 than Treatment 2.

Size effects amongst shoots arising both during grazing and after grazing followed the same pattern as that of Treatment 2, i.e. of the independent and subtended shoots which arose during the grazing period, the later they arose the greater their average weight at the preliminary harvest. Shoots arising after the grazing period were lighter at the preliminary harvest than those appearing towards the end of grazing.

Once again, as a result of these combined effects, the majority (71%) of t.b.s.wt. at the preliminary harvest came from shoots arising in the last five days of grazing and the first five days post-grazing.

The total number of subtended shoots exceeded that of independent shoots at the preliminary harvest (42% and 27% respectively of t.b.s.no.) and because the average weight of these two main shoot classes was not significantly different, subtended shoots made a greater contribution to t.b.s.wt. than independents (52% and 39% respectively). This result is quite different from that obtained on Treatment 2 (Table 8) where subtended shoots as a class were not only lighter than independents but also had no numerical superiority and therefore contributed less than independents to t.b.s.wt.

Independent and subtended shoots that appeared at the same time grew to the same average weight at the preliminary harvest.

TABLE 6. Shoot population studies.
Treatment 3 - Preliminary harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	-	-	-	-	-
		- subt'g	0.1	< 1%	< 0.01	-	0.01
During the grazing period	1st 5	- indep	0.3	1%	0.02	1%	0.08
		- subt'g	2.2	7%	0.05	3%	0.02
	2nd 5	- indep	0.5	2%	0.02	1%	0.04
		- subt'g	2.4	8%	0.05	3%	0.02
	3rd 5	- indep	0.5	2%	0.01	< 1%	0.03
		- subt'g	1.9	6%	0.03	2%	0.02
		- subtd'd	-	-	-	-	-
	4th 5	- indep	0.8	3%	0.05	3%	0.06
		- subt'g	1.8	6%	0.03	2%	0.02
		- subtd'd	-	-	-	-	-
	5th 5	- indep	2.3	8%	0.23	12%	0.10
		- subt'g	0.8	3%	0.01	< 1%	0.02
		- subtd'd	0.9	3%	0.08	4%	0.09
	6th 5	- indep	2.8	9%	0.35	19%	0.13
		- subt'g	0.3	1%	< 0.01	-	0.02
		- subtd'd	5.1	17%	0.54	29%	0.11
During the regrowth period	1st 5	- indep	1.1	4%	0.05	3%	0.05
		- subtd'd	6.7	22%	0.37	20%	0.06
	2nd 5	- indep	-	-	-	-	-
		- subtd'd	-	-	-	-	-
	Basal shoot totals		30.5		1.89		
		CV%	51.7		55.3		38.9
		LSD 5%	1.2		0.13		0.03
		1%	1.6		0.18		0.04
Relative contributions from the 3 main basal shoot classes		Indep	8.3	27%	0.73	39%	0.09
		Subt'g	9.5	31%	0.17	9%	0.02
		Subtd'd	12.7	42%	0.99	52%	0.08
		CV%	25.7		26.3		24.1
		LSD 5%	2.8		0.18		0.02
		1%	3.9		0.25		0.02

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	0.3	1%	0.01	< 1%	0.03

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5	4th 5	5th 5	6th 5	1st 5	2nd 5
No.	-	-	-	-	-	-	0.1	0.1	-
%	-	-	-	-	-	-	50%	50%	-

4:3:1(b) Stubble Shoots

There were very few stubble shoots on Treatment 3 and once again their light weight ensured that their contribution to t.s.wt. was very small (< 1%).

4:3:2 FINAL HARVEST (Table 7)

4:3:2(a) Basal Shoots

A similar pattern of shoot mortality to that of Treatment 2 occurred on Treatment 3 - decreases, which just failed to reach the 5% significance level, in the percentage contribution of the latest developing shoots and no difference in the survival of independent and subtended shoots of the same age. However, in addition to these effects, it appeared that losses were occurring in the second half of regrowth from the early developing independents, i.e. shoots which arose early in the grazing period and yet were still undecapitated independents at the preliminary harvest. This is not surprising in view of the fact already mentioned that only the smallest and slowest growing of the early developing shoots would escape decapitation under a 15 or 30 day grazing period. It seems likely that these early developing independents which escaped decapitation are responsible for the slightly higher total of independent and subtended shoots on Treatment 3 than Treatment 2 in the herbage results noted in the early part of the regrowth period.

4:3:2(b) Stubble Shoots

No stubble shoots were found at the final harvest of Treatment 3.

DISCUSSION

The results of Treatment 1 are in close agreement with those of Leach (1968). On this treatment shoot development was straightforward. Very few shoots were present at the start of grazing, those that were present were very small and grazing was so quick (2-4 days) that there was no time for shoot development following stem apex removal. Consequently no shoot damage occurred and 100% of the basal shoot population were independents.

The very clear relationship on Treatment 1 between the time of

TABLE 7. Shoot population studies.
Treatment 3 - Final harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	-	-	-	-	-
		- subt'g	-	-	-	-	-
During the grazing period	1st 5	- indep	-	-	-	-	-
		- subt'g	1.6	6%	0.06	1%	0.04
	2nd 5	- indep	-	-	-	-	-
		- subt'g	2.9	11%	0.08	1%	0.03
	3rd 5	- indep	0.1	< 1%	0.02	< 1%	0.20
		- subt'g	2.4	9%	0.06	1%	0.03
		- subtd'd	-	-	-	-	-
	4th 5	- indep	0.4	2%	0.10	2%	0.25
		- subt'g	1.2	5%	0.04	1%	0.03
		- subtd'd	-	-	-	-	-
	5th 5	- indep	2.0	8%	0.71	13%	0.36
		- subt'g	0.7	3%	0.02	< 1%	0.03
		- subtd'd	0.7	3%	0.29	5%	0.42
	6th 5	- indep	2.7	11%	1.07	19%	0.40
		- subt'g	-	-	-	-	-
		- subtd'd	6.1	24%	2.29	41%	0.38
During the regrowth period	1st 5	- indep	0.6	2%	0.13	2%	0.22
		- subtd'd	3.9	15%	0.69	12%	0.18
	2nd 5	- indep	-	-	-	-	-
		- subtd'd	-	-	-	-	-
	Basal shoot totals		25.3		5.56		
		CV%	47.3		52.4		29.3
		LSD 5%	1.3		0.46		0.09
		1%	1.7		0.62		0.13
Relative contributions from the 3 main basal shoot classes	Indep		5.8	23%	2.03	37%	0.35
	Subt'g		8.8	35%	0.26	5%	0.03
	Subtd'd		10.7	42%	3.27	59%	0.31
	CV%		23.9		24.7		22.2
	LSD 5%		2.2		0.49		0.05
	1%		3.0		0.68		0.08

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	-	-	-	-	-

Comparison of Preliminary & Final Harvest Data

		CV%	LSD 5%	
Basal shoots - main classes				
no. as % of total basals:	Indep	15.1	4.5	ns (as)
	Subt'g	14.4	5.6	ns
	Subtd'd	11.9	5.9	ns
tot. wt. as % of t.b.s.wt.:	Indep	16.6	7.4	ns
	Subt'g	13.1	1.1	**
	Subtd'd	12.2	8.0	ns (as)
Basal shoots - individual classes				
no. as % of total basals: 4th 5 (grazing)	-indep	85.0	2.5	ns
1st 5 (regrowth)	-indep	67.3	2.4	ns (as)
" " "	-subtd'd	36.1	7.9	ns (as)
Stubble shoots				
no. as % of total I&S shoots		-	-	
wt. " " " t.s.wt.		-	-	

TABLE 8. Shoot population studies.
Treatment comparisons.

Basal shoots - main classes		Preliminary harvest Tmt 2	Tmt 3	CV%	LSD 5% 1%	Final harvest Tmt 2	Tmt 3	CV%	LSD 5% 1%
No. as % of total basals	Indep	34%	27%	17.3	6.2* 9.2	41%	23%	18.1	6.8 10.1**
	Subt'g	30%	31%	18.4	6.6 ns 9.8	25%	35%	17.7	6.3 9.3**
	Subtd'd	36%	42%	14.0	6.4 as 9.6	34%	42%	12.8	5.7* 8.5
Tot. wt. as % of tbswt.	Indep	56%	39%	15.1	8.5 12.6**	64%	37%	14.9	8.9 13.2**
	Subt'g	5%	9%	18.8	1.6 2.3**	2%	5%	14.4	0.6 0.9**
	Subtd'd	39%	52%	17.5	9.4* 13.9	33%	59%	16.7	9.1 13.4**

appearance of a shoot and its subsequent development was probably caused by a number of factors in the plant associated with intershoot competition. Nutritional and hormonal factors could all be involved in ensuring the dominance of the early developing shoots. In addition to Leach (1968), Hodgkinson (1973) has also noted the dominance and importance of these early arising shoots when the mature herbage is removed instantaneously.

On Treatments 2 and 3, although the shoot population at the start of grazing was again minimal, with 15 and 30 day GDs, there was sufficient time for appreciable shoot development following stem apex removal and consequently shoot decapitation occurred. This introduced a complicating effect for now many of the shoots which arose early in the grazing period were decapitated. However, it is clear from the results that, in a population of shoots arising within any five day period, there was a variety of different initial sizes and potential growth rates - a fact also noted by Hodgkinson (1973). The longer grazing continued, the fewer of these early developing shoots escaped decapitation and increasingly those that did were the ones with the least potential for future development. Consequently, in contrast to Treatment 1, it was not the earliest shoot class which had the largest average shoot size and made the greatest contribution to yield on Treatments 2 and 3, but rather the class in which the shoots arose sufficiently late in the GD to just escape decapitation, thus permitting the biggest, most vigorous shoots in that class uninterrupted expression of their potential.

Once the danger of decapitation had passed (i.e. last five days of grazing, for this grazing severity and, of course, the post-grazing period), the importance of shoots appearing as early as possible was again evident in the average shoot weights. Thus the major yield contribution on Treatments 2 and 3 came from shoots arising towards the end of grazing and in the immediate post-grazing period.

The relative contributions of independent and subtended shoots on Treatments 2 and 3 involved a number of interacting effects. On Treatment 2, subtended shoot development was just commencing when grazing ceased. Thus the majority of the subtended shoots, which predominantly arose in the immediate post-grazing period, were 'late' relative to the independent shoots present at the preliminary harvest, many of which arose towards the end of the grazing period. Consequently, subtended shoots were small and appeared to have a higher mortality than the

independents. In contrast, on Treatment 3, a substantial amount of subtended shoot development occurred towards the end of the grazing period and thus the subtended shoots as a class compared better with the independents than on Treatment 2 in terms of both size and survival.

The increasing numerical importance of subtended relative to independent shoots as GD increased was predictable, for almost invariably decapitation of a vigorous young independent shoot resulted in the development of a subtended shoot, provided at least one node was left on the decapitated 'stump' i.e. the potential subtending shoot. This may assist the survival of the plant under a prolonged grazing period. However, the shoot population studies have shown that this increasing numerical importance of subtended relative to independent shoots as GD increases will not, *per se*, impair regrowth, for independent and subtended shoots of the same age always performed comparably.

In the preliminary glasshouse studies, the apex of subtended shoots was removed and development of new shoots on these decapitated subtendeds was observed, but no information was collected on the growth potential of these 'double subtendeds'. Therefore it is not possible to predict from these results whether the regrowth following GDs longer than 30 days would be affected by the growth potential of the shoot population.

As in the herbage results, the stubble shoots were found to make little contribution to yield in the first half of the regrowth period. However, the shoot population studies showed their contribution in the second half of regrowth was even less because of their slow growth rate and poor survival. In view of their small size at the preliminary harvest, this is not surprising. Intraplant competition would be expected to intensify in the second half of the regrowth period and these stubble shoots, along with late-developing basals were the ones to succumb. Leach (1970) noted that shoots developing higher on the stem generally arose later than those developing near the crown, and these shoot studies confirm that, in general, stubble shoots tend to arise later than basals. However, in neither Leach's work or this study is it clear whether the size of the stubble shoots is due to their position, or their time of appearance, or both. Keoghan (1970) noted poor survival amongst stubble shoots in a simulated sward and suggested it may be due to breakdown of translocation in the rapidly senescing stubble.

Throughout these shoot population studies, the importance of the independent and subtended shoots arising towards the end of grazing and in the immediate post-grazing period of Treatments 2 and 3 has been stressed. However, in the herbage data (Figures 8 and 10), there was no change in the total number of independent and subtended shoots through this period on Treatments 2 and 3. This emphasises the difference between the data of Figures 8 and 10 and those of the shoot population harvests. The latter simply presents a picture of the shoot population half way through regrowth with information on when these shoots arose. The former simply shows how the total number of shoots changed during grazing and regrowth.

Clearly, if the shoot population studies show that independent and subtended shoots were appearing in a period when Figures 8 or 10 showed no change in the total number of shoots of this type, then either mortality or transfer to another class (e.g. independent to subtending) was nullifying the effect. A certain number of independent shoots became subtending shoots around the end of grazing on both Treatments 2 and 3, but it seems that some shoot mortality also occurred around this time. This is the only indication in the results of shoot death occurring so early.

These shoot population studies have given a detailed insight into the dynamics of shoot development during grazing. As a result, it is now clear that the differences in herbage growth rate between Treatments 2 and 3 in the first half of the regrowth period cannot be attributed to either the size or morphological composition of the shoot population from which regrowth occurred. The basis of this claim is the equal growth potential of independent and subtended shoots of the same age and the ample number of shoots on Treatment 3 arising in the period (last ten days of grazing and first five post-grazing) which contributed nearly 90% of the yield at the preliminary harvest of both Treatments 2 and 3.

CHAPTER 5 : CONTROLLED ENVIRONMENT STUDIES - INTRODUCTION AND EXPERIMENTAL

Having studied the effect of GD on lucerne through one season and gained an insight into the causes of some of the effects on the herbage, it was apparent that, if a better understanding of lucerne's response to GD was to be obtained, further work should be conducted under controlled environmental conditions. In this way more reliable treatment comparisons than would be possible in a field study could be made of a number of factors which could be affected by GD and which may influence herbage development. Of particular interest in this respect was the size, composition and functioning of the underground organs.

In addition, because of the possible involvement of climate with GD, it was considered important that the interaction of at least one or two climatic factors with GD be investigated.

5 : 1 PLANT ESTABLISHMENT

The growth medium used in the controlled environment (CE) studies was a mixture of Manawatu sandy loam and Opiki peat loam in a 7 : 3 (v : v) ratio. The following nutrients were added when the two soils were mixed thus ensuring thorough distribution through the medium :

lime	:	at the rate equivalent to 3760 kg/ha
superphosphate	:	" 1000 "
potash	:	" 500 "
copper sulphate	:	" 11 "

The whole mixture was steam sterilised for 24 hours and weighed out into 550 5 litre plastic pots (18x18x18 cm). 4400 g of oven dry soil was added to each pot. On October 2, 1975, 16-20 inoculated seeds of Certified 'Wairau' lucerne were sown in each pot. Over the next six weeks, the developing seedlings were carefully thinned to leave four strong young lucerne plants in each pot, sited approximately in the

four quadrants of the pot.

The plants were held in a temperature regulated glasshouse (temperature maximum 25°/minimum 15°C) and watered daily for the first two months after sowing while they steadily increased in size. They were clipped to a stubble height of about 5 cm once during this period and then again just prior to their transfer outdoors. From December 1975 to May 1976, plant development continued vigorously outside. The lucerne reached the 50% flower stage twice during this period following cutting to about 5 cm.

On May 9, 1976, eight weeks after the last cut and one day before entry to the controlled environments, 276 pots were selected to give the most uniform group of lucerne plants possible from the 550 pots of lucerne available. The height, stem number, colour and general appearance of the lucerne herbage was the basis for selection of these 'treatment' pots. These 276 pots were then randomly divided into three groups of 92 each. Two pots were removed at random from each group for an assessment of the uniformity of the three groups. The lucerne in the remaining 90 pots in each group was then clipped to 2 cm. Another dressing of fertiliser was applied to each pot (superphosphate and copper sulphate at rates equivalent to 600 kg/ha and 12 kg/ha respectively) and lightly worked into the top 2 cm of soil. The following day (May 10, 1976) these 270 'treatment' pots were transferred to three controlled environment rooms (1 group of 90 pots/room) in the D.S.I.R. Climate Laboratory at Palmerston North (Plate 13).

The remaining 270 pots of the original 550 were also cut to 2 cm and moved into a glasshouse held at about 20°C.

5 : 2 TREATMENT DESCRIPTION AND EXPERIMENTAL DESIGN

The CE project really involved three studies, one in each of the three CE rooms. Each study examined the same three 'grazing' durations but under different environmental conditions.

In each room the 90 pots were placed on six movable trolleys at 15 per trolley. Approximately 30 pots per treatment were needed for the

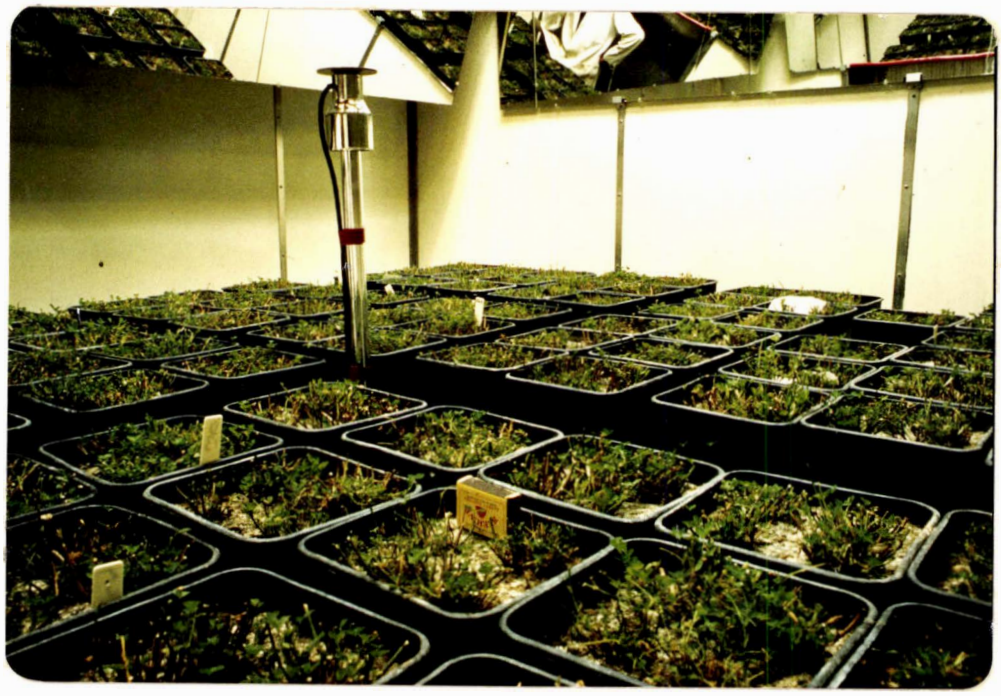


PLATE 13. General view of some of the pots in one of the controlled environment rooms at the start of the CE studies.

destructive harvesting envisaged. Thus a pair of trolleys carried enough pots for one GD treatment. It was clear that, if this CE project was to have any relevance to the field situation, conditions as close as possible to those in a sward would have to be reproduced in the rooms. Thus it was decided that all 30 pots in a treatment should be kept together to form as large a 'sward' as possible. Accordingly, three pairs of trolleys were arbitrarily formed in each room, by tying two trolleys together, to give the three groups of 30 plants required per room. The construction of the trolley permitted each pot in the group of 30 to be sited equidistantly from its neighbours, no more than 1-2 cm away.

The 30 pots on each pair of trolleys were moved every four days in a systematic manner over the 30 available 'sites' on the two trolleys. (The only time this could not be done was for the last few days of each regrowth period when moving the individual pots caused physical damage to the herbage.) In addition to this, the three trolley pairs in each room were moved every four days into a new position in the room. In this way, the effect of any positional effects either within a treatment 'sward' or within the room itself were virtually eliminated.

Whenever pots were removed from the rooms for destructive sampling, pots of lucerne which were at a similar stage of development to those just removed were brought in from the 270 'spares' in the glasshouse to fill the gaps in the 'sward'. Thus the 'sward' always comprised 30 pots. The 'spares' on entry to the 'sward' were handled in the same way as the 'treatment' pots except, of course, that 'spares' were never used for sampling.

To reduce light penetration into the simulated 'sward' from the side and improve its relevance to a field sward where, of course, all light filters down from the top, a screen of black material was erected around each 'sward' of 30 pots. The top of the screen was lifted as the 'sward' increased in height but was always kept about 5-6 cm below the top of the stems.

Whenever a destructive harvest was taken, two of the 'treatment' pots were removed at random from the appropriate 'sward'. The two plants in each half of a pot comprised a replicate, giving four replicates of two plants each for all the herbage and root harvests. The study in each CE room was analysed as a completely randomised design.

5 : 3 THE SIMULATED GRAZING TECHNIQUE

As mentioned earlier, three 'grazing' duration (GD) or defoliation duration treatments were compared in each CE room. They were :

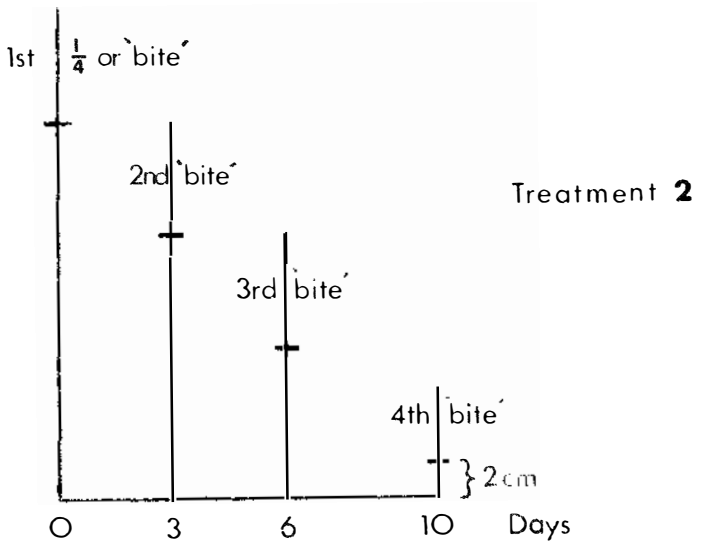
Treatment 1 : zero GD - i.e. instantaneous defoliation
Treatment 2 : 10 day "
Treatment 3 : 30 " "

Each 'grazing' commenced at the 1% flowering stage. Ten days was adopted for the intermediate GD because it was felt the 15 day GD of the intermediate treatment in the field trial resulted in too much interference (for an intermediate treatment) with the new shoot population elongating at the base of the sward.

The field trial results indicated the pattern of herbage consumption under different GDs. It was considered possible to simulate this very closely by plucking and cutting with hand shears. However, a compromise had to be reached between accurate simulation of the animals' grazing effect and what could be done with reasonable repeatability. The following technique was adopted. On Treatment 1 - zero GD - the herbage was removed instantaneously with one cut at 2 cm above soil level.

On Treatment 2 - 10 day GD - the herbage was removed in four 'bites' spaced over the 10 day 'grazing' period. Each 'bite' removed 25% of the difference between the ungrazed vertical height (measured just prior to commencement of 'grazing') and the final 'grazing' height of 2 cm. For example, if the lucerne was 34 cm tall at the 1% flower stage, a 2 cm final 'grazing' height left 32 cm to be removed in four 'bites' i.e. 8 cm 'bites'. Therefore the first 'bite' removed all the herbage above 26 cm (by simply cutting the lucerne with hand shears 26 cm above soil level), the second 'bite' all the herbage above 18 cm, the third 'bite' all the herbage above 10cm and the fourth 'bite' all the herbage above 2 cm.

On Treatment 3 - 30 day GD - the herbage was removed down to the 2 cm final 'grazing' height in four 'bites' spaced over the first 20 days followed by two further 'bites' at 2 cm on Days 25 and 30 to remove any shoot development that emerged above this height during the last ten days of the 'grazing' period. Treatments 2 and 3 are depicted diagrammatically in Figure 15.



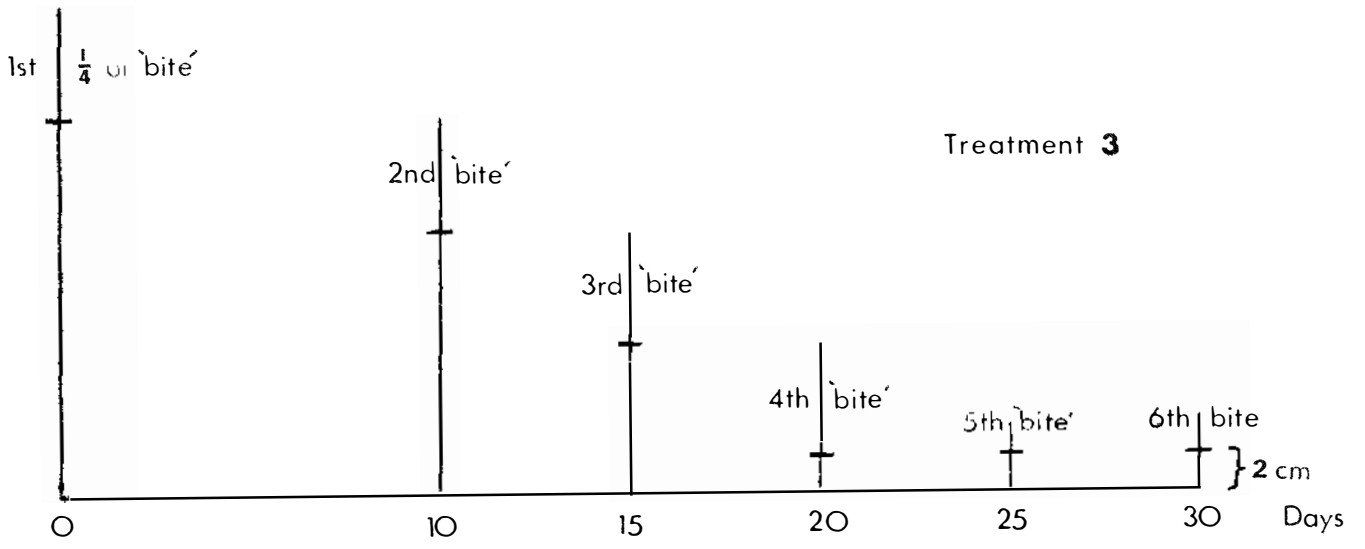


Figure 15. Diagrammatic depiction of simulated grazing on Treatments 2 and 3.

At each 'bite' the shade screens were lowered to keep them about 5-6 cm below the cutting height. Plate 14 shows the three 'swards' at different stages of 'grazing' and regrowth in one of the three CE rooms.

5 : 4 THE CONTROLLED ENVIRONMENTS

The three CE studies were conducted in three of the Climate Rooms of the D.S.I.R. Climate Laboratory at the Plant Physiology Division in Palmerston North. Practical considerations prevented more than three Climate Rooms being used for this project. It was decided that any environmental conditions imposed should be relevant to New Zealand conditions. In addition, the lucerne had to be capable of flowering under each environment so that the GD treatments in each environment would commence at a uniform stage of development, an objective which is much more difficult to attain under non-flowering conditions.

With these restrictions in mind, the following three 'environments' were adopted (with abbreviations in brackets) :

'Seasonal Condition'			Day/Night Temp	
spring	-	cool and moist	16°/10°C	(Cool)
moist summer	-	warm and wet	22°/12°C	(W-Wet)
dry summer	-	warm and dry	22°/12°C	(W-Dry)

These temperatures were decided on after examining the 40 year averages of the mean daily maximum and minimum temperatures for the months of September, October and November (spring) and December, January and February (summer) at five sites in New Zealand where lucerne is, or could be, used extensively (Wairakei, Hastings, Dannevirke, Blenheim and Winchmore).

The average spring temperatures for these five sites were 17.5°/6.5°C while the average summer temperatures were 22.5°/11.2°C. The 16°/10°C temperature combination in the Cool room was about the lowest day/night regime that would give reliable flowering (Thomas 1967).

The moisture differences were imposed via the soil. Soil moisture in the W-Wet and Cool rooms was maintained close to Field Capacity by

PLATE 14. General view inside one of the CE rooms showing shade screens, one 'sward' (at back) with just the first 'bite' removed, one 'sward' (middle) on which 'grazing' has just finished, & one 'sward' (at front) well into the regrowth period.

regular automatic additions of approximately 100 ml water 4-5 times daily. Water logging did not occur due to the free-draining nature of the soil mix. Moisture stress was maintained in the W-Dry room by daily watering each pot to a constant pot weight (due allowance being made for increase in plant fresh weight). Soil moisture at this pre-determined pot weight was 18.6% and under daily watering soil moisture did not fall below 15.1%. These percentages convert to approximately -1 and -4 bars soil moisture tension respectively for this potting mix. (Field Capacity was approximately 26% and 'Wilting Point' 11%.)

A common light regime was used in all three rooms: 14 hour photoperiod with a light intensity or irradiance throughout of 140-150 watts/meter^2 (photosynthetically active range : 400-700 nanometers) with an abrupt light-dark change. The lighting system consisted of four 1000 watt Sylvania "Metal-arc" high pressure discharge lamps, together with four 1000 watt Philips tungsten iodide lamps.

The day/night vapour pressure deficit (in millibars) for the Cool room was 5/2 and for the two warm rooms 10/2. (These convert to relative humidity percentages of 48/84 and 62/85 respectively.) Day/night humidity and temperature changes occurred over two hours, the photoperiod beginning or ending halfway through the changeover.

Carbon dioxide concentration was ambient at 320-340 ppm.

5 : 5 CALENDAR OF EVENTS

The lucerne entered the three CE rooms on May 10, 1976, one day after being cut to 2 cm. It grew uninterruptedly to the 50% bud stage when the three GD treatments in each room commenced for the first time. Two pots were removed from each 'sward' for a uniformity harvest, just prior to this first 'grazing'. All subsequent GDs commenced at the 1% flower stage. The study in each room terminated when Treatment 3 in that room reached the 1% flower stage at the end of the second full cycle. Figure 16 depicts schematically the timing of events in the W-Wet room. The same sequences occurred in the other two rooms, but the length of the regrowth period differed because the environmental conditions in each room affected flowering time.

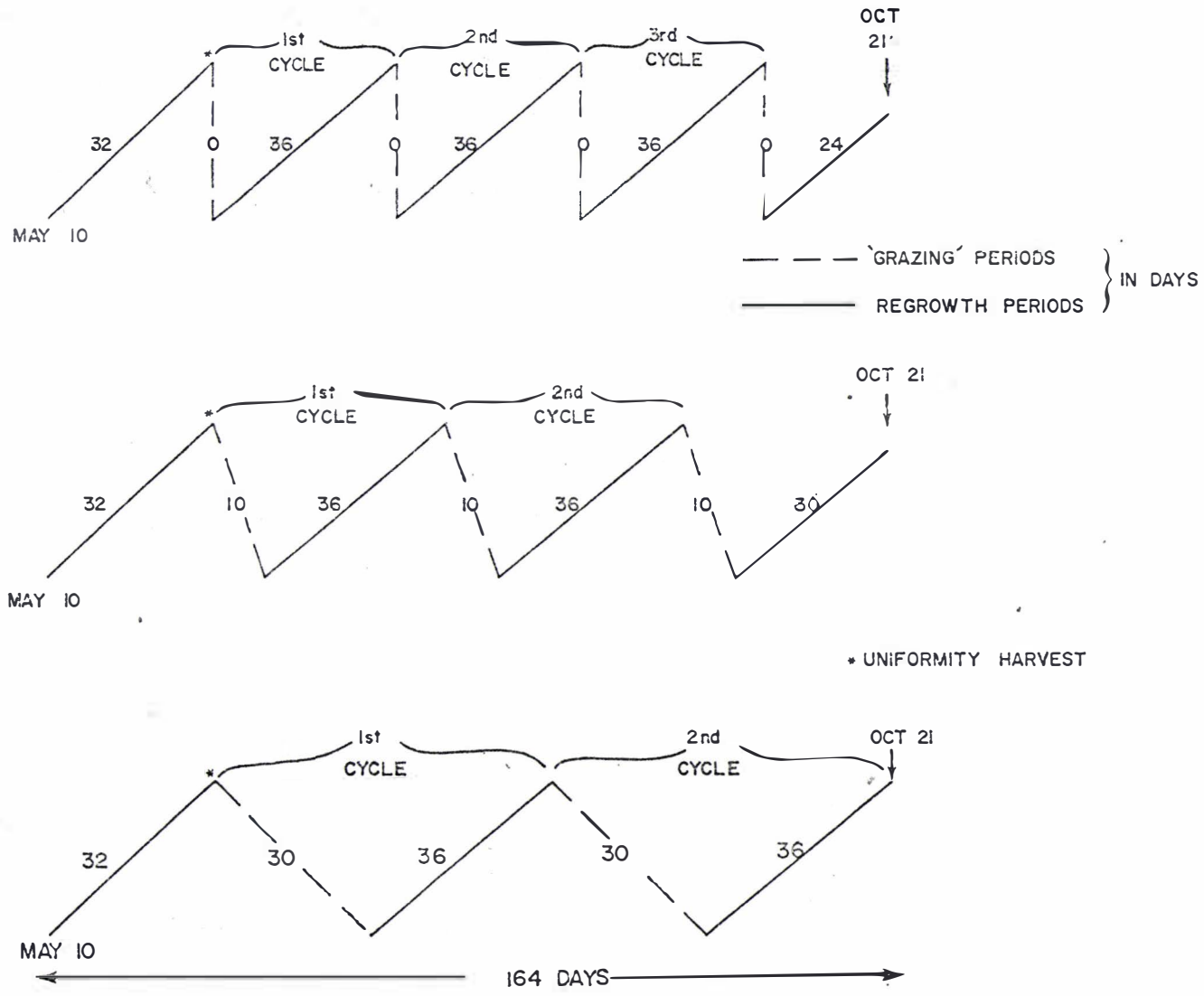


FIGURE 16. Timing of 'grazing' & regrowth periods on the three GD treatments in the W-WET room through the full trial duration.

All detailed plant measurements were taken through the second cycle, thus allowing the plants the whole of the first cycle and the regrowth period prior to the uniformity harvest to adjust to and reflect room conditions.

5 : 6 COLLECTION OF HERBAGE DATA

Detailed measurements of herbage development were taken right through the second cycle of all three GD treatments. These detailed measurements involved destructive harvesting. The limitations on pot numbers imposed by room capacity meant that destructive harvesting could be maintained through one cycle only on each treatment. Therefore herbage development outside this second cycle was recorded non-destructively by simply collecting a sample of the herbage harvested at each 'bite' taken from the three 'swards' in each room.

This system provided the important detailed herbage figures through one full grazing and regrowth cycle plus the equally important figures of herbage production for the full study period.

Harvests for the detailed measurements through the second cycle of each GD treatment were taken at the start of the second 'grazing', at each 'bite' during 'grazing' (for Treatments 2 and 3) and then on Days 3, 7, 14 and 21 through the regrowth period with the final harvest at the end of the regrowth period, i.e. immediately before the start of the third 'grazing' on Treatments 1 and 2. The only exception to this pattern was in the Cool room where, because of a longer regrowth period to flowering, the harvest on Day 3 of the regrowth period was replaced with one on Day 28.

At each of these harvests, two 'treatment' pots were removed at random from the appropriate 'sward' and after root washing (see later for details), the tops were severed from the roots by cutting at the base of the crown. (The four pairs of plants, i.e. the replicates, and their components were kept separate at all times.) All basal and stubble shoots were plucked off, counted, separated into leaf and stem and, after determination of leaf areas, dried and weighed. For harvests taken during the 'grazing' period and before the 2 cm cut, the mature herbage, or what remained of it, was cut into segments at the appropriate 'bite' heights for that treatment (calculated on the length of the 20 tallest stems in each replicate at the start of 'grazing') the leaf and stem separated in each of these 'bite' segments, the leaf areas determined and all fractions dried and weighed. The live stubble material left below the 2 cm final cutting or 'grazing' height was dried and weighed

with the crown. All plant components were thus accounted for; the roots (see later), the live residues and crown, the mature herbage leaf and stem and the basal and stubble shoot leaf and stem, and changes in all these components could be monitored.

An additional destructive harvest to those already mentioned was taken on Treatments 2 and 3 in the second cycle immediately after a 'bite' to 2 cm was imposed, for this 'bite' involved decapitation of basal and stubble shoots and it was impossible without an 'after' harvest to determine the amount of shoot material remaining after the 'bite'. This was just a consequence of the way the plants were dissected in these destructive harvests.

The non-destructive measurements of herbage development outside the second cycle were obtained by simply collecting the herbage cut off from the four pairs of plants in two randomly selected 'treatment' pots in the appropriate 'sward' when each 'bite' was taken during 'grazing'.

All the herbage samples were dried overnight in a vacuum oven (2.0 mm Hg) at 40°C. Leaf areas were measured with the same type of machine as that used in the field trial.

Light penetration through the mature herbage to the new shoots at the base of the sward was measured during 'grazing' on Treatments 2 and 3 with the same meter at that used in the field trial. Twenty readings were taken randomly per 'sward' before and after each 'bite'.

5 : 7 SHOOT POPULATION STUDIES

The technique of individual shoot tagging and harvesting employed in the field trial was also used in the three CE studies. Four pots were randomly selected in each 'sward' and during the second cycle every shoot that arose in those pots was tagged in the manner described in Chapter 2. The individual shoots were then harvested from two of the pots (i.e. 8 plants) halfway through the regrowth period and from the other two pots at the end of the regrowth period (preliminary and final harvests respectively).

5 : 8 COLLECTION OF ROOT DATA

At each of the destructive harvests for herbage data, the root system was also harvested. The two 'treatment' pots were removed from the appropriate 'sward' eight hours after the photoperiod started (i.e. the lights came on) in that room. The soil was carefully washed away from the root system over a fine sieve (a task made considerably easier by the sandy nature of the potting mix) and all but the finest rootlets collected. After the tops were removed the roots were immediately placed in a freezer at -8°C. This whole process was done as quickly as possible : the washed roots were always in the freezer within 45 minutes of the pots leaving the CE room. Once frozen, the roots were transferred to a freeze drier (0.1 mm Hg, -15°C) for seven days. The dried roots were then quickly weighed, ground to pass a 0.5 mm screen and placed back in the freezer in small sealed bottles. On removal, this root material was analysed for soluble sugars and starch by the methods of Haslemore & Roughan (1976) and the level of these two constituents summed to give the level of total non-structural carbohydrates.

5 : 9 ACETYLENE REDUCTION MEASUREMENTS

Severe defoliation of a legume is generally quickly reflected in a substantial drop in the level of all the indicators of nitrogen (N) fixation, followed by a slow rise again as the plant recovers (Hardy *et al* 1968, Moustafa *et al* 1969, Sinclair 1973, Chu & Robertson 1974, Halliday & Pate 1976). Because of this, it was decided to examine the possibility that a long GD could affect N fixation to the extent that N availability would limit herbage development in the early part of the regrowth period. The indicator of N fixation adopted in this project was that of Sinclair (1973) - a non-destructive acetylene reduction assay employed on plants growing in soil. Assays were performed at the following times through the second cycle of each GD treatment : immediately prior to 'grazing', once or twice (Treatments 2 and 3 respectively) during 'grazing' and then on the first, fifth, tenth, fifteenth and last day of the regrowth period.

Four large, glass incubation chambers (20x20x45 cm) were constructed. Two mylar bags were attached to each chamber to facilitate gas mixing (Plate 15).

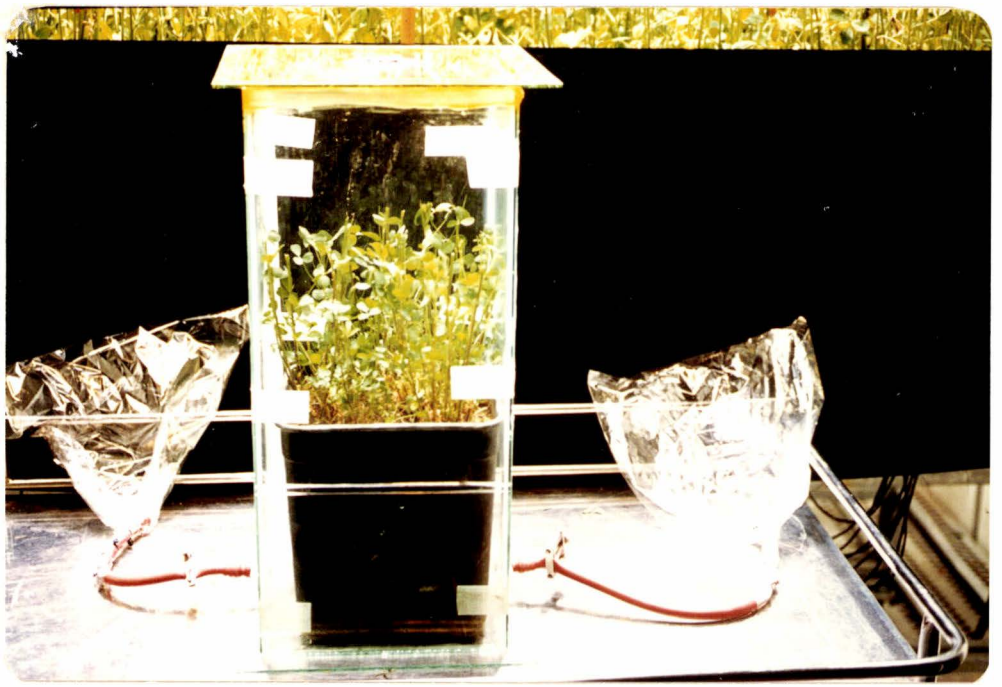


PLATE 15. Incubation chamber for acetylene reduction assays.

At each assay four 'treatment' pots chosen at random from the appropriate 'sward' were placed in the four chambers, the mylar bags were completely deflated, the tops were placed on the chambers, sealed with grease and 1500 ml of acetylene injected into each chamber through a rubber stopper in the top. (This gave a concentration of 10% acetylene by volume). Each incubation began eight hours after the photoperiod started (by which time the soil temperature in that room had stabilised at its daily maximum), ran for four hours and was conducted in the room to which the assayed pots belonged. The gases in each chamber were mixed thoroughly every fifteen minutes during incubation by alternately inflating and deflating the two mylar bags. After four hours, three small samples of gas were withdrawn from each chamber and the ethylene content of these samples determined with a gas chromatograph. (The gas chromatograph was fitted with a hydrogen flame ionisation detector and an 86 cm x 3.15 mm diameter stainless steel column packed with Poropak T. The column temperature was held at 85°C and the carrier gas (N_2) flow rate of approximately 20 ml/minute gave an elution time of approximately one minute.)

Preliminary tests had shown that :

a) the rate of ethylene production was constant for incubation times ranging from 90 minutes to at least six hours,
b) air temperatures in the chambers and soil temperatures in the pots never increased by more than 2° C during incubation, and
c) no measurable ethylene was produced by the herbage either before or after a 'bite'.

Although it has been shown that the acetylene reduction test has very little effect on the subsequent performance of the tested plants (Sinclair 1973, Huang *et al* 1975), as a precaution, the pots that had been exposed to acetylene were used as soon as possible afterwards for a destructive harvest.

5 : 10 HERBAGE MINERAL ANALYSES

Mitchell & Denne (1967) suggested that the capacity of the lucerne root system for mineral uptake could be a major determinant of herbage regrowth rates following severe cutting regimes on this crop. To determine whether mineral uptake was involved in the limitation of

herbage regrowth rates following long GDs, mineral analyses for percentage phosphorus and percentage potassium were performed on the herbage harvested during the regrowth period following all three GD treatments in the W-Wet room.

5 : 11 ANALYSIS OF RESULTS

Each study was analysed as a completely randomised design with four replicates for all measurements. Analysis of variance was performed both on the results of different GD treatments at comparable sampling times and on the results of different sampling times within a GD treatment. Logarithmic and arc sine transformations were occasionally used on the data prior to its analysis; this is always noted in the results.

In the analysis of leaf area, herbage weight and root weight changes during regrowth, the regrowth period was divided into the Day 0-7, Day 7-21 and Day 21 - final harvest (21-x) periods to assist understanding and interpretation of the data. Linear regressions ($y = a + bx'$ where y = the dependent variable and x' = time) for leaf area, herbage weight and root weight changes during these periods were calculated and, if the regressions were significant, the slope of the regressions (i.e. the b values) for the three GD treatments during these periods were compared with paired t tests. The slopes, of course, expressed rate of change of the particular parameter.

The Coefficient of Variation and the Least Significant Differences are given in the tables; on the graphs just L.S.D. at the 5% level is shown. (Where large differences exist between the three CE rooms, these are mentioned in the text. No statistical verification of the differences is given but generally their magnitude was such that verification was considered unnecessary.)

CHAPTER 6 : CONTROLLED ENVIRONMENT STUDIES - HERBAGE COMPONENTS AND YIELD

RESULTS

All data for these CE studies (with the exception of the acetylene reduction results) are expressed on a per plant basis.

The uniformity measurements just before the pots entered the rooms and then at the uniformity harvest in each room, i.e. just before the first 'grazing' started, established uniformity both at the start of the study and within each study at the start of 'grazing' (Appendices 4 - 7).

6 : 1 HERBAGE CHARACTERISTICS IN THE THREE CONTROLLED ENVIRONMENT ROOMS

6:1:1 FLOWERING TIME

The lucerne required a 36, 35 and 53 day regrowth period to reach the 1% flower stage in the W-Wet, W-Dry and Cool rooms respectively. This did not change during the course of the studies and was the same for all three GD treatments in a room (see Figure 16). Clearly, while moisture stress had very little effect on flowering time, temperature had a large effect.

6:1:2 STEM AND LEAF WEIGHTS AND AREAS THROUGH THE PROFILE

The herbage in the W-Dry room, in terms of both absolute amounts and the distribution of leaf and stem through the profile, differed greatly from that in the other two CE rooms at the 1% flower stage (Plates 16, 17 and 18 and Figure 17). Moisture stress greatly reduced total herbage yield at the 1% flower stage and the very high leaf:stem ratio for the whole profile in the W-Dry room contrasts sharply with the much stemmier herbage in the moist conditions of the other two rooms. The distribution of leaf and stem weights was relatively even down through the profile in the W-Dry room - a situation very different from that of

PLATES 16, 17 & 18. Lucerne at the 1% flower stage ie. just before 'grazing' started, from the three CE rooms.

PLATE 16: W-WET.

PLATE 17: W-DRY.

PLATE 18: COOL.

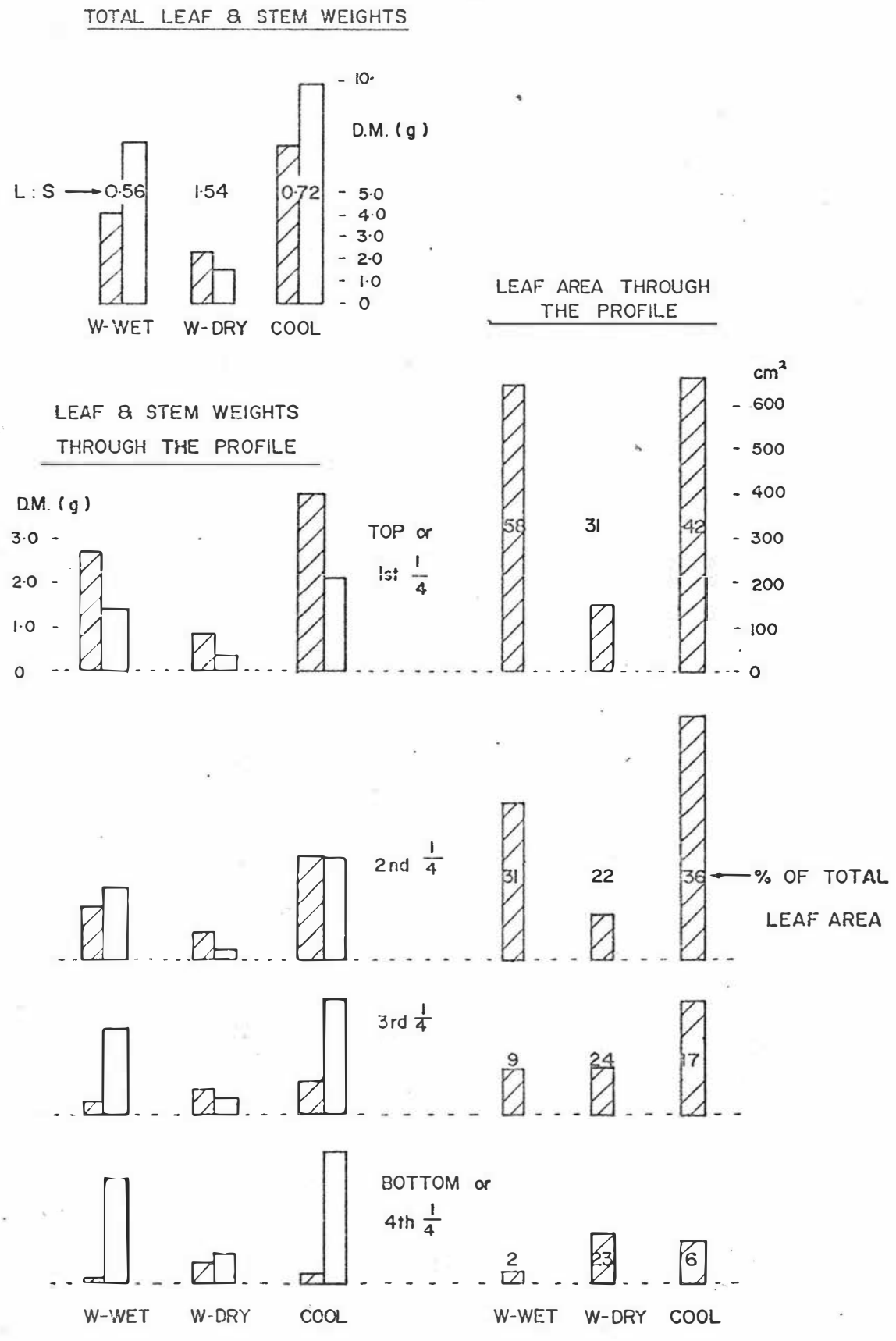


FIGURE 17. Distribution of stem weight, leaf weight & leaf area through the herbage profile at the 1% flower stage (average of two harvests).

leaf stem L:S = leaf:stem ratio

the other two rooms where leaf weight was concentrated in the upper fractions and stem weight in the lower.

The distribution of leaf area down through the profile in the three CE rooms (Figure 17) broadly reflects the distribtuion of leaf weight. In the W-Dry room, there were similar leaf areas in each fraction of the profile while in the other two rooms there was a marked concentration of leaf area in the upper fractions of the profile.

In all three rooms, the specific leaf area (sla) of the herbage increased steadily down through the profile (Table 9), expressing a shading and probably also an age effect. However, it is noticeable that the increase in sla from the top to the bottom of the profile was less in the W-Dry than the other two rooms. This is probably an expression of both the very uniform leaf distribution and the low absolute leaf area in this room which have permitted excellent light penetration to the lower leaves. Light penetration to the basal shoots when measurements were taken at the 1% flower stage was 0.6%, 9% and 0.2% for the W-Wet, W-Dry and Cool rooms respectively. Water stress has been shown to retard leaf ageing (Ludlow & Ng 1974) and this may be partially responsible for the very small change in sla through the W-Dry profile.

6:1:3 NEW SHOOTS

The number of new shoots present on the lucerne at the 1% flower stage in the W-Dry room appeared to be greater than in the other two rooms. This was evident in the uniformity tables presented in Appendices 5 - 7, but is presented more concisely in Table 10.

6:1:4 DAILY GROWTH RATE

The average growth rate for the full regrowth period was high and very similar in the W-Wet and Cool rooms, 0.31 and 0.32 g DM/day respectively, but was little more than one third of these values in the W-Dry, 0.11 g DM/day. The high growth rate in the Cool Room, coupled with the long regrowth period (53 days), resulted in this room having the highest herbage yield at the 1% flower stage (Figure 17).

The results are now presented of the detailed measurements taken through the second cycle of each GD treatment.

TABLE 9. Specific leaf areas (in cm^2/mg) through the herbage profile at the 1% flower stage (average of 2 harvests).

	W-WET	W-DRY	COOL
1st ¼	0.24	0.17	0.17
2nd ¼	0.30	0.19	0.25
3rd ¼	0.42	0.21	0.36
4th ¼	0.50	0.23	0.44
increase in s.l.a. from 1st to 4th ¼	2.1	1.4	2.6
full canopy figures	0.27	0.20	0.22

TABLE 10. Number & total weight of new shoots at 1% flower stage (average of 2 harvests).

	W-WET	W-DRY	COOL
number	3.8	23.0	9.3
total weight (g)	0.03	0.29	0.10

6 : 2 HERBAGE EFFECTS DURING DEFOLIATION OR 'GRAZING'

6:2:1 LEAF AREA CHANGES

The changes in total leaf area during 'grazing' in the three CE rooms are depicted in Figure 18, while the amount of leaf area remaining at the end of 'grazing' is given in Table 11. (Appendix 8 a,b & c shows in which fractions of the herbage the leaf area changes were occurring during 'grazing'.)

The one 'bite' to 2 cm of Treatment 1 removed abruptly virtually the entire leaf area. Only in the W-Dry room was there any leaf area left after this treatment, for only in this room was there any leaf area on the residue stubble material below 2 cm and only in this room was there any appreciable new shoot development at the 1% flower stage. (N.B. There were never any new shoots at the 1% flower stage that extended above the 2 cm cutting height.)

The 10 day GD of Treatment 2 allowed time for some development of new shoot leaf area in all three rooms but, with no interference to new shoot development prior to the final cut to 2 cm, the shoots became rather etiolated and most of the leaf area was removed at this final 'bite'. The only development in the mature herbage leaf area during the 10 day GD was a small increase in the bottom fraction (or fourth quarter) resulting from some axillary leaf development. This occurred only in the W-Wet and Cool rooms and was, of course, removed at the last 'bite'.

During the 30 day 'grazing' period of Treatment 3, some appreciable changes in leaf area occurred. The new shoots had an uninterrupted growth period of 20 days between the start of 'grazing' and the first 'bite' to 2 cm. During this time new shoot leaf area expanded at an increasing rate as the mature herbage was progressively removed. After the first 'bite' to 2 cm on Day 20, the new shoots contributed virtually all of the leaf area for only in the W-Dry room was there any leaf area on the residue stubble material. With three 'bites' to 2 cm over the last ten days of the GD, leaf development below 2 cm was encouraged with the result that an appreciable new shoot leaf area remained on Treatment 3 at the end of the 'grazing' period. Once again, the only development that occurred in the mature herbage leaf area during 'grazing' were some

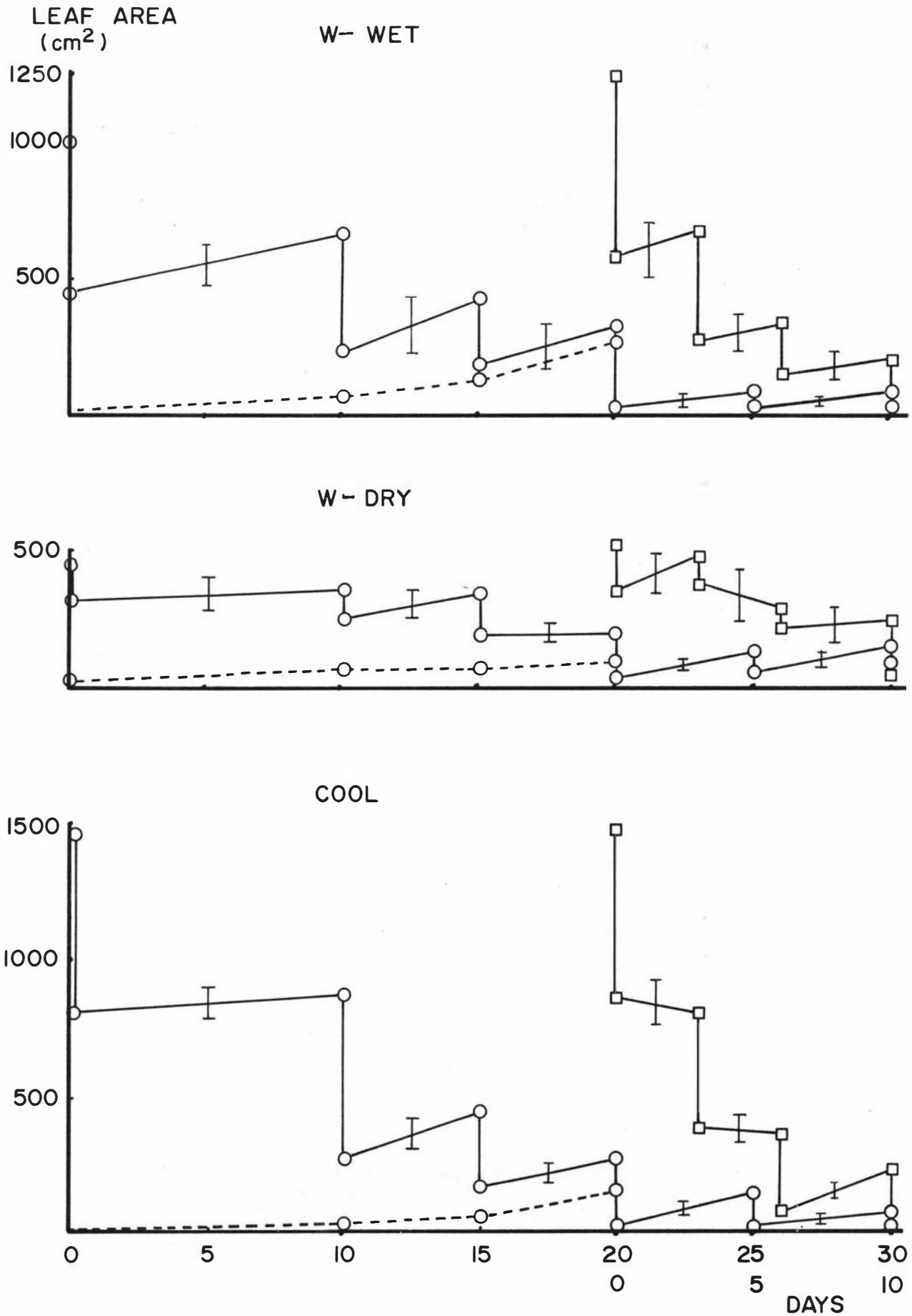


FIGURE 18. Leaf area changes during 'grazing'.

(total leaf area is the sum of the leaf area on the mature herbage plus the leaf area on the new basal & stubble shoots)

□ Tmt 2 ——— total leaf area

○ Tmt 3 - - - - - - new shoot leaf area (Tmt 3)

| 5% LSD for changes in total leaf area between 'bites'

TABLE 11. Leaf area (cm^2) at end of 'grazing' period.

	Tmt 1	Tmt 2	Tmt 3	S.E.#	LSD 5% 1%
		W-WET			
New shoot	2	6	31	1.6	6 9**
Residue	-	-	6	-	
Total	2	6	37	1.6	6 9**
		W-DRY		CV%	
New shoot	31	38	55	28.1	18* 26
Residue	12	15	32	39.3	12* 18
Total	43	52	87	23.4	23 32**
		COOL		S.E.	
New shoot	5	12	27	1.5	8 12**
Residue	-	-	-		
Total	5	12	27	1.5	8 12**

analysis performed on logarithm transformations ie. CV% not appropriate

rather small increases, mainly in the W-Wet and Cool rooms, despite the fact that twenty days elapsed on Treatment 3 between the start of 'grazing' and the removal of the last of the mature herbage at the first 2 cm 'bite'.

The net result of these effects was that, in each CE room at the end of the 'grazing' period, the total leaf area of Treatment 3 exceeded that of Treatment 2 which generally exceeded that of Treatment 1 (Table 11).

6:2:1(a) Effects on specific leaf area values

In addition to these changes in leaf area during 'grazing', the composition of the leaf population also changed during 'grazing'. At the start of 'grazing', sla values increased from the top to the bottom of the profile (Table 9). Thus, when 'grazing' started and the younger leaves in the upper part of the canopy were progressively removed, the plant became increasingly dependent on the older mature herbage leaves in the lower part of the canopy. Whole canopy sla values increased from 0.28 to 0.41 in the W-Wet room and from 0.24 to 0.34 in the Cool room in the first 20 days of the Treatment 3 'grazing' period. Even the young leaves on the new shoots that developed in the very low light conditions of the first ten days of the Treatment 3 'grazing' in the W-Wet and Cool rooms had relatively high sla values (Table 12). When these leaves were removed at the first 'bite' to 2 cm on Day 20, the subsequent leaves that developed in full light had much lower specific leaf areas.

These sla effects during 'grazing' were much less evident in the W-Dry room than the W-Wet and Cool rooms, due probably to both the better penetration of light into the canopy in the W-Dry room (Figure 19) and the effects of the moisture stress in this room on leaf ageing.

6:2:1(b) Effects on light penetration

Figure 19 depicts the changes that occurred in light penetration to the new shoots during 'grazing' on Treatments 2 and 3. Very little light penetrated through to the base of the large herbage canopy in the W-Wet and Cool rooms at the 1% flower stage (0.6 and 0.2% respectively) in contrast to the greater light penetration through the very much smaller herbage canopy in the W-Dry room (9%).

The light readings at the level of the new shoots increased both with the progressive removal of the mature herbage at each 'bite' and

TABLE 12. Changes in new shoot specific leaf area values during the 'grazing' period: Treatment 3 only.#

	Day 15	Day 20	Day 25	Day 30	CV%	LSD 5% 1%
W-WET	0.35	0.38	0.18	0.17	6.6	0.03 0.04**
W-DRY	0.18	0.16	0.17	0.16	9.9	0.03 0.04
COOL	0.27	0.29	0.18	0.16	7.1	0.03 0.04**

the s.l.a. values in cm^2/mg, relate to the leaf area on the new shoots immediately before the 'bite' due on Day 15, 20 etc. - N.B. no new shoot leaf area was removed by the 'bite' on Day 15

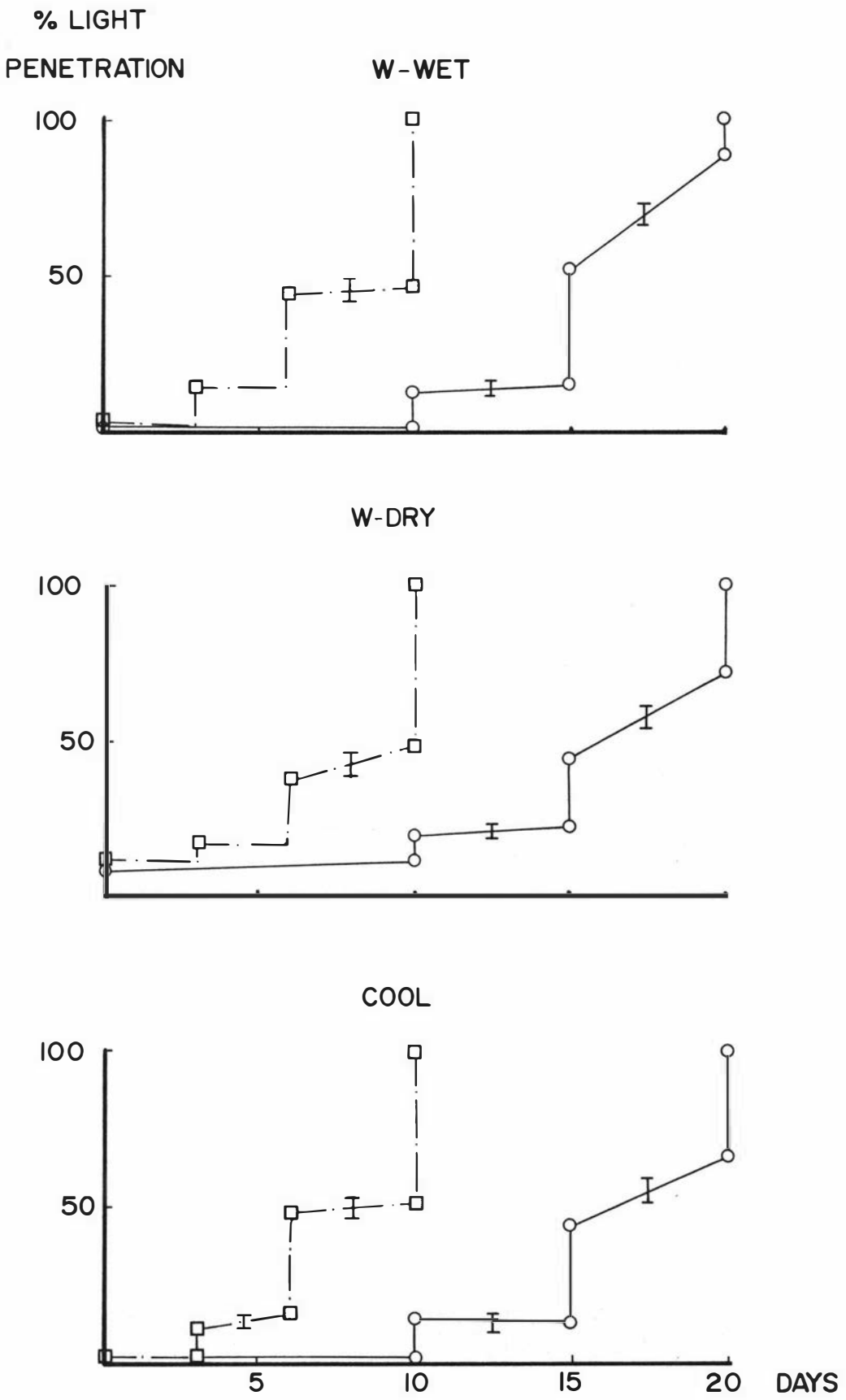


FIGURE 19. Light penetration to new shoots during the 'grazing' period.

(light readings were taken immediately before & after each 'bite')

Tmt 2

Tmt 3

LSD-5%

with the elongation of the shoots themselves up through the lower parts of the canopy. This latter effect was particularly noticeable in the five day period between the third and fourth 'bites' on Treatment 3 when three quarters of the mature herbage had been removed and the new shoots were growing up quite rapidly through the remaining fairly stemmy material.

6:2:2 NEW SHOOT NUMBERS

The reaction to decapitation of new shoots during 'grazing' was the same in the CE studies as in the field trial. When an independent shoot was decapitated, it fairly quickly subtended one or two new shoots (subtendeds) from its lower undamaged nodes and, in doing so, became a subtending shoot. Figure 20 shows how the total number of independent and subtended basal shoots (the main shoot classes for yield contribution) increased during the 'grazing' period of Treatments 2 and 3 in the three studies.

Basal shoot numbers at the 1% flower stage were variable but, as noted earlier, there tended to be more new shoots on plants from the W-Dry than the other two rooms at this stage. However, in all three rooms, shoot numbers increased steadily as the mature herbage was progressively removed. The increase in shoot numbers from Day 0 to Day 10 on Treatment 3 indicates that, provided the apices are taken, just 'topping' of the mature herbage (only the first quarter had been removed) stimulates proliferation of a new shoot population at the base of the sward. However, the counts taken on Days 3 and 6 of Treatment 2 show that, where herbage removal is incomplete, three to six days elapse before this proliferation becomes evident.

On Treatment 3, the total number of independent and subtended shoots, although already quite high, increased further following the two 'bites' to 2 cm on Days 20 and 25 of the 'grazing' period. These 'bites' not only generated subtended shoot development but also further independent shoot development (see results of shoot population studies - Appendices 22-24). As a result of this and also the longer time for shoot development during 'grazing' on Treatment 3 than Treatment 2, shoot numbers were higher on Treatment 3 than Treatment 2 at the end of 'grazing'.

Stubble shoot numbers were low, about 10% of total shoot numbers, throughout 'grazing' on both Treatments 2 and 3.

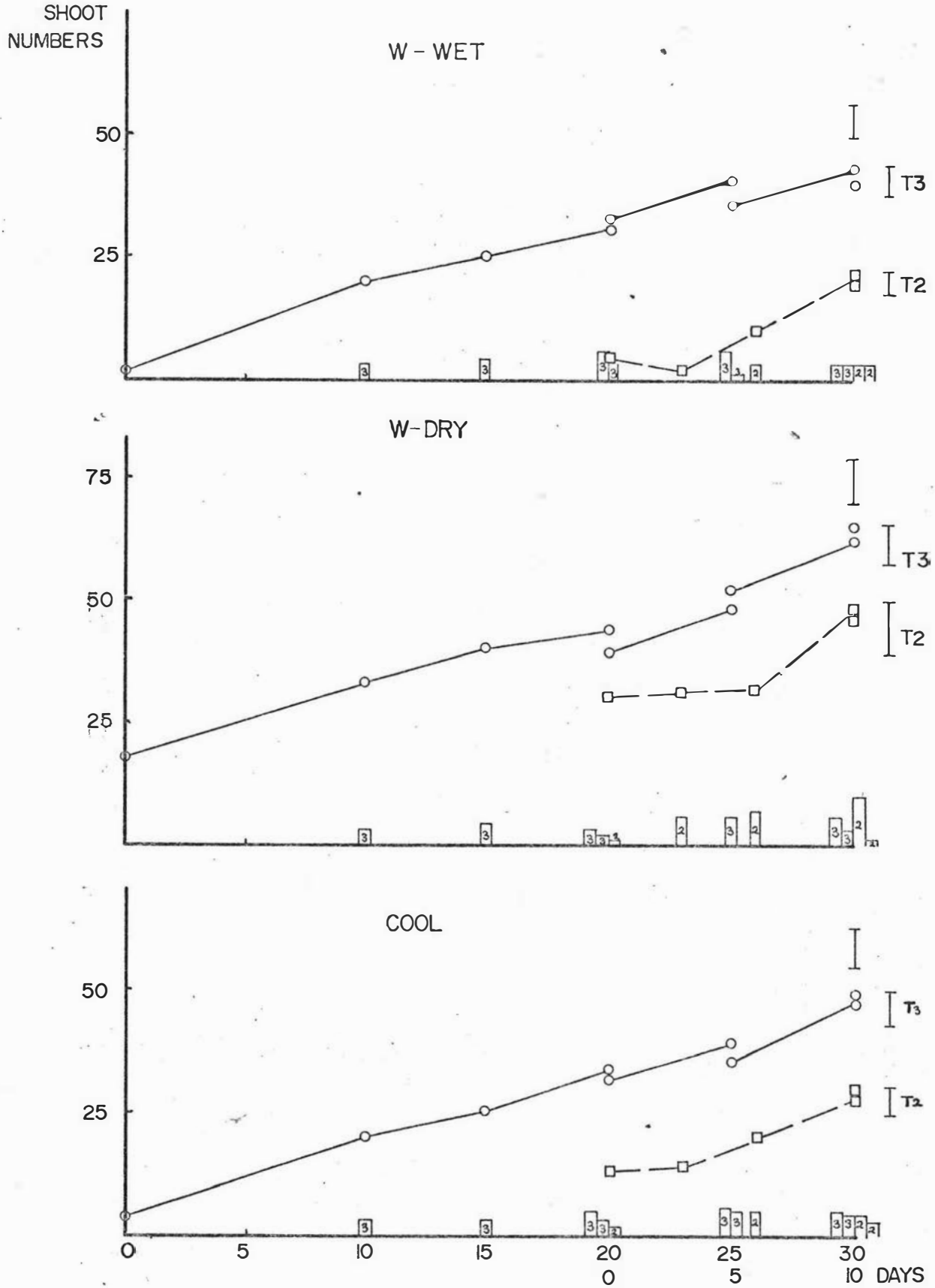


FIGURE 20. Shoot numbers during the 'grazing' period.

(basal shoot numbers shown are the sum of independent & subtended basals - the two values shown for both basal & stubble shoot numbers on Days 20, 25 & 30 of Tmt 3 & Day 10 of Tmt 2 are the values before & after the 'bites' taken on those days)

Tmt 2 } basal shoot numbers
Tmt 3 }

3|2 stubble shoot numbers on Tmts 2 & 3

LSD-5%

6:2:3 NEW SHOOT YIELD

The following results relate to the total new basal shoot population.

Basal shoot yield, which was initially very low at the 1% flower stage (except in the W-Dry room), increased steadily with the progressive removal of the mature herbage on both GD treatments in all three CE rooms until the first 'bite' to 2 cm (Figure 21). This 'bite' of course abruptly reduced basal shoot yield. On Treatment 2 the 'grazing' period concluded with this 'bite' and the regrowth period commenced. On Treatment 3, with two further 2 cm 'bites' being taken before 'grazing' ceased ten days later, there was an increase in shoot weight below the 2 cm cutting height with the result that basal shoot yield at the end of 'grazing' on Treatment 3 was considerably greater than that at the end of 'grazing' on Treatment 2.

Stubble shoot yield was low throughout the 'grazing' period of both Treatments 2 and 3 in all three studies. The average stubble shoot contribution to total shoot yield was about 8%.

6:2:4 HERBAGE HARVESTED DURING 'GRAZING'

Figure 22 shows that during the ten day 'grazing' period of Treatment 2, there was no significant development of the mature herbage under any of the CE conditions and a relatively small amount of new shoot material developed above the 2 cm cutting height. However, during the 30 day 'grazing' period of Treatment 3, there was substantial development of new shoots in all three rooms and, in addition, some small increases in mature herbage leaf weights in the W-Wet and Cool rooms through axillary leaf development on the lower herbage fractions (see Appendix 8 and Plate 19).

6 : 3 HERBAGE RESPONSE ON COMPLETION OF DEFOLIATION OR 'GRAZING'

6:3:1 SHOOT NUMBERS

The regrowth period commenced with the total of independent and subtended basal shoots on Treatment 3 exceeding that on Treatment 2 which exceeded that on Treatment 1. (The instantaneous complete herbage removal

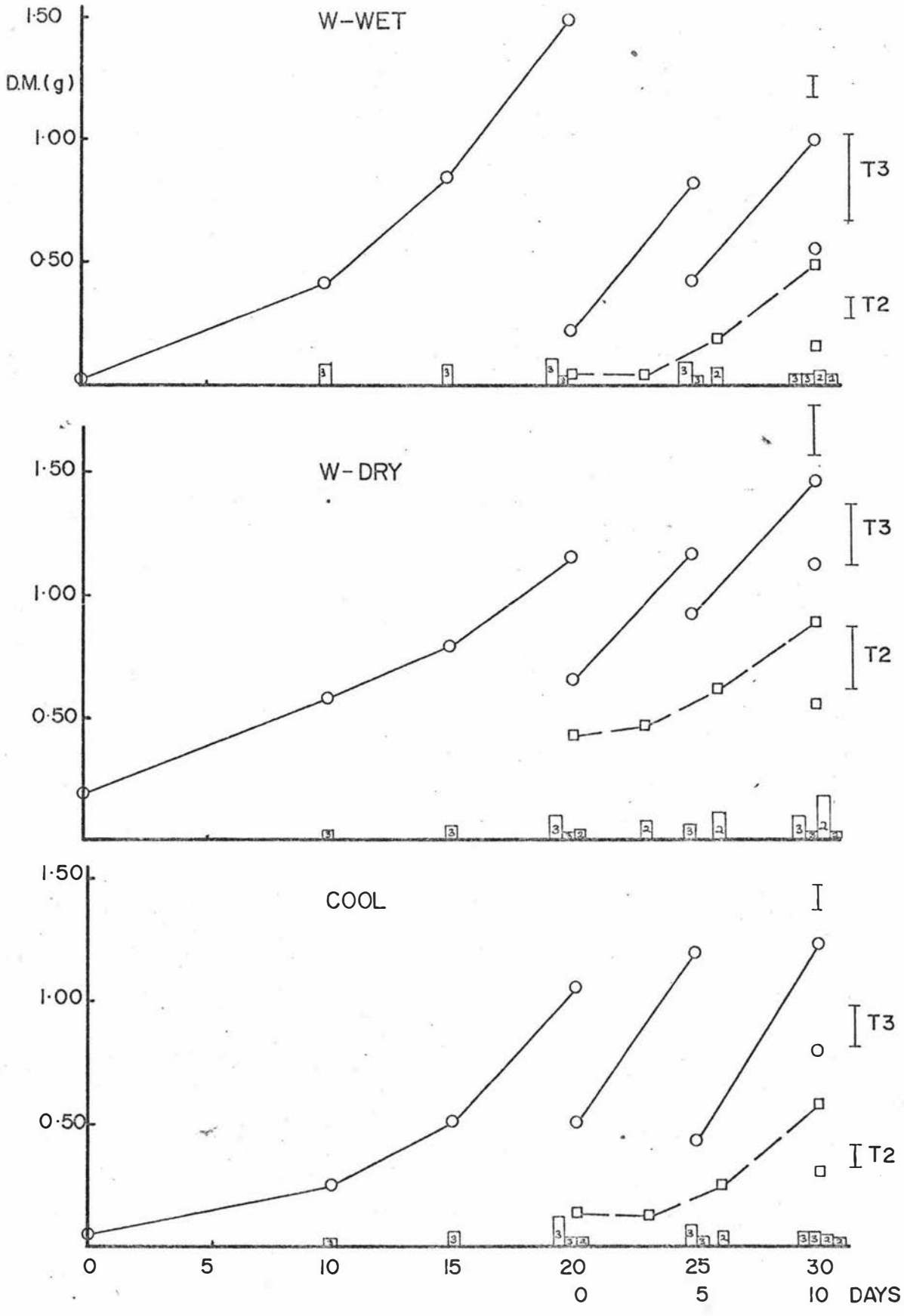


FIGURE 21. Shoot yield during the 'grazing' period.

(the two values shown for both basal & stubble shoot yield on Days 20, 25 & 30 of Tmt 3 & Day 10 of Tmt 2 are the values before & after the 'bites' taken on those days)

Tmt 2 } basal shoot yield
Tmt 3 }

stubble shoot yield on Tmts 2 & 3

LSD-5%

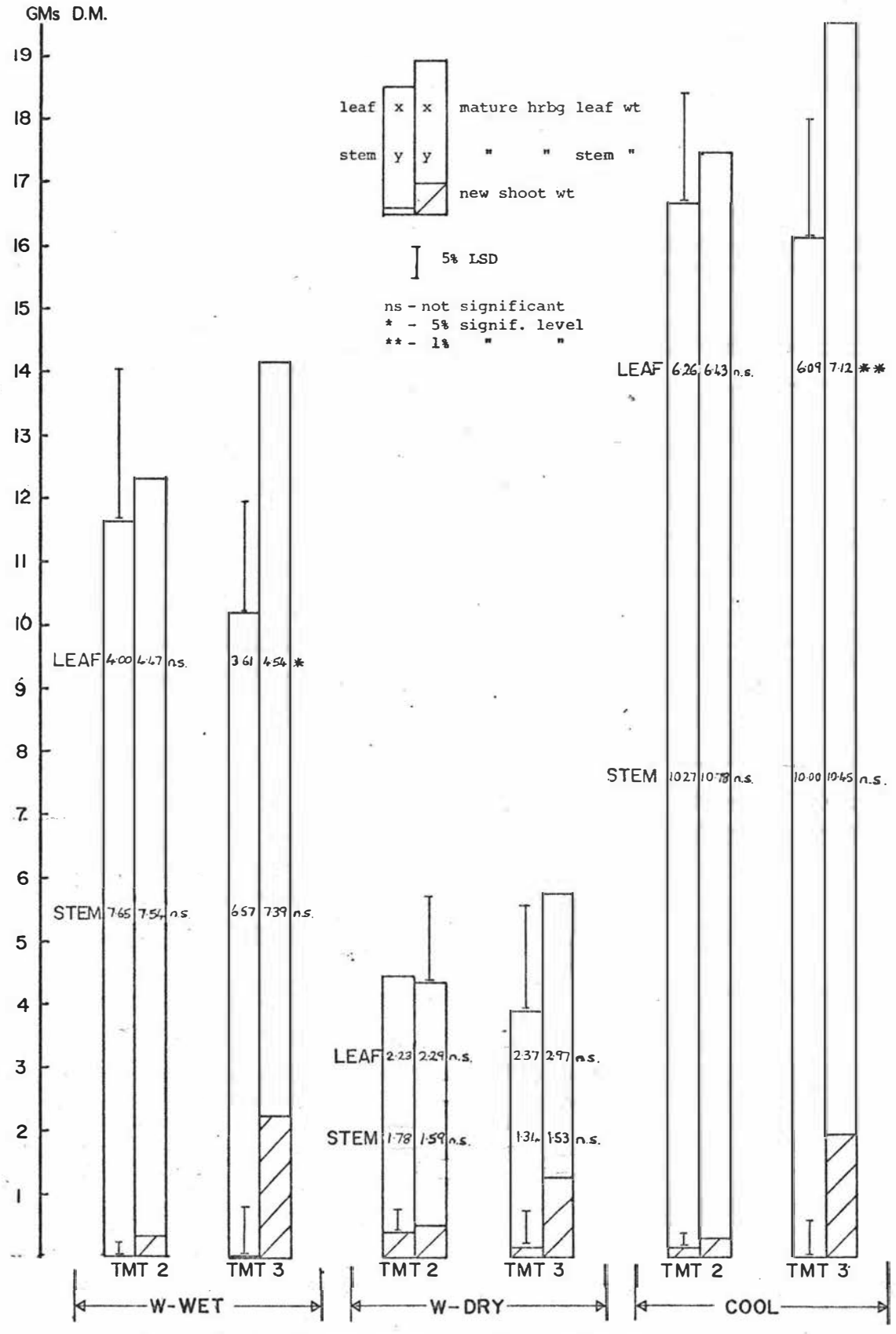


FIGURE 22. Herbage harvested during 'grazing'.

(The left-hand column of each pair represents herbage present at the start of 'grazing' while the right-hand column represents herbage harvested during 'grazing'.)

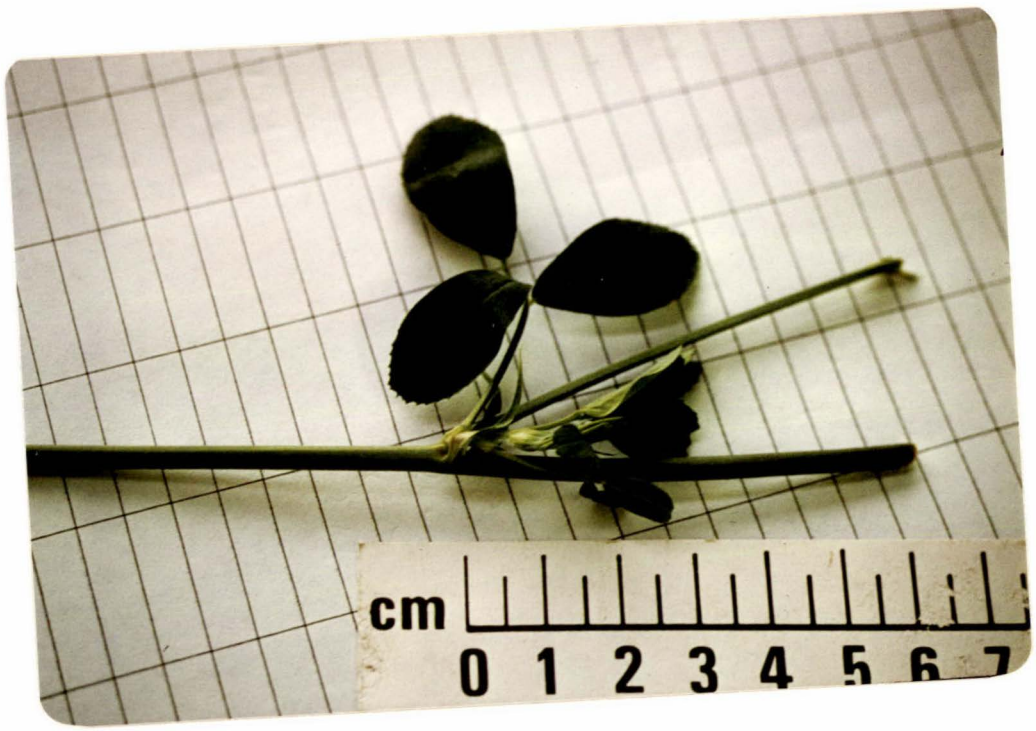


PLATE 19. The type of axillary leaf development that occurred to a limited extent on the mature stems following apex removal during the long GDs in the W-WET & COOL rooms.

of Treatment 1 gave no time for shoot proliferation.)

Basal shoot numbers on Treatment 1 increased very rapidly following defoliation to reach a fairly stable level by Day 7 (Figure 23). The counts taken on Day 3 of Treatment 1 indicated that shoot proliferation occurred more rapidly following complete herbage removal than following partial herbage removal.

Basal shoot numbers on Treatment 2 also increased over the first seven days of the regrowth period before stabilising. This initial increase was to be expected for, on this treatment, shoot numbers by the end of the ten day 'grazing' period had barely reached the level at which shoot numbers on Treatment 1 stabilised following 'grazing'. In addition to this, of course, the last 'bite' on Treatment 2, for the first time, decapitated many of the taller new shoots thereby initiating both subtended and further independent shoot development (see results of shoot population studies - Appendices 16, 18 and 20).

On Treatment 3, the total of independent and subtended basal shoot numbers did not increase significantly following 'grazing' for this total was already high by the end of the 30 day 'grazing' period and the last 'bite' thus had a relatively small effect.

These effects combined to substantially reduce the differences in shoot numbers that existed between the three GD treatments at the start of the regrowth period. However, the differences were never completely eliminated and, for as long as counts were taken, i.e. right through the first half and into the second half of the regrowth period, the highest total of independent and subtended shoots occurred on Treatment 3 and the lowest on Treatment 1, although the differences between Treatments 1 and 2, and 2 and 3 were often not significant.

Stubble shoot numbers were low throughout the regrowth period on all treatments in all three studies (Figure 23) although they comprised a somewhat higher percentage of total shoot numbers than during the same period in the field trial. There were no consistent treatment effects on the contribution of stubble shoots to total shoot numbers (Appendix 9).

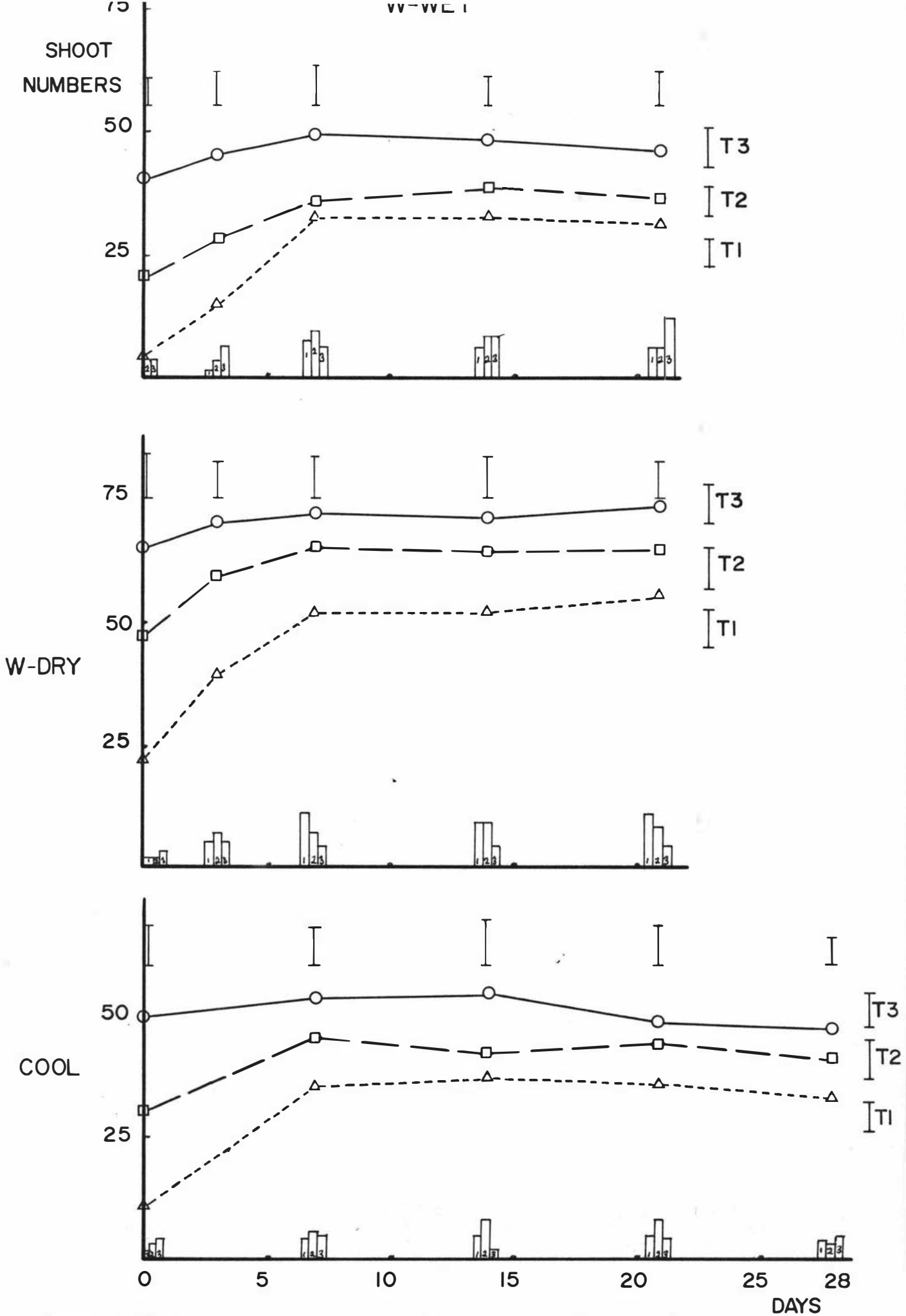


FIGURE 23. Shoot numbers during the regrowth period.

(basal shoot numbers are the sum of independent & subtended basals)

△- - - - -△ Tmt 1 } basal
□——□ " 2 } shoot
○——○ " 3 } numbers

stubble shoot numbers on Tmts 1,2 & 3

LSD-5%

6:3:2 LEAF AREA

The treatment ranking for leaf area at the beginning of the regrowth period was consistently Treatment 3> Treatment 2> Treatment 1, although none of the differences were large (Figure 24). In the W-Wet and Cool rooms, leaf area on Treatment 1 at the beginning of the regrowth period was barely measurable. In these two rooms, leaf area increase followed a similar pattern. For the first seven days, the absolute rate of leaf area expansion was low on Treatment 1 (starting as it did from almost negligible initials) but higher on Treatments 2 and 3 (Table 13). Over the next 14 days, Days 7-21, leaf area expansion rate increased on all treatments.

After 21 days of regrowth, the earlier significant differences in leaf area between the three GD treatments had disappeared and, for the remainder of the regrowth period (Days 21-x), leaf area on all treatments increased at a steady and similar rate.

In the W-Dry room, leaf area increased throughout the regrowth period on all three treatments; during the Day 0-7 period at similar rates to the other two rooms but at much slower rates for the rest of the regrowth period (Table 13). Indeed, the average leaf area expansion rate declined at each successive period; Day 0-7, Day 7-21 and Day 21-x. The differences in leaf area expansion rate between the three GD treatments noted in the other two rooms were not as evident in the W-Dry room.

6:3:3 HERBAGE YIELD AND GROWTH RATES

Total shoot weight on the three GD treatments at the start of regrowth was ranked in the same order as shoot numbers and leaf area : Treatment 3> Treatment 2> Treatment 1. Shoot weight on Treatment 1 at the start of the regrowth period was very low especially in the W-Wet and Cool rooms where it was less than 10% of that on Treatment 3 at this time. Total shoot weight increased throughout the regrowth period on all treatments in such a way that, by the 1% flower stage, no significant differences in total shoot weight remained between the three GD treatments in any of the three CE studies (Figure 25). However, there were obvious differences between the three studies in total shoot yield at the 1% flower stage. Over a 36 day regrowth period, the lucerne in the W-Wet conditions had developed approximately 250% more shoot material

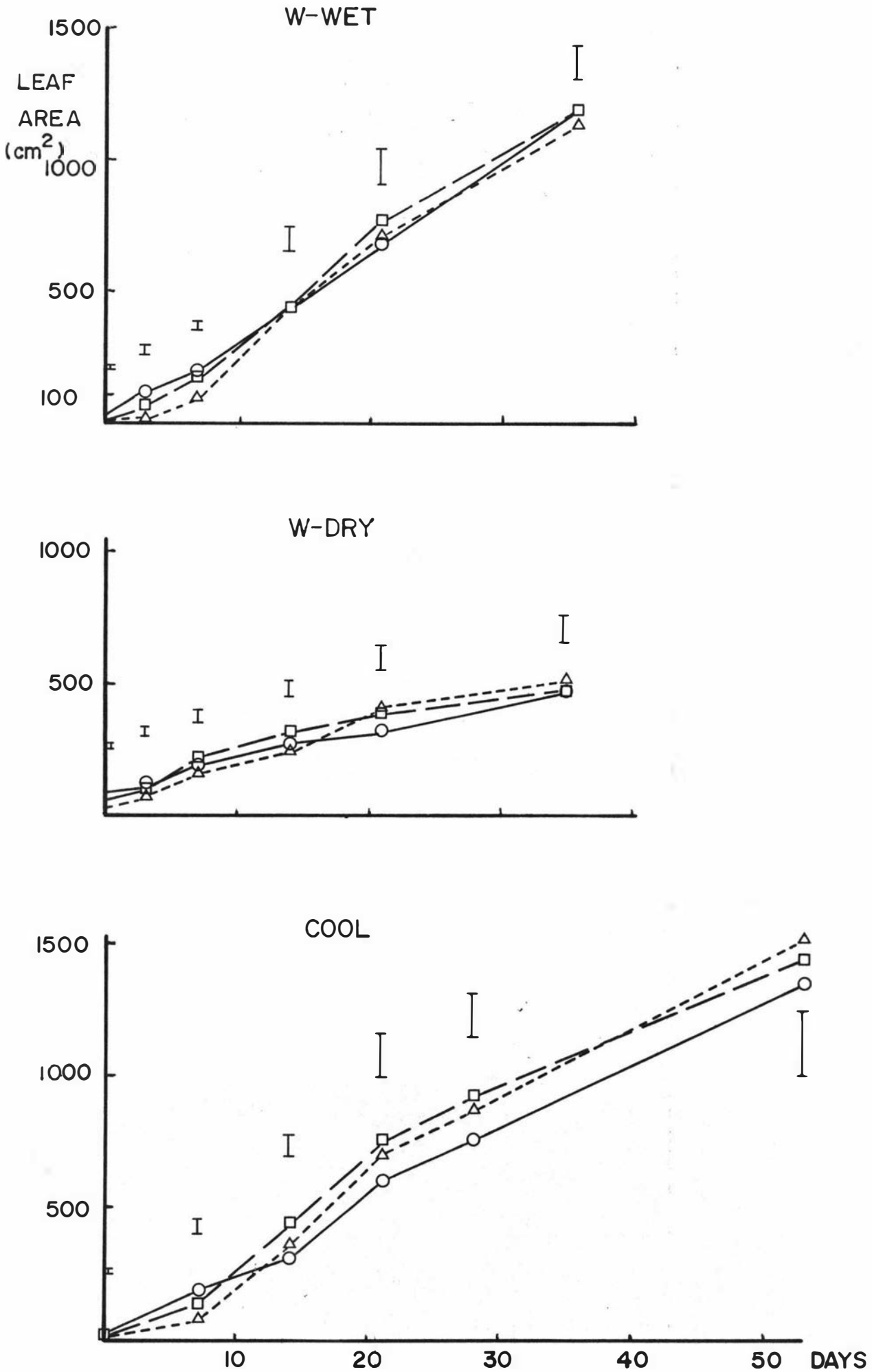


FIGURE 24. Total leaf area during the regrowth period.

△- - - - -△ Tmt 1 ○——○ Tmt 3

□—— ——□ Tmt 2 I LSD-5%

TABLE 13. The slopes or b values of the regressions of leaf area with time during the regrowth period - these b values represent absolute rate of leaf area expansion (in cm^2/day).

	Tmt 1	Tmt 2	Tmt 3	r^2 value of the regression		
				Tmt. 1	2	3
		W-WET				
Day 0-7 #	13.47 b	22.21 a	20.61 a	0.92	0.97	0.93
Day 7-21	43.32 a	43.27 a	36.34 a	0.90	0.99	0.96
Day 21-x	28.32 a	27.65 a	32.80 a	0.82	0.96	0.95
		W-DRY				
Day 0-7	16.19 b	23.28 a	15.42 ab	0.96	0.94	0.84
Day 7-21	17.30 a	12.16 ab	8.25 b	0.89	0.87	0.74
Day 21-x	8.59 a	6.64 a	11.11 a	0.68	0.74	0.84
		COOL				
Day 0-7	9.25 b	18.64 a	22.39 a	0.86	0.96	0.94
Day 7-21	45.20 a	43.66 a	29.98 b	0.97	0.97	0.93
Day 21-x	25.78 a	21.89 a	23.31 a	0.95	0.89	0.98

treatment values on the same horizontal with a letter in common are not statistically different at the 5% level

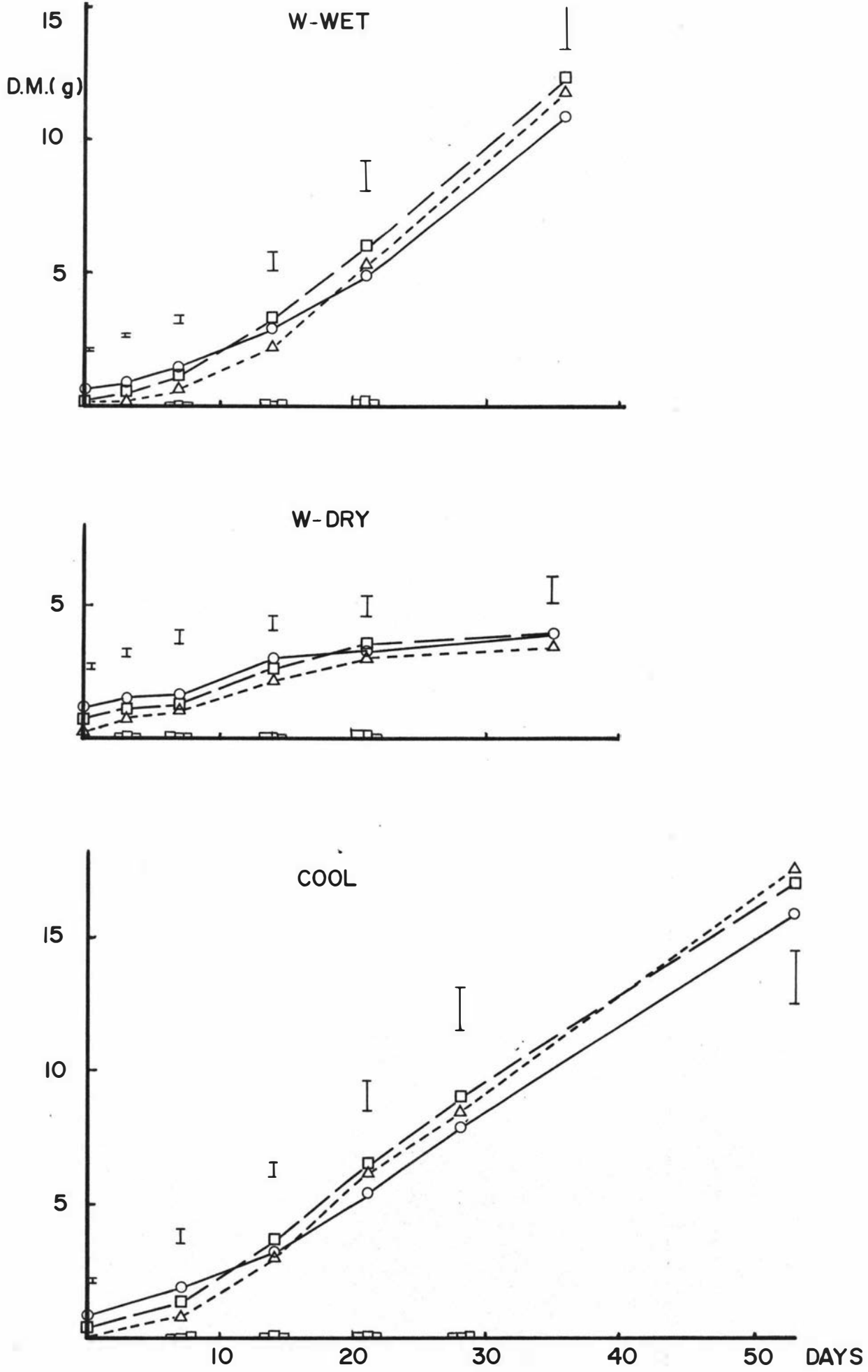


FIGURE 25. Herbage yield during the regrowth period - sum of basal & stubble shoot weight.

△- - - - -△ Tmt 1
□—— ——□ Tmt 2
○———○ Tmt 3

stubble shoot yield on Tmts 1,2 & 3 (left to right)

LSD-5%

than the lucerne in the W-Dry conditions over a very similar regrowth period (35 days). In the Cool conditions, although overall growth rate was similar to the W-Wet room, the longer regrowth period to the 1% flower stage (53 days) resulted in nearly 50% more shoot material present at harvest in the Cool than the W-Wet room.

The graphs of total regrowth for the full period from end of 'grazing' to 1% flower (Figure 25) indicate that a number of changes are occurring between the three GD treatments over this period. To highlight these treatment differences and aid the understanding of them, the regrowth period was subdivided into the Day 0-7, Day 7-21 and Day 21-final harvest (21-x) periods. The regression of herbage weight with time over each of these periods was calculated and the slopes (or b values), representing absolute growth rates (Figure 26), compared by paired t tests (Chapter 5).

Before discussing the effects of the GD treatments, the general effect of the three CE conditions on absolute growth rates (AGRs) through the regrowth period will be examined. It is apparent from Figure 26 that the moisture stress of the W-Dry room had very little effect on the growth rate of the lucerne for the first week of the regrowth period. However, in the next two weeks, the moisture stress began to restrict growth rates severely and, in the final two weeks to flowering, growth in the W-Dry room was only about 10% of that in the W-Wet. The minimal growth rate in the last two weeks of regrowth in the W-Dry room, in contrast to the growth rates of the first three weeks in that room, suggests that, once the tops reached a certain size, or transpirational surface area, there was only sufficient available moisture to barely maintain turgidity under these conditions and further growth was extremely limited.

The general picture of growth rate in the W-Wet room contrasts sharply with that just described for the W-Dry. With unrestricted soil moisture, the absolute growth rate (AGR) increased appreciably in each successive regrowth period.

Growth rate in the Cool room was as good as or better than that in the W-Wet room except over the Day 21-x period. During this period - which was much longer in the Cool room than in the W-Wet room (32 and 15 days respectively) - the lucerne in the Cool room was clearly incapable of sustaining the high growth rates recorded in the W-Wet room.

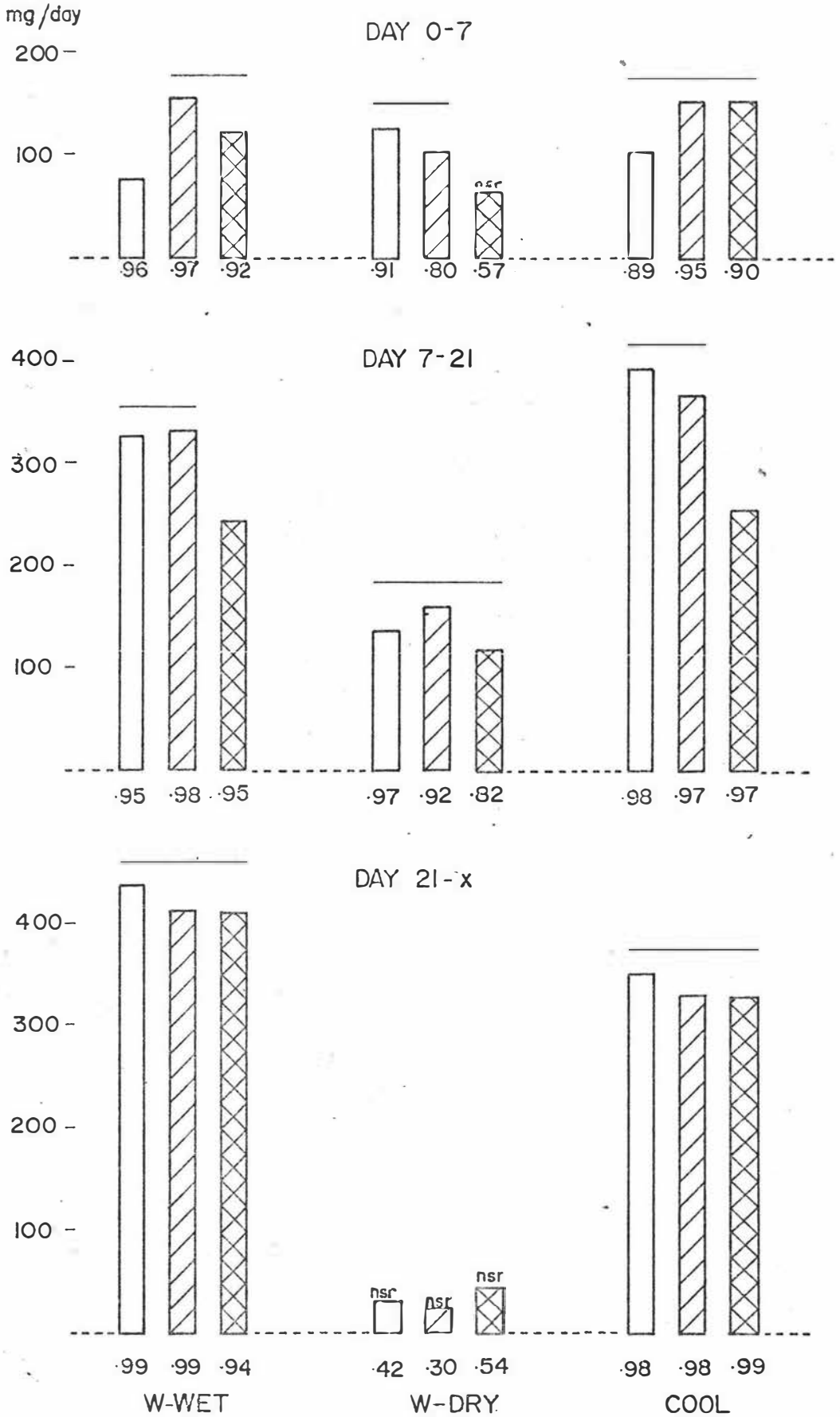


FIGURE 26. The slopes or b values of the regressions of herbage weight with time during the regrowth period - these b values represent absolute growth rates (in mg/day).

(within each room, columns with a line over them on the same horizontal are not statistically different at the 5% level - -

nsr : no significant regression was established)

Tmt 1 (.99) Tmt 2 (.97) Tmt 3 (.89) ← r^2 value of the regression

The effect of the GD treatments on AGRs during the regrowth period can now be examined. The three GD treatments had a similar effect in the W-Wet and Cool rooms. For the first seven days, the AGR of Treatment 1 was lower than that of the other two treatments (although the difference fell just short of the 5% significance level in the Cool room). Over the Day 7-21 period, Treatment 1 attained the level of Treatment 2 and it was the AGR of Treatment 3 that fell substantially below the other two. Over the last period, Day 21-x, no significant differences existed between the AGR of all three GD treatments within a room.

In the W-Dry room, higher variability and generally smaller treatment effects resulted in a complete absence of statistically significant differences in AGR between the three GD treatments right through the regrowth period.

While the AGR of Treatment 1 was low in the W-Wet and Cool rooms in the first seven days, Table 14 shows that its relative growth rate (RGR) substantially exceeded that of Treatments 2 and 3 over this period. However, during the Day 7-21 period in these two rooms, Treatment 3 had not only the lowest AGR but also the lowest RGR. Finally, Table 14 confirms the similarity in the growth rate of all three GD treatments over the last part, Day 21-x, of the regrowth period.

This whole section on yields and growth rates through the regrowth period has been expressed in terms of total herbage yield, i.e. the sum of basal and stubble shoots. It should be emphasised that stubble shoots at all times made only a very small contribution to regrowth yield (Figure 25). Rarely did their yield reach or exceed 10% of the total herbage yield and, for most of the time, it fluctuated between 3-7%. There were no obvious differences in the contribution of stubble shoots either between rooms or within a room between treatments.

6 : 4 TOTAL HERBAGE HARVESTED FOR PROJECT DURATION

Because flowering time varied between the three CE rooms, the duration was different in each of the three rooms :

TABLE 14. The slopes or b values of the regressions of the logarithm of herbage weight with time during the regrowth period - these b values represent relative growth rates (in g/g/day).

	Tmt 1	Tmt 2	Tmt 3	r^2 value of the regression		
		W-WET		Tmt. 1	2	3
Day 0-7	0.20 a	0.13 b	0.06 c	0.96	0.97	0.94
Day 7-21	0.07 a	0.05 b	0.04 c	0.98	0.98	0.95
Day 21-x	0.02 a	0.02 a	0.02 a	0.97	0.99	0.96
		W-DRY				
Day 0-7	0.10 a	0.05 b	0.02 c	0.82	0.81	0.58
Day 7-21	0.03 a	0.03 a	0.02 a	0.96	0.91	0.81
Day 21-x	< 0.01 nsr	< 0.01 nsr	< 0.01 nsr			
		COOL				
Day 0-7	0.15 a	0.09 b	0.05 c	0.95	0.98	0.94
Day 7-21	0.07 a	0.05 b	0.03 c	0.96	0.97	0.97
Day 21-x	0.01 a	0.01 a	0.01 a	0.94	0.98	0.96

nsr : no significant regression was established

W-Wet : 164 days
W-Dry : 160 "
Cool : 211 "

This of course confounds comparisons between rooms of 'total herbage harvested'.

Figure 27 shows that the total herbage harvested in each of the three studies was generally greatest under the instantaneous 'grazing' of Treatment 1 and least under the 30 day GD system of Treatment 3. Total herbage harvested under the 30 day GD system was about 20% less than that harvested under the instantaneous 'grazing' of Treatment 1 in the W-Wet and Cool rooms but in the W-Dry room the effect of the long GD system appeared to be less severe, for a reduction of only 13% was recorded. However, as noted in the field trial, these differences between GD treatments in total yield were generated almost entirely by differences in stem yield. There were no differences in the total production of leaf and new shoot between the three GD treatments in the W-Wet and W-Dry rooms although in the Cool room the difference between Treatments 1 and 3 just reached the 5% significance level.

6 : 5 SHOOT POPULATION STUDIES

The results of the shoot population studies done in the CE rooms were very similar to the results of the same studies done in the field trial. The tables of results from the CE studies are given in Appendices 10-24 and just the main points are mentioned here.

Under the instantaneous GD of Treatment 1 all the basal shoots were independents as no shoot decapitation occurred. Under the 10 and 30 day GDs of Treatments 2 and 3 respectively, shoot decapitation did occur and subtending and subtended shoots developed in all three studies. Independent shoots comprised 80-90% of total basal shoot numbers at the preliminary harvest following the ten day GD of Treatment 2 and about 40% following the 30 day GD of Treatment 3.

Once again, the independent and subtended shoots that arose towards the end of the 'grazing' period generally grew to the largest

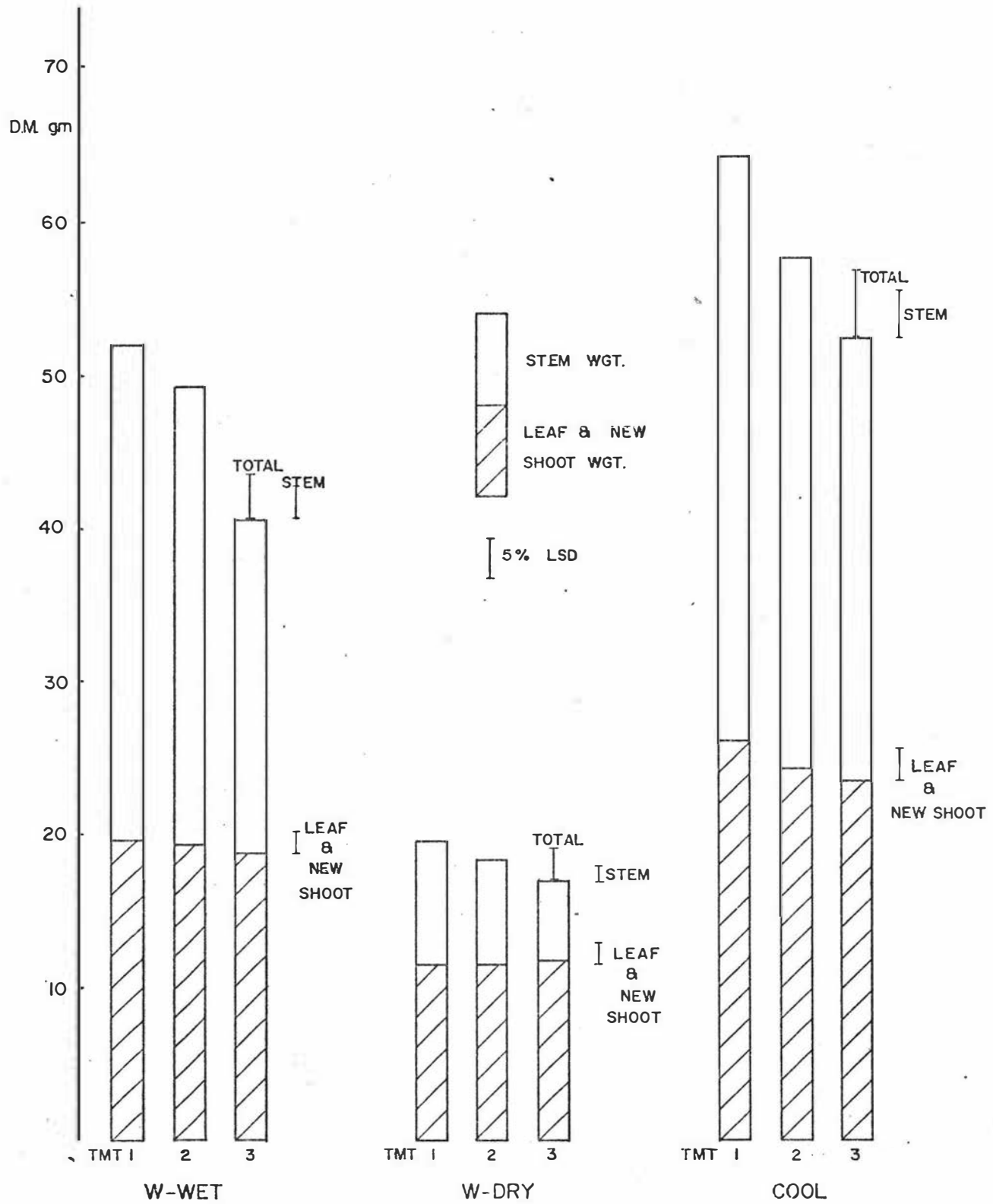


FIGURE 27. Total herbage harvested for project duration.

size and were the major contributors to total basal shoot weight. Shoots arising after the fifth day of the regrowth period developed little weight and survived poorly in the second half of the regrowth period.

Subtended shoots grew to the same size as independents of the same age.

Subtending shoots were always small and because of this made little contribution to total basal shoot weight.

Stubble shoots were few in number and light in weight (contributing only about 5-6% or less to toal shoot weight) and had a slightly later pattern of appearance than basal shoots.

Basal shoot numbers decreased in the second half of the regrowth period, the greatest mortalities generally occurring in the latest developing shoot classes.

There did not appear to be any difference in the survival of independent and subtended shoots of the same age.

The contribution of stubble shoots to total shoot weight decreased in the second half of the regrowth period due to both mortality and negligible weight increases of the survivors.

Generally, the pattern of shoot appearance and the contribution of the different shoot types to total shoot weight was very similar in all three CE rooms.

DISCUSSION

These herbage results from the CE studies have confirmed and defined more closely virtually all of the GD effects monitored in the field trial as well as providing some insight into the interaction of two climatic factors with GD. The confirmation of the field trial GD effects with potted plants in a simulated sward under simulated grazing in CE rooms is an indication of both the stability of the GD effects and the success of the simulations. For example, the attempt to

simulate sward conditions was clearly successful for in the two CE rooms where soil moisture was unrestricted (W-Wet and Cool), the pattern of new shoot development, the pattern of leaf and stem distribution in the mature herbage, the decline in specific leaf areas down through the profile and the degree of light penetration to the base of the 'sward' were very similar to that recorded in the field trial.

The simulated grazing also resulted in reasonable duplication of the field situation under actual grazing. The mature herbage was removed progressively from the top downwards and the size, composition and leaf area of the new shoot population at the end of the three GD treatments quite closely reflected the situation on the three treatments in the field trial at the end of grazing.

The information on herbage development during grazing that was obtained in the field trial was confirmed in the CE studies. Basically herbage production during grazing was largely dependent on the development of the new shoots for the only change on the mature herbage was some rather limited axillary leaf development and even this was curtailed in the W-Dry room. Thus herbage production during grazing was low in both the field trial and the CE studies but was composed almost entirely of leaf and new shoot material.

The herbage results of the CE studies have confirmed that a long GD (30 days) under good growing conditions has a restrictive effect on herbage growth rates in the first half of the regrowth period. The CE herbage results have also confirmed the initial inertia of regrowth following quick defoliation of well-watered lucerne at the 1% flower stage. This sudden herbage removal left the plant with very few new shoots and very little leaf area and, in both the CE studies and the field trial, it took several days to develop a shoot population and leaf area which could generate reasonable absolute growth rates.

The intermediate GD, this time of 10 days, once again appeared to have been about the right length to allow sufficient shoot development and leaf area expansion for rapid resumption of regrowth, without incurring the depressive effects on herbage regrowth that followed the long (30 day) GD.

At the end of the 30 day GD the lucerne had a higher leaf area

and a higher yield and number of new shoots than the lucerne at the end of the 10 day or instantaneous GD. Despite this, both the absolute and relative growth rates of the herbage through the Day 7-21 section of the regrowth period were lower following a 30 day than a 10 day or instantaneous GD. The reason for this is not evident in the herbage results. The shoot counts and shoot population studies indicate it is not due to either the size or composition of the shoot population on Treatment 3 - a conclusion which was also reached in the field trial.

The CE shoot population studies showed again that subtended shoots grew just as rapidly as independent shoots of the same age so the greater dominance of subtendeds on Treatment 3 cannot be implicated in the slower regrowth. Further, the shoot studies also showed that Treatment 3 had just as many undecapitated shoots arising in the main contributing period (last 10 days of 'grazing') at the end of 'grazing' as Treatment 2.

The suggestion that Treatment 3 may have had too many shoots for maximum herbage growth rates does not bear close scrutiny. For example, in the field trial the effect of the long GD was still expressed in the first half of the regrowth period despite the fact that treatment differences in the total of independent and subtended shoots had disappeared by Day 8 of the regrowth period. In contrast, in the CE studies, treatment differences in the total of independent and subtended shoots still existed in the second half of the regrowth period by which time of course treatment differences in herbage growth rates had disappeared. It would appear that, above a certain minimum, differences in the total of independent and subtended shoot numbers generated by GD trials have little influence on herbage growth rate. This is probably because the total number of large dominant shoots is fairly similar on all treatments after the first 7-8 days of the regrowth period and the 'extras' on the long GD treatments are merely those early arising shoots which escaped decapitation by virtue of their small size and slow growth rate.

The field trial demonstrated the effect of GD on total lucerne herbage production over an eight month period and the CE studies confirmed these general findings under more controlled conditions. The greatest total herbage production in all three CE studies occurred under the instantaneous 'grazing' of Treatment 1. The 10 day GD reduced total herbage production by 5-10% and under the 30 day GD in the W-Wet and Cool rooms, the reduction was about 20%. These GD effects on total herbage

production are less than the 14% and 29% reductions recorded in the field trial under Treatments 2 and 3. One reason obviously is that the intermediate GD, Treatment 2, was 10 days in the CE studies and 15 days in the field trial. The absence of any treading damage on the newly emerging shoots in the CE studies may also account for the reduced effect of the longer GDs indoors than under actual grazing in the field trial.

Despite the differences in total herbage yield between the three GD treatments in the CE studies, the total production of leaf and new shoot was once again very similar under all three GD treatments in all three 'climates'.

The reductions in total herbage yield were again the result of the very limited herbage development that occurred during the 'grazing' periods and the virtual absence of treatment differences in total non-stem yield was the consequence of herbage development during 'grazing' being entirely in the form of leaf and new shoot.

The practical significance of these GD effects on herbage production over one full growing season were discussed in Chapter 3. The CE studies simply confirm the validity of the findings for GDs of up to 30 days.

In the W-Dry room the 30 day GD appeared to have less effect on total herbage production (13% reduction) than in the W-Wet and Cool rooms (22% & 19% reductions respectively). This is not altogether surprising in view of (a) the herbage canopy that developed in the W-Dry room and (b) the effect of the moisture stress on herbage growth rates. The high leaf:stem ratio, excellent distribution of leaf area through the profile and low specific leaf area values for the lower leaves indicate that lucerne under the W-Dry conditions would maintain both a more effective and a relatively higher leaf area for a greater proportion of a long GD than would lucerne under the W-Wet or Cool conditions. The figures on leaf area during 'grazing' bear this out. In addition, the impact of the slow herbage growth rate associated with the 'grazing' period has been reduced in the W-Dry room, for the moisture stress in this room has restricted the expression of the rapid growth rates which occurred from about Day 7 onwards in the regrowth periods of the W-Wet and Cool rooms.

It would appear therefore that, as conditions became drier, the impact of GD on total herbage production from lucerne may decrease.

One other effect noted in the W-Dry room has important practical implications. The moisture stress imposed in this room had no effect on the growth rate of the lucerne in the first week of the regrowth period, but an increasingly restrictive effect thereafter. This ability of lucerne to establish its new shoot population and at least commence vigorous herbage growth under the degree of moisture stress imposed in the W-Dry room provides flexibility for lucerne irrigation programmes.

The difference in the temperature regime between the W-Wet and Cool rooms affected flowering time and herbage yield at first flower very much in accordance with the findings of other workers (Smith 1970, Lee & Smith 1972) but it did not seem to influence the effect of GD on any of the herbage factors monitored in these CE studies. Had lower temperatures been used in the Cool room, e.g. 12.5 /5 C or 10 /4 C, the effect of GD may well have been altered, but as stated earlier, it would be more difficult to assess a constant 'grazing' commencement time in the absence of flowering and for this reason lower temperatures were not employed.

* * * *

The next chapter examines the effect of GD on the size, composition and functioning of the underground organs in the three CE studies.

CHAPTER 7 : CONTROLLED ENVIRONMENT STUDIES - THE UNDERGROUND ORGANS

RESULTS

The impact of grazing durations of up to 30 days on the growth rate of lucerne herbage during the subsequent regrowth period has been demonstrated in both the field and controlled environments, and under actual and simulated grazing. In each case, a long GD has impaired both the absolute and relative growth rate of lucerne herbage for the first half of the regrowth period and, despite detailed herbage measurements, the cause of the reduced growth rates is not evident. In this chapter the effects of GD - in the three CE studies - on the size, composition and functioning of some of the underground organs are presented and discussed.

7 : 1 MINERAL UPTAKE

Table 15 gives the levels of phosphorus (P) and potassium (K) found in the herbage harvested during the regrowth period of the second cycle in the W-Wet room. Percentage P decreased with time on all treatments whereas percentage K did not decline significantly during regrowth. However, of greater importance to this study is the finding that no significant differences were found between the three GD treatments at any one harvest in the level of either P or K in the herbage. This absence of any treatment differences in herbage mineral levels suggests that the regrowth of one treatment was not being restricted more than that of another by the capacity of the root system for mineral uptake.

In this context it is important to note that the potting mix in the CE studies was not atypically enriched, for the levels of phosphate and potassium in this soil mix were slightly lower than in the top 15 cm of the soil on the field trial site. Incidentally, there were no treatment differences in the W-Wet room in the levels of phosphate or potassium in soil samples taken during the regrowth period of the second cycle (Appendix 25).

TABLE 15. Herbage mineral analyses: % phosphorus & % potassium in the herbage during the regrowth period - W-WET.

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% / 1%
		% P			
Day 7	0.53	0.54	0.51	4.9	0.04 / 0.06
Day 14	0.51	0.47	0.49	12.0	0.09 / 0.13
Day 21	0.40	0.36	0.32	12.4	0.07 / 0.10
Day X	0.28	0.30	0.27	18.3	0.08 / 0.12
CV%	6.7	11.8	12.6		
LSD 5%	0.04	0.08	0.08		
1%	0.06**	0.11**	0.11**		
		% K			
Day 7	1.82	2.11	2.01	9.6	0.30 / 0.44
Day 14	2.23	1.87	1.86	15.8	0.50 / 0.72
Day 21	1.78	1.99	1.77	16.8	0.50 / 0.71
Day X	1.71	1.73	1.53	23.4	0.62 / 0.89
CV%	20.9	10.6	16.7		
LSD 5%	0.60	0.31	0.46		
1%	0.85	0.44	0.65		

7 : 2 ACETYLENE REDUCING ACTIVITY

In each room the rate of acetylene reduction (AR) declined as the mature herbage was removed (Figure 28). Under the 30 day 'grazing' the decline was gradual; under the instantaneous herbage removal of Treatment 1, AR rate dropped abruptly. During the first 10 days of the regrowth period, AR rate on the three GD treatments differed quite markedly. On Treatment 1 the rate fell sharply to a minimum at Day 5 and then rose sharply. Treatment 3 did not exhibit the sharp minimum of Treatment 1 but, for the first five days of the regrowth period, did not change significantly but remained at a level which in both the W-Wet and Cool rooms was substantially higher than the Treatment 1 minimum. AR rate on Treatment 2 occupied an intermediate position between that of Treatments 1 and 3 during early regrowth.

After Day 5 of the regrowth period, the AR rate of all three treatments in all three rooms increased quickly such that by Day 15 treatment differences had completely disappeared. At no time during the first 15 days of the regrowth period was the AR rate of Treatment 3 significantly lower than that of Treatment 2 : indeed the reverse was more often the case although the differences were generally not significant.

By Day 15 of the regrowth period, AR in the W-Wet and Cool rooms had regained the rates recorded at the 1% flower stage when grazing commenced. These rates were still operative at the end of the regrowth period when the 1% flower stage was again reached. Recovery of AR rates was not quite as rapid as this in the W-Dry room for by Day 15 the rates were still significantly lower than those recorded at the 1% flower stage at the beginning and end of the second cycle.

These results indicate that, under all three CE conditions, the effect of the long GD (30 days) on herbage development in the first half of the regrowth period cannot be attributed to impaired nitrogen (N) fixation on this treatment at this time. This is reinforced by the results of N analyses done on herbage from the W-Wet and W-Dry rooms (Table 16): there were no significant treatment differences in the level of herbage N at any stage during the regrowth period in either room.

The theoretical figure for the ratio of ethylene produced to N fixed in the whole plant is 3.00, although values for this ratio reported in the literature range from 2.18 to 5.49 (Bergersen 1970, Sinclair 1975).

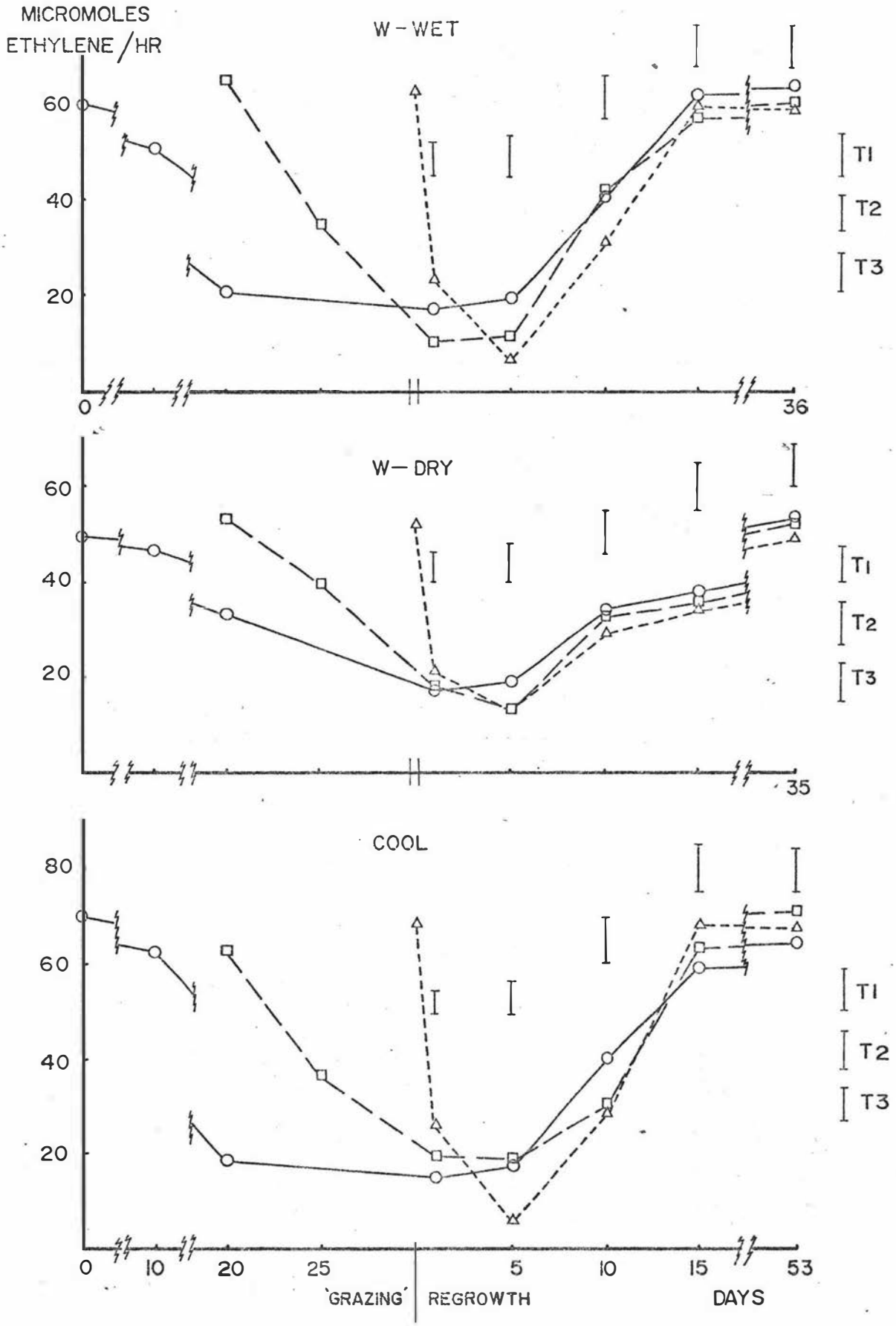


FIGURE 28. Acetylene reduction rates during the 'grazing' & regrowth periods.

Tmt 1
Tmt 2
Tmt 3
LSD-5%

TABLE 16. Percentage nitrogen in the herbage during the regrowth period.

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% / 1%
		W-WET			
Day 7	3.90	4.02	4.38	7.3	0.48 / 0.69
Day 14	4.12	4.48	4.39	6.5	0.45 / 0.65
Day 21	3.77	3.84	3.92	5.6	0.34 / 0.49
Day X	3.64	3.63	3.56	8.1	0.47 / 0.67
CV%	7.4	5.9	6.6		
LSD 5%	0.44	0.36	0.41		
1%	0.62	0.51**	0.58**		
		W-DRY			
Day 7	3.96	3.86	4.19	5.1	0.32 / 0.47
Day 14	3.85	3.93	4.17	5.2	0.33 / 0.48
Day 21	3.86	3.90	4.04	2.9	0.18 / 0.26
Day X	4.03	4.06	4.18	8.9	0.58 / 0.83
CV%	4.2	5.8	7.3		
LSD 5%	0.26	0.35	0.47		
1%	0.36	0.49	0.65		

When this ratio was calculated for the Day 15-x period (this period was chosen because AR rates had become relatively stable by this time), the ratio was 1.25 in the W-Wet room and 2.37 in the W-Dry room.

This suggests that the AR assay was underestimating N fixation in the W-Wet room. (There were no significant differences between the two rooms in the level of soil N - Appendix 26). This may be associated with the moist conditions that were maintained in the pots in the W-Wet room. However, whatever factor(s) were influencing absolute rates of AR between rooms, the mineral N levels in the herbage (Table 16) indicate that the principal conclusion of the AR assays remains unchanged : the effect of the long GD on herbage development in the first half of the regrowth period cannot be attributed to impaired N fixation under any of the three CE conditions.

7 : 3 ROOT WEIGHT

In the W-Wet and Cool rooms, root weights on all three GD treatments declined significantly in the second cycle with the removal of the mature herbage to reach minimum levels one-three weeks into the regrowth period before increasing again to reach their original levels at the end of the regrowth period, i.e. the 1% flower stage (Figure 29). In both rooms root weight following the long GD of Treatment 3 not only reached the lowest minimum but was the first in the regrowth period to reach this minimum and begin increasing again, while the root weight of Treatment 1 was the last in the regrowth period to begin increasing again. These differences between the three GD treatments in root weight changes during the regrowth period are further illustrated in Table 17 where changes during the Day 0-7, Day 7-21 and Day 21-x sections of the regrowth period are presented and compared. The general trend of root weight was downward on all three GD treatments in both the W-Wet and Cool rooms during the Day 0-7 section, although significant regressions were not often established. During the Day 7-21 section of the regrowth period in both CE rooms, the slope of the regression for Treatment 1 was still negative but on Treatment 3 the slope was positive, i.e. root weight was increasing. On Treatment 2 where root weight was following an intermediate course during this period, no significant regression could be established. By the Day 21-x section, root weight on all three GD

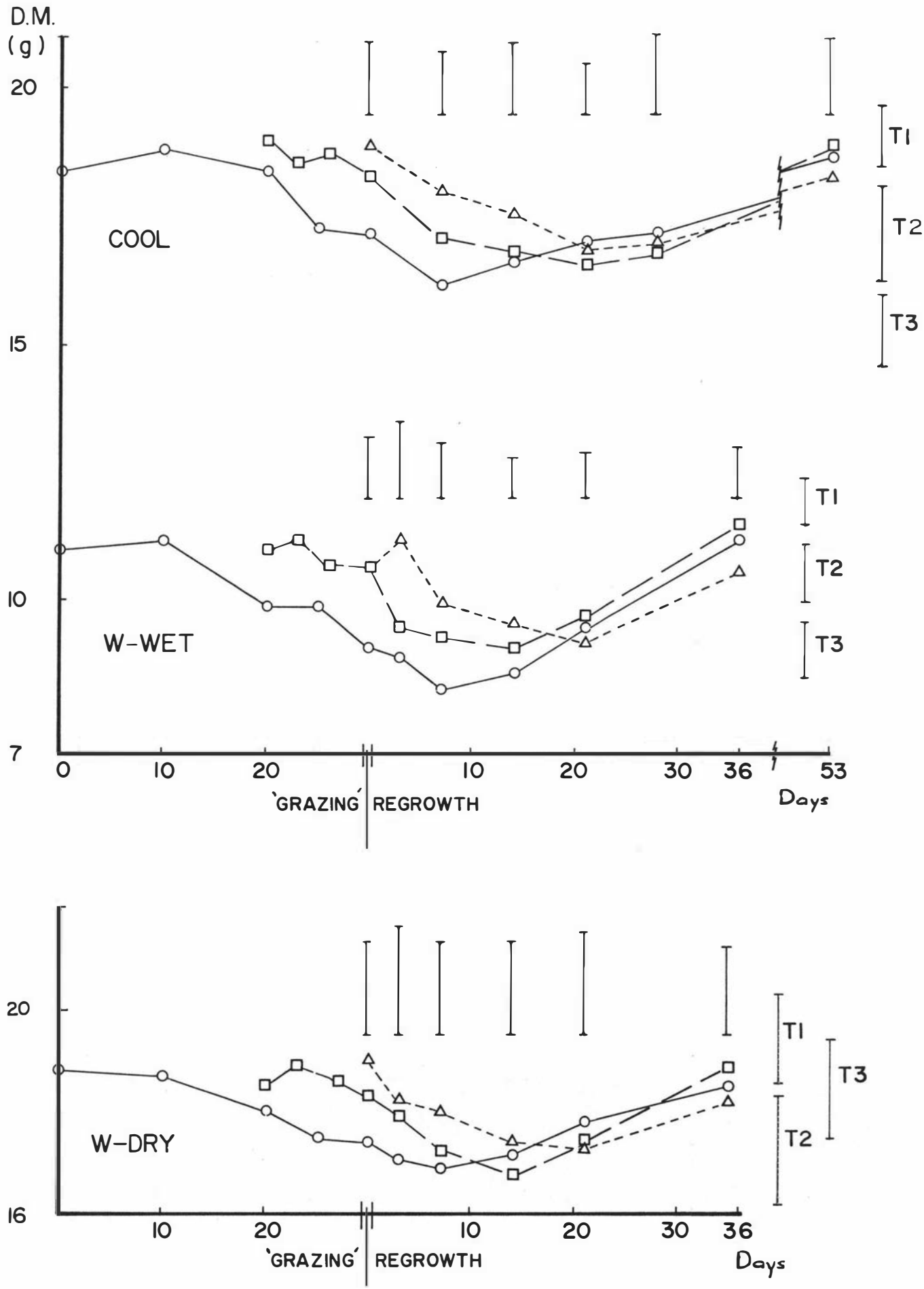


FIGURE 29. Root weights during the 'grazing' & regrowth periods.

TABLE 17. The slopes or b values of the regressions of root weight with time during the regrowth period - these b values represent rate of root weight change (in g/day).

	Tmt 1	Tmt 2	Tmt 3	r^2 value of the regression		
		W-WET		Tmt. 1	2	3
Day 0-7	nsr	-0.19	nsr	-	0.62	-
Day 7-21	-0.06 b	nsr	0.09 a	0.61	-	0.70
Day 21-X	0.09 a	0.12 a	0.11 a	0.82	0.85	0.90
		COOL				
Day 0-7	nsr	nsr	-0.14	-	-	0.80
Day 7-21	-0.08 b	nsr	0.06 a	0.60	-	0.61
Day 21-X	0.05 a	0.07 a	0.06 a	0.69	0.73	0.78

treatments was increasing and the slopes of the regressions did not differ significantly between treatments.

In the W-Dry room, although there appeared to be a general decline in root weight with the removal of the mature herbage followed by an increase to the original levels by the end of the regrowth period, the effects were small and variability was high with the result that root weight did not change significantly on any of the three GD treatments during the second grazing/regrowth cycle (Figure 29).

7 : 4 ROOT COMPOSITION

The pattern of changes in total non-structural carbohydrates (TNC), starch and soluble sugar concentrations was very similar in the W-Wet and Cool rooms (Figure 30). TNC percentages which were high at the flowering stage declined with removal of the mature herbage - gradually on Treatment 3 and more sharply on Treatment 1. The decline continued for about one-three weeks into the regrowth period before minimum levels were reached and net accummulation of TNC in the root system commenced. Percentage TNC then rose at a fairly steady rate until the original high concentrations were reached once again at the end of the regrowth period. Percentage starch followed an almost identical pattern to TNC concentrations. The percentage of soluble sugars changed very little but tended to move in the opposite direction from that of starch and TNC percentages. Thus changes in starch concentrations were generally a little greater than changes in TNC concentrations.

In the W-Dry room the pattern of changes in TNC and starch concentrations during the 'grazing'/regrowth period (Figure 30) was similar to that in the W-Wet and Cool rooms. However, the amplitude of the changes in the W-Dry room appeared to be smaller than in the other two rooms (Table 18). In addition, the concentration of soluble sugars did not change significantly on any of the treatments in the W-Dry room during the 'grazing'/regrowth cycle.

In each room the root TNC and starch concentrations reached their minimum and began increasing again, first, following the 30 day GD of Treatment 3 and, last, following the instantaneous GD of Treatment 1

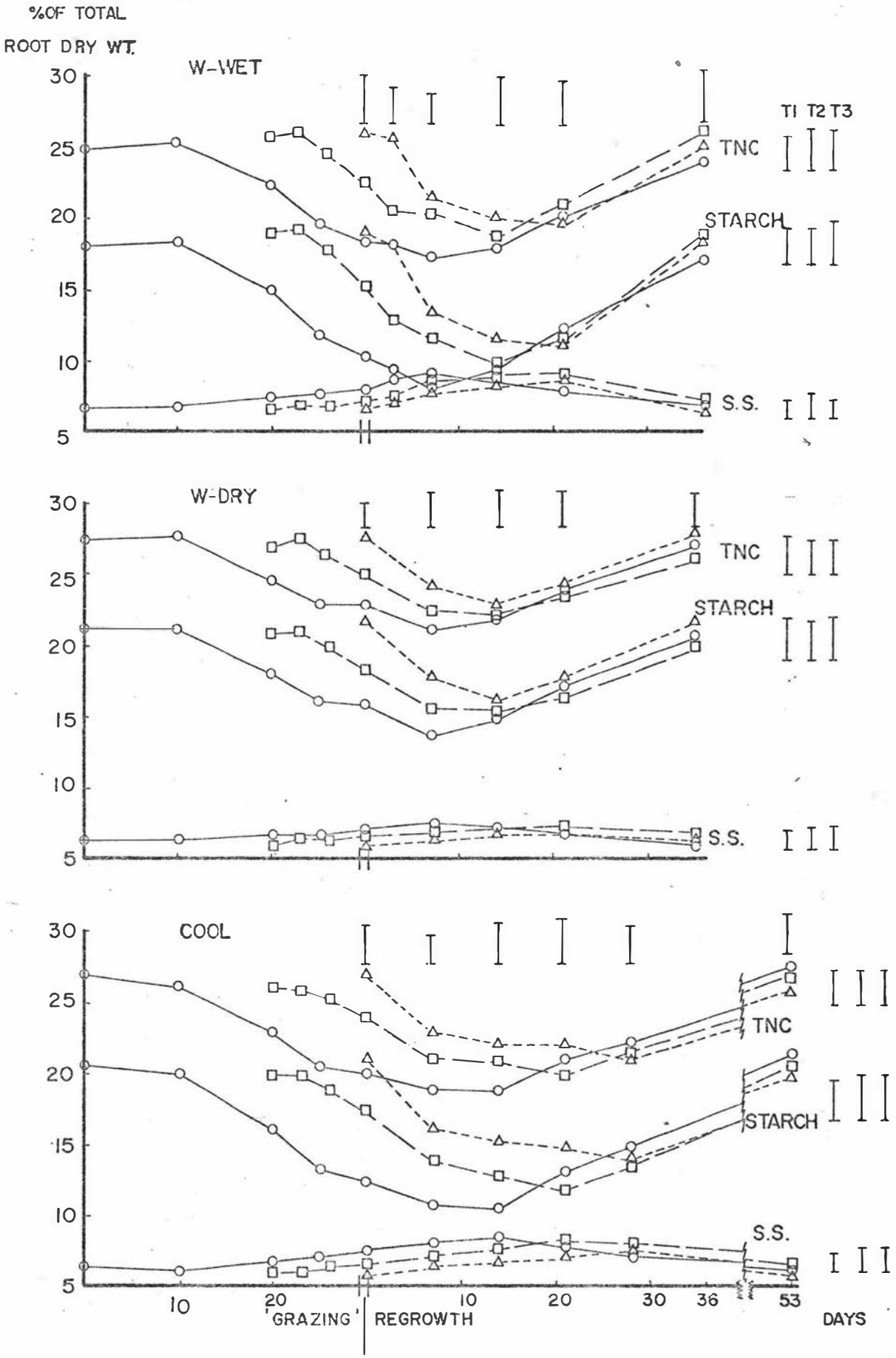


FIGURE 30. The concentration of total non-structural carbohydrates (TNC), starch & soluble sugars (s.s.) in the roots during the 'grazing' & regrowth periods.

Tmt 1
Tmt 2
Tmt 3
LSD-5%

TABLE 18. Percentage change in TNC concentration* recorded during the grazing / regrowth cycle on each GD treatment in the 3 CE rooms.

	W-WET	W-DRY	COOL
Tmt 1	23	17	20
Tmt 2	28	17	24
Tmt 3	31	23	31
Average	27	19	25

* the % change in TNC concentration on each GD treatment is the difference between the lowest reading & the average of the 2 highest readings on that treatment expressed as a % of the latter (ie. the average of the 2 highest readings on that treatment)

(7-10 and 14-28 days respectively after 'grazing' finished).

It is quite evident that the general pattern of changes in TNC and starch concentrations in the three CE rooms is similar to the general pattern of root weight decline and restoration in the three rooms, except of course that in the W-Dry room the changes in TNC and starch concentrations reached the 5% significance level, whereas the changes in root weight did not.

DISCUSSION

Where growth has not been restricted by moisture stress, defoliation in these studies has generated the classical fall and subsequent rise in root weight and root TNC and starch concentrations that normally follows the removal of lucerne tops under active growing conditions (Brown *et al* 1972). The three GD treatments have influenced the shape of these root responses and obviously also the value of the parameters at the end of 'grazing'.

However, although the three GD treatments generated significant differences in root weight and composition by the end of the 'grazing'/start of the regrowth period, the results have indicated that differences in herbage growth rates between the three treatments during the first half of the regrowth period cannot be attributed to either the capacity of the root system for mineral uptake or the capacity of the nodules for N fixation. Clearly, as Hodgkinson (1973) has already noted, the lucerne root system has considerable plasticity in terms of mineral uptake and it would appear that the N fixation system has a similar degree of flexibility.

The treatment differences in the pattern of root weight change during the regrowth period were of considerable interest for this finding confirmed a suspicion aroused by the NAR calculations performed on the field trial data. It is pertinent that the study in which there were no significant treatment differences recorded in herbage growth rates during the regrowth period (W-Dry) was also the study in which there were no significant treatment differences recorded in root weights during the regrowth period. In the other two studies (W-Wet and Cool) treatment

differences in root weight changes occurred principally in the Day 7-21 section of the regrowth period. This is evident in the graphs of root weight (Figure 29) and the regressions of root weight with time (Table 17). Treatment differences in root composition changes also occurred principally in the Day 7-21 section (Figure 30). These treatment differences are attributable to the effect exhibited in both the W-Wet and Cool rooms in which root weight and TNC levels began to increase again earlier in the regrowth period following the 30 day GD than following the 10 day GD, and following the 10 day GD they began to increase again earlier than following the instantaneous GD.

It is interesting to link these changes in the roots with the concurrent changes in the tops. For instance, total plant weight (the sum of root and top weight), after an initial period of inertia in the first seven days, increased for the rest of the regrowth period at the same rate on all three GD treatments in both the W-Wet and Cool rooms (Table 19). Clearly, the lower herbage production of Treatment 3 than Treatment 2 over the Day 7-21 section of the regrowth period was associated with a compensating change in root weight such that the increase in total plant weight over this period was identical on both treatments.

Also Table 20 shows that, in the W-Wet and Cool rooms, apart from the first seven days, the three GD treatments in a room had the same net assimilation rates through the regrowth period. This equivalence between the three GD treatments of (a) net assimilation rates and (b) absolute growth rates of the total plant indicates that the differences between the three GD treatments in herbage growth rates during the Day 7-21 section of the regrowth period were the result of differences in the partitioning of assimilate in the plant.

Treatment differences in the AGR and NAR of the total plant in the first seven days of the regrowth period - in contrast to the rest of the regrowth period - reflect the differences that existed between the three GD treatments in leaf area at the start of this period. With virtually no leaf area at the start of the regrowth period on Treatment 1 in the W-Wet and Cool rooms, an initial loss in total plant weight with its associated negative NAR was inescapable. However, on Treatment 3 the quite substantial leaf area that had developed by the end of 'grazing' was able to maintain total plant weight through this first seven day period.

TABLE 19. Total plant weight (sum of top & root weights) & absolute growth rate (AGR) of the total plant during the regrowth period.

		Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% 1%
			W-WET			
Total plant weight (g)	Day 0	10.73	10.86	9.65	7.2	1.19* 1.72
	Day 3	11.34	10.01	9.75	8.9	1.48* 2.13
	Day 7	10.56	10.55	9.74	9.3	1.53 2.20
	Day 14	11.62	12.26	11.50	7.8	1.47 2.11
	Day 21	14.30	15.60	14.34	9.3	2.19 3.15
	Day X	22.26	23.60	21.94	6.6	2.39 3.43

					r^2value of the regression		
					Tmt. 1	2	3
AGR (g/day) #	Day 0-7	nsr	nsr	nsr			
	Day 7-21	0.27 a	0.36 a	0.33 a	0.78	0.93	0.90
	Day 21-X	0.53 a	0.53 a	0.51 a	0.95	0.97	0.94

			COOL		CV%	LSD 5% 1%
Total plant weight (g)	Day 0	18.98	18.61	18.02	9.3	2.75 3.96
	Day 7	18.80	18.45	18.07	10.5	3.10 4.45
	Day 14	20.62	20.34	19.80	6.7	2.20 3.10
	Day 21	23.16	23.06	22.37	7.6	2.78 3.99
	Day 28	25.43	25.84	25.09	9.0	3.68 5.29
	Day X	35.81	35.85	34.59	7.5	4.23 6.09

					r^2value of the regression		
					Tmt. 1	2	3
AGR (g/day) #	Day 0-7	nsr	nsr	nsr			
	Day 7-21	0.31 a	0.33 a	0.31 a	0.76	0.79	0.77
	Day 21-X	0.40 a	0.40 a	0.38 a	0.93	0.96	0.94

these figures are the slopes or b values of the regressions of total plant weight with time during the regrowth period

N.B. no significant regressions of total plant weight with time could be established with the data from the W-Dry room.

TABLE 20. Net Assimilation Rate (NAR) in g/dm^2/week during the regrowth period.

	Tmt 1	Tmt 2	Tmt 3
		W-WET	
Day 0-7	-0.36	-0.29	0.03
Day 7-21	0.27	0.29	0.26
Day 21-X	0.18	0.17	0.17
		COOL	
Day 0-7	-0.31	-0.11	0.03
Day 7-21	0.35	0.27	0.26
Day 21-X	0.11	0.12	0.12

One other pertinent relationship between the roots and the tops is presented in Table 21. Clearly, increase in root weight and TNC concentration following the 30 day GD began not only earlier in the regrowth period but at a much lower leaf area than following the 10 day and instantaneous GD. The reason for this is not clear but its relationship to both the size of the root system and the concentration of TNC and starch in the root system at the start of the regrowth period is interesting. The lower the root weight and the lower the TNC and starch concentration in the roots at the start of the regrowth period the lower the leaf area at which the plant began to restore root weight and carbohydrate concentration.

N.B. Partitioning to the roots would almost certainly have commenced before the root parameters (weight, TNC percentage, starch percentage) began to increase, for Hodgkinson (1970) has demonstrated bi-directional movement of carbohydrates in the regrowing lucerne stem. However, since the point at which these root parameters began to increase would be closely linked to the commencement of partitioning to the roots, it provides a convenient point for treatment comparisons.

These results have indicated that, following a 30 day GD, 'Wairau' lucerne's capacity for increases in total plant weight was undiminished but, for some reason, it began to partition assimilate towards the root system so early in the regrowth period and at such a low leaf area that for a time assimilate supplies to the tops were insufficient to maintain the top weight increases of lucerne plants regrowing after shorter GDs.

It is important to note that, because carbohydrates are part of a dynamic energy-balance system interrelated to rates of growth and photosynthesis, any factor which restricts growth relatively more than photosynthesis would cause a carbohydrate build up in plant tissue (Blaser *et al* 1966). However, no such factor occurred in the W-Wet and Cool rooms and thus some other mechanism must have generated the earlier upturn of TNC, starch and root weight on Treatment 3. It is tempting to invoke a source/sink relationship in considering these results, with the more depleted root system following the 30 day GD acting as a slightly stronger sink and thus 'attracting' assimilate to it earlier than the less depleted root systems following the shorter GDs.

TABLE 21. Approximate time & leaf area when net gain of root TNC% commences in the regrowth period.

	Tmt 1	Tmt 2	Tmt 3
		W-WET	
# Day	18	14	7
# Leaf area (cm^2)	580	430	180
		COOL	
Day	28	21	12
Leaf area (cm^2)	880	750	280

the day when net gain of root TNC% commences is taken from the graphs of root TNC% (Figure 30) & then the leaf area that is present on this day is taken from the graphs of leaf area (Figure 24).

N.B. Root weight also began to increase again earlier in the regrowth period & at a lower leaf area following the 30 day GD than following the 10 day & instantaneous GD.

This suggestion certainly does not lack support in the literature. It is well known that environmental conditions, e.g. light intensity (Ryle & Powell 1976), water stress (Sosebee & Wiebe 1971) and low soil nitrogen (Leafe *et al* 1974) can alter the partitioning of assimilate between the tops and roots of plants. There have also been many studies on the influence of one plant organ on the export of assimilate from another. For example, experiments with decapitated and partially defoliated sugar beet plants (Geiger 1966, Geiger & Swanson 1965; Terry 1966, Winter & Mortimer 1967) indicate generally that amounts of assimilate translocated to particular regions are determined to a considerable extent by the relative activities of the various sinks. In a recent review Pate (1975) stated, "there is evidence from several crop species that a consuming organ (sink) can exercise a controlling influence over the production and export of assimilates by 'source' organs such as photosynthesising leaves."

The mechanism by which the influence of one plant part is exerted on another is probably hormonal. Went (1938, 1943) first suggested that the root exerted some hormonal control over shoot growth. In a study with *Pisum sativum*, McDavid *et al* (1973) concluded that the proportion of current assimilates retained by the shoot may be dependent on the amount of cytokinin or other hormones supplied from the roots. A reduction in this supply following root pruning or adverse conditions for root growth may reduce the capacity of the shoots to retain assimilate and increase the proportion partitioned downwards to the roots. The results of Clifford and Langer (1975) with ryegrass suggested that root-pruning increased the sink activity of the remaining roots for they attracted labelled assimilate more strongly than the roots of intact plants. In view of the effects that the 30 day GD in the CE studies had on root weights and composition, it is conceivable that this treatment could have a similar effect on the hormonal 'messages' from the roots, as root pruning.

Working with lucerne, Silva (1968) showed that, in the absence of leaves at the start of regrowth, export of photosynthate down to the roots started at a lower leaf area in plants with an initially low root TNC status than in plants with an initially high root TNC status. A similar effect was recorded by Hodgkinson (1973) except that he monitored root weight rather than root TNC status. Two groups of lucerne plants were prepared by pre-treatments of infrequent and frequent cutting. The total

root weight on the 'infrequent' plants was more than double that on the 'frequent' plants at the final cut, i.e. the start of the experimental period. As the plants regrew following the final cut, total root weight reached its minimum and began increasing again on both treatments on Day 7. At this time the 'infrequent' treatment had double the shoot weight of the 'frequent' treatment, i.e. root weight increases on the 'frequent' (low root weight) treatment started at a lower shoot weight and presumably also leaf area than on the 'infrequent' (high root weight) treatment.

Finally, the work of Chatterton *et al* (1974) is of considerable interest for it indicates there are differences between lucerne varieties in the priority they assign to the restoration of root TNC percentage following defoliation. These CE studies suggest that 'Wairau' lucerne assigns it a fairly high priority during regrowth.

In the W-Dry room, although the pattern of the GD effects on the underground organs was the same as in the other two rooms, in general the size of the effects were smaller to the extent that statistically significant differences often did not occur. This, coupled with the fact that significant treatment differences in herbage yield and growth rate during the regrowth period were not found in the W-Dry room, meant that many of the relationships linking changes in tops and roots during regrowth, which helped to clarify GD effects in the other two rooms, did not occur in the W-Dry room. The smaller effect of GD on the underground organs in the W-Dry room can no doubt be attributed to such things as the high leaf:stem ratio, the excellent distribtuion of leaf area through the profile, the retarded leaf ageing and the high root:top ratio in the W-Dry room.

The findings of this chapter tend to confirm the suggestion made in the previous one - as conditions become drier the impact of GD will be reduced. This would indicate that the suggestion of O'Connor (1970) that GD be shortened during periods of summer drought is unnecessary. Indeed, these results indicate that under dry conditions the lucerne plant is <u>better</u> able to survive the stress of longer GDs and, as shown in Chapter 6, the effect on herbage production is <u>less</u> than under moist conditions.

* * * *

It would seem that the objectives of the CE studies have been achieved. By examining the effect of GD under controlled environment conditions, reliable treatment comparisons were made of a number of factors which were not measured in the field trial but which were thought to be influenced by GD. As a result of this, the reason for the depressive effect of a very long GD on initial herbage regrowth has apparently been revealed. In addition, the herbage effects recorded in the field trial have been confirmed and an insight has been gained into the interaction of at least one environmental factor with GD.

CHAPTER 8 : CONCLUDING COMMENTS AND SUMMARY

CONCLUDING COMMENTS

This project has examined the impact of grazing duration (GD) on lucerne. However it is important to note that each GD, from the very short (0-3 days) to the much longer (30 days) duration - in both the field trial and the three controlled environment (CE) studies - involved a gradual defoliation (or removal of the mature herbage) over the appropriate period. This reflected the situation in which a certain number of stock enter a paddock, their numbers are not altered during grazing and they are removed, i.e. grazing ceases, once the majority of the mature herbage has been consumed. It would certainly be most unwise to conclude that the findings of this project on the relative effects of different GDs would apply to GDs of a similar length but a vastly different defoliation pattern. Thus a situation in which lucerne was kept closely grazed for much of a 30 day GD could be expected to generate considerably more severe effects than the 30 day GDs in this project. Conversely if the lucerne was only lightly 'topped' for much of the GD and then quickly defoliated right at the end of the grazing period, this could be expected to generate a smaller effect than a GD of similar length defoliated in the manner adopted for this project.

There are two reasons for the importance of the defoliation pattern. Firstly, the results of this project indicate that, in 'Wairau' lucerne, provided a GD is long enough to allow development of a reasonable population of new shoots by the end of grazing, its effect on subsequent herbage regrowth is largely determined by the energy balance of the plants during grazing. This will affect the state of the root system at the end of grazing and, as a consequence, the partitioning of assimilate between tops and roots during the regrowth period. Energy balance of course is closely linked to leaf area. The second reason is that herbage production during grazing - being largely determined by new shoot development, which is of course both sigmoidal and halted by apex removal - would be adversely affected by sustained close decapitation of the new shoots throughout the grazing period.

The pattern of defoliation then should not be overlooked in a consideration of GD effects.

The shoot population studies demonstrated the capacity of 'Wairau' lucerne to maintain a high population of shoots throughout grazing periods of up to 30 days. There were clearly a large number of sites for independent shoot development on the crown and stubble bases of the mature lucerne and then, once decapitation of the new independent shoots commenced, subtended shoot development was initiated. It seems fairly clear that, provided the energy balance of the plant was not allowed to fall too low (by maintaining a reasonable leaf area), 'Wairau' lucerne could maintain a high population of entire (undecapitated) shoots through grazing periods considerably longer than 30 days.

The practical implications of this project to lucerne grazing management are important. It has long been suspected that maximum total lucerne production over a full season would only occur under a system involving very quick grazings, i.e. very short GDs, and this has been proved in this project. However, the magnitude of the effect of longer GDs was not known and quantification of this alone has been worthwhile. The impact of the 10-15 day GDs on total lucerne production was sufficiently small to make the adoption of longer GDs, than the recommended 2-4 days, an attractive proposition in many circumstances. A 10-14% reduction in total lucerne yield may well be considered a reasonable price to pay for a less intensive system involving 10-15 day GDs rather than the idealistic one involving 2-4 day GDs.

In contrast to the effects on total lucerne production (i.e. sum of stem, leaf and new shoot yield) are the effects of GD on non-stem lucerne production (i.e. leaf and new shoot yield only). Here, the absence of a significant GD effect on production over a 6-8 month period in all but one of the four trials indicates how unwise it would be to extrapolate directly the effects of GD on total lucerne production to animal production. Since the stem is the least digestible fraction of lucerne herbage, it seems fairly clear from these results that the effects of GD on animal production could be less than the effects on total herbage production. Further, since different classes of stock have different abilities to digest stem material, the effect of GD on animal production is likely to be governed by the class of stock grazing the lucerne. For example, a system involving GDs of 30 days is not

likely to reduce the production from young weaned lambs because only the fraction of herbage which is virtually indigestible to these animals will be affected. However, the same system may well significantly reduce production from mature sheep for much of the stem fraction is digestible by these animals and therefore long GDs will have the effect of reducing the yield of utilisable herbage for this class of stock.

These comments of course ignore the behavioural responses of the animals to the different stock concentrations and frequencies of shifting implicit in different GDs. Generally, young animals in particular react favourably to a reduction in crowding and frequency of disturbance so it is entirely conceivable that, if longer GDs do not reduce utilisable feed for a particular class of stock, they may well increase animal production relative to very short GDs.

All this can be summarised into a simple statement. When grazing lucerne under conditions favouring rapid herbage growth, maximum production from mature animals will probably be achieved under relatively short GDs, although it appears likely the idealistic recommendation of 2-4 day GDs can be relaxed to GDs of about 10 days with little appreciable effect on animal performance. However, maximum production from very young stock is more likely to result under longer GDs - possibly of up to 30 days. Under dry conditions the impact of GD is reduced and, if necessary, these recommended GDs can probably be increased somewhat with little additional effect on animal production.

Throughout this project regrowth periods have been of sufficient length to allow the lucerne to reach the 1% flower or basal shoot appearance stage. In all the discussion of the results it has been a basic assumption that this policy will be adhered to because, as stated in the Introduction, the concept of spelling lucerne to this stage is internationally accepted as essential for both maximum herbage and animal production - and it is readily integrated into a grazing system.

This whole project has been conducted with one variety of lucerne - New Zealand Certified 'Wairau'. The relevance of the findings to other varieties is an important question. Varietal differences have been found in the response of lucerne to harvesting at immature stages (Gross *et al* 1958, Brown 1963, Iversen 1967) and the pattern has generally been for the dominantly *M. sativa* types to be more susceptible to this

type of mismanagement than the dominantly *M. falcata* types. The reasons proposed for the greater resilience of the *M. falcata* types have either implicated the greater residual leaf area of these more prostrate types (Keoghan 1967) or the slower rate at which they seem to reduce their root reserves following cutting (Brown 1963). However, the two reasons are probably quite closely related.

It is possible there could be some small differences in varietal response to GD. In view of the way in which GD appears to influence lucerne, it seems likely that the factor(s) governing any varietal responses to GD may be similar to the factor(s) which appears to influence varietal response to immature harvesting. Thus a variety with a high leaf:stem ratio and a relatively even distribution of leaf area through the profile may be less affected by GD than a very stemmy variety with its leaf area concentrated in the upper part of the canopy. However, any varietal differences in response to GD are only likely to be in degree of expression and will probably be rather small.

SUMMARY

This project was conducted to study the influence of grazing duration (GD) on lucerne. GD was simply the duration of a grazing, or the period over which defoliation continued before uninterrupted regrowth was again permitted. New Zealand Certified 'Wairau' was the cultivar used throughout the project and each grazing (actual or simulated) commenced only when the lucerne had reached the 1% flower/basal shoot appearance stage.

A field trial was conducted for eight months through the spring, summer and autumn at Palmerston North, New Zealand. Irrigation reduced soil moisture fluctuations through the season and sheep were used for all grazing treatments. The trial examined three grazing durations : 2-4, 15 and 30 days.

At the start of each grazing, the first new shoots were just beginning to appear at the base of the sward. At each grazing the pattern of mature herbage consumption was the same - stem apices and upper leaves first, followed by middle leaves and upper stems, then lower leaves

and much more slowly the middle and lower stem material. Removal of the upper stem and leaf fraction stimulated new shoot development at the base of the sward. Shoot numbers and size increased quickly such that, on the 15 and 30 day GD treatments as the last of the leaf material on the mature herbage was consumed, the stock began 'topping' the rapidly elongating new shoots. The stock continued to do this while grazing the remaining stem material. It was found that decapitation of these new shoots (independents) stimulated development of at least one new shoot (a subtended) on each of the decapitated 'stumps' as well as generating further independent shoot development on the crown, stubble and extreme bases of the mature stems. At the end of the 15 and 30 day grazing periods, a large shoot population with a significant leaf area had developed below grazing height and was poised to commence uninterrupted development with the start of the regrowth period. On the 2-4 day GD however, there was insufficient time for any new shoot development before grazing ceased so on this treatment the regrowth period started with only a very small number of very small shoots with a negligible leaf area.

Following the 2-4, 15 and 30 day GD treatments, the lucerne regrew to the 1% flower/basal shoot appearance stage again but treatment differences in herbage absolute growth rates were evident through the first half of the regrowth period. Maximum absolute growth rates through this period were recorded following the 15 day GD treatment. The initial inertia following the 2-4 day GD treatment was attributed simply to the very low shoot numbers, shoot size and leaf area on this treatment when the regrowth period started, but the reason for the initially depressed absolute growth rates following the 30 day GD was not clear.

To monitor shoot development through the grazing and regrowth periods of all three GD treatments, detailed shoot population studies were conducted. Within the basal shoot class the time at which a shoot arose was the most important factor governing its subsequent growth rate and ultimate size. Shoots arising more than 10 days before or 5 days after the end of grazing made little contribution to yield. If they arose too early, all the largest and fastest growing shoots were decapitated and if they arose too late they were severely suppressed apparently by their slightly older neighbours which quickly achieved dominance. Thus the major yield contribution came from shoots arising around the end of the grazing period.

As GD increased from the minimum of 2-4 days to the maximum of 30 days, the proportion of independent shoots in the regrowth population declined and the proportion of subtended shoots increased. However, a comparison of these two shoot classes revealed that independent and subtended shoots of the same age had the same growth rate through the regrowth period, grew to the same ultimate size and sustained the same level of mortality.

In the second half of the regrowth period, basal shoot numbers decreased slightly with the greatest mortalities occurring amongst the shoots which had been the last to arise in the regrowth period.

Stubble shoots throughout the grazing and regrowth periods on all three treatments were few in number and light in weight (contributing only about 5-6% or less to total shoot weight). Their growth rate was low, they had a slightly later pattern of appearance than basal shoots and poor survival through the latter half of the regrowth period.

These shoot population studies established conclusively that the initial difference in herbage growth rates following the 15 and 30 day GD treatments could not be attributed to either the size or composition of the shoot population at the end of grazing.

The total production of lucerne herbage over the full eight month period of the trial was highest under the 2-4 day GD system, 14% lower under the 15 day GD system and 29% lower under the 30 day GD system. However, these differences were generated almost entirely by differences in stem yield for there were no significant differences between the three GD treatments in the total production of non-stem (i.e. leaf and new shoot) material.

Three studies were then conducted, one in each of three large controlled environment rooms, to examine the impact of GD on lucerne under more controlled conditions than had been possible in the field trial and in particular to examine GD effects on the size, composition and functioning of the underground organs. A further objective was to examine the interaction of at least one climatic factor with GD effects. In each room a different 'climate' was imposed and in each 'climate' three GD treatments applied. The three 'climates' or environments were (with abbreviations in brackets) :

spring	-	cool and wet	16°/10°C	(Cool)
wet summer	-	warm and wet	22°/12°C	(W-Wet)
dry summer	-	warm and dry	22°/ 12°C	(W-Dry)

The three GD treatments were - instantaneous defoliation, i.e. zero GD, 10 days and 30 days - and they were imposed by a simulated grazing technique. This involved progressive defoliation with hand shears to mimic as closely as practical the actual pattern of defoliation recorded in the field trial under sheep grazing.

The results of these studies effectively confirmed the findings of the field trial on the response of lucerne top growth to GD. Although the magnitude of some of the responses were occasionally different from the field trial, the overall trends and general pattern were unquestionably the same. In the W-Wet and Cool rooms the characteristics of the herbage and its response to GD in all respects was very similar to the lucerne in the field trial. In the W-Dry climate a very different type of herbage canopy developed and, although the effects of GD on shoot numbers and shoot development were very similar to the field trial, the effects of GD on herbage regrowth rates and total yield were less than in either of the other two rooms or in the field trial.

In the W-Wet and Cool rooms root weights decreased under all three GD treatments with the removal of the mature herbage to reach minimum levels 1-3 weeks into the regrowth period before increasing again to reach their original levels by the end of the regrowth period at the 1% flower stage. In both rooms root weight following the 30 day GD fell to the lowest level but was also the first to begin increasing again. Herbage mineral analyses indicated regrowth on the three GD treatments was not being differentially affected by the capacity of the root system for mineral uptake. In addition, acetylene reduction measurements demonstrated substantial reductions in nitrogen fixation with the removal of the mature herbage, but showed quite clearly that rates increased quickly again on all three GD treatments during the first half of the regrowth period and there was certainly no evidence of impaired nitrogen fixation following the 30 day GD.

Under each of the three GD treatments, total non-structural carbohydrate (TNC) and starch percentages in the roots decreased significantly in both the W-Wet and Cool rooms with the removal of the

mature herbage to reach minimum levels at about the same time in the regrowth period as minimum root weight occurred, before increasing again to reach their original levels at the 1% flower stage. When these changes in the roots were linked with concurrent changes in the tops, it was found that the more depleted the root system at the start of the regrowth period, the shorter the time before, and the lower the leaf area at which, restoration of root weight, TNC and starch concentrations commenced during regrowth. It was also found that, despite differences in herbage growth rates, the three GD treatments generated the same total plant weight increases and Net Assimilation Rates through the regrowth period. As a result of these findings and evidence from the literature, it was concluded that some mechanism, which was apparently influenced by the degree of depletion of the root system at the start of the regrowth period, was affecting the partitioning of assimilate between the tops and roots of the lucerne during regrowth. It was considered that differences in the partitioning of assimilate between the tops and roots were largely responsible for differences in the effects of intermediate (10-15 day) and very long (30 day) grazing durations on top weight increases through the first half of the regrowth period.

Although the pattern of GD effects on root size, composition and functioning was similar in all three rooms, the magnitude of the effects in the W-Dry room was generally smaller than in the other two rooms. The results from the W-Dry room strongly suggested that, as conditions become drier, the impact of GD in a lucerne system will be reduced.

Finally, this project has shown that the morphology of the plant and the grazing pattern of stock preclude high lucerne growth rates under grazing. Thus maximum herbage production will be achieved only under systems of very quick grazing, i.e. 2-4 day GDs. However, because production of the most digestible fractions of the herbage is least affected by extending the GD, longer grazing durations of 10-15 days and, for very young stock, even up to 30 days, are likely to have much less effect on animal production than total herbage yields would suggest.

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APPENDIX 1. Herbage data at first harvest (Nov.9).
(wts. or yields in g/m², leaf areas in cm²/m², counts are per m²)

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% 1%
tot.hrbg.wt. #	339.80	335.12	311.19	8.5	48.09 72.83
tot.stem wt.	205.48	211.67	189.55	13.1	45.82 69.40
tot.leaf wt.	134.36	123.44	121.65	9.2	20.19 30.58
tot.leaf area	40558	36971	35868	11.5	7519 11388
stem length(cm)	41.2	41.9	41.2	3.1	2.24 3.39
Top half					
stem wt.	66.34	67.88	62.76	9.8	11.17 16.92
leaf wt.	112.88	92.87	103.45	11.8	21.01 31.82
leaf area	32575	25050	29052	14.1	7035 10655
Bottom half					
stem wt.	139.15	143.80	126.79	14.9	35.20 53.31
leaf wt.	21.48	30.57	18.20	16.3	6.60 9.99**
leaf area	7982	11922	6815	20.5	3158* 4783
Flowering stage	11.1% bud	9.7% bud	4.4% bud	86.7	12.6 19.1
Basal shoots:					
number	101	126	21	51.3	73.0* 110.6
weight	0.73	0.89	0.11	94.4	0.93 1.41
Stubble shoots:					
number	-	-	-	-	-
weight	-	-	-	-	-

mature herbage only ie. excludes any new shoots at the base of the sward

APPENDIX 2. Calculation of adjusted plot values for absolute growth rate (AGR) of herbage during the regrowth period : Day 0-18.

	unadjstd plot value for AGR	unadjstd means	calculated residual (y)	days from Nov.9 (X′)	adjstd day no. (Jan.8)	regression residual	adjstd plot value for AGR	adjstd means
1st cycle								
Tmt 1	8.33	7.20	0.29	20	-40	-1.32	7.01	5.88
	7.08		0.77	"	"	"	5.76	
	6.60		0.61	"	"	"	5.28	
	6.79		-0.11	"	"	"	5.47	
Tmt 2	15.08	14.07	0.79	33	-27	-0.90	14.18	13.17
	14.54		1.98	"	"	"	13.64	
	15.96		3.72	"	"	"	15.06	
	10.71		-2.44	"	"	"	9.81	
Tmt 3	13.54	9.73	4.51	48	-12	-0.40	13.14	9.33
	7.57		0.27	"	"	"	7.17	
	7.67		0.69	"	"	"	7.27	
	10.12		2.23	"	"	"	9.72	
2nd cycle								
Tmt 1	6.89	6.42	-1.15	64	+4	+0.10	6.99	6.52
	5.93		-0.38	"	"	"	6.03	
	6.47		0.48	"	"	"	6.57	
	6.39		-0.51	"	"	"	6.49	
Tmt 2	12.98	12.04	-1.31	86	+26	+0.82	13.80	12.86
	11.07		-1.49	"	"	"	11.89	
	8.05		-4.19	"	"	"	8.87	
	16.06		2.91	"	"	"	16.88	
Tmt 3	5.85	5.87	-3.18	114	+54	+1.74	7.59	7.61
	6.15		-1.15	"	"	"	7.89	
	5.67		-1.31	"	"	"	7.41	
	5.79		-2.10	"	"	"	7.53	

regression equation: $y = 1.9851 - 0.0327\ X'$

F value: 7.64* (approaching 1%)

Rep.	1	2	3	4	overall mean	Tmt	1	2	3
total	62.67	52.34	50.42	55.86	9.22	total	54.48	104.45	62.36
mean	10.45	8.72	8.40	9.31		mean	6.81	13.06	7.80
Rep. effect	1.23	-0.50	-0.82	0.09		Tmt effect	-2.41	3.84	-1.42

APPENDIX 3. Stubble shoot yield as % of total shoot yield - during the regrowth period.

	Day 0	Day 3	Day 8	Day 18
1st cycle				
Tmt 1	-	-	10.4	5.3
Tmt 2	< 1.0	3.9	3.3	1.2
Tmt 3	< 1.0	2.8	4.4	3.7
CV%	178.3	40.2	44.7	34.6
LSD 5%	1.8	3.1	4.7*	2.1
1%	3.3	5.6	7.1	3.1**
2nd cycle				
Tmt 1	-	1.6	2.2	2.7
Tmt 2	3.9	2.6	6.9	2.6
Tmt 3	1.6	2.9	1.7	0.4
CV%	119.6	117.5	50.8	79.9
LSD 5%	7.4	4.8	3.2	2.6
1%	13.6	7.3	4.8**	4.0

APPENDIX 4. Uniformity just before entry to CE rooms.

	W-WET	W-DRY	COOL	CV%	LSD 5% / 1%
Top wt.(g)	8.10	7.78	7.18	9.9	1.2 / 1.8
Root wt.(g)	13.9	13.8	12.8	5.8	1.3 / 1.8

APPENDIX 5. Uniformity harvest : W-WET.
(wts. in g/plant; leaf areas in cm^2/plant)

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% / 1%
tot.hrbg.wt.	10.70	11.64	11.30	6.0	1.10 / 1.58
tot.stem wt.	6.82	7.59	6.98	7.4	0.86 / 1.23
tot.leaf wt.	3.88	4.05	4.32	9.7	0.64 / 0.92
tot.leaf area	1122	1206	1305	13.5	272 / 392
top or 1st ¼					
stem wt.	1.21	1.19	1.12	19.0	0.36 / 0.52
leaf wt.	2.43	2.38	2.68	8.7	0.35 / 0.51
leaf area	662	594	717	13.3	147 / 211
2nd ¼					
stem wt.	1.51	1.62	1.61	11.9	0.30 / 0.44
leaf wt.	1.13	1.02	1.17	19.5	0.35 / 0.50
leaf area	341	347	403	19.9	121 / 173
3rd ¼					
stem wt.	1.91	2.07	1.88	13.2	0.42 / 0.60
leaf wt.	0.28	0.52	0.34	33.4	0.20* / 0.29
leaf area	100	205	129	36.2	85* / 122
4th ¼					
stem wt.	2.19	2.70	2.37	5.8	0.23 / 0.33**
leaf wt.	0.04	0.14	0.13	51.7	0.09* / 0.12
leaf area	19	61	57	57.8	42 / 61
Residual					
stem wt.	1.86	1.74	1.80	10.2	0.29 / 0.42
leaf wt.	-	-	0.01		
Flowering stage	64% bud	72% bud	52% bud		
Basal shoots:					
number	2	1	1		
weight	0.01	0.04	0.01		
stubble shoots:					
number	-	-	1		
weight	-	-	< 0.01		

APPENDIX 6. Uniformity harvest : W-DRY.
(wts. in g/plant; leaf areas in cm^2/plant)

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% / 1%
tot.hrbg.wt.	4.26	3.84	4.40	13.3	0.91 / 1.31
tot.stem wt.	1.88	1.74	1.92	13.8	0.42 / 0.61
tot. leaf wt.	2.38	2.10	2.48	14.5	0.55 / 0.80
tot.leaf area	428	393	480	13.0	93 / 134
top or 1st ¼					
stem wt.	0.34	0.36	0.27	31.3	0.17 / 0.24
leaf wt.	0.90	0.78	0.87	28.9	0.40 / 0.58
leaf area	153	105	130	22.8	48 / 69
2nd ¼					
stem wt.	0.36	0.29	0.35	18.6	0.10 / 0.15
leaf wt.	0.65	0.56	0.74	21.2	0.22 / 0.32
leaf area	103	117	140	24.3	48 / 68
3rd ¼					
stem wt.	0.47	0.45	0.53	16.9	0.14 / 0.19
leaf wt.	0.50	0.43	0.57	19.0	0.16 / 0.23
leaf area	104	90	131	20.1	36 / 52
4th ¼					
stem wt.	0.71	0.64	0.77	12.0	0.14 / 0.20
leaf wt.	0.33	0.33	0.30	27.2	0.14 / 0.21
leaf area	68	81	79	28.0	36 / 52
Residual					
stem wt.	2.10	1.98	1.86	16.6	0.52 / 0.75
leaf wt.	0.04	0.04	0.06	66.8	0.05 / 0.07
Flowering stage	67% bud	42% bud	57% bud		
Basal shoots:					
number	16	19	13		
weight	0.12	0.20	0.11		
Stubble shoots					
number	-	-	-		
weight	-	-	-		

APPENDIX 7. Uniformity harvest : COOL.

(wts. in g/plant: leaf areas in cm^2/plant)

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% 1%
tot.hrbg.wt.	12.68	12.02	13.29	10.4	2.14 3.07
tot.stem wt.	7.42	6.86	7.60	11.7	1.38 1.99
tot.leaf wt.	5.26	5.16	5.69	11.4	0.99 1.42
tot.leaf area	1317	1381	1494	8.7	197 284
top or 1st ¼					
stem wt.	1.41	1.38	1.52	31.9	0.74 1.06
leaf wt.	3.32	3.41	3.81	16.7	0.94 1.35
leaf area	656	774	786	14.1	168 240
2nd ¼					
stem wt.	1.71	1.39	1.52	14.9	0.37 0.53
leaf wt.	1.05	0.84	0.97	16.7	0.26 0.37
leaf area	330	268	322	18.5	93 133
3rd ¼					
stem wt.	1.93	1.59	1.97	5.7	0.17* 0.24
leaf wt.	0.63	0.48	0.68	20.8	0.20 0.29
leaf area	239	168	290	20.3	77* 111
4th ¼					
stem wt.	2.37	2.50	2.58	8.2	0.33 0.47
leaf wt.	0.26	0.43	0.23	26.3	0.13* 0.18
leaf area	92	171	96	24.7	47 68**
Residual					
stem wt.	1.88	1.74	1.84	6.0	0.17 0.25
leaf wt.	0.01	0.01	0.01		
Flowering stage	51% bud	54% bud	50% bud		
Basal shoots					
number	2	1	1		
weight	0.01	0.01	0.01		
Stubble shoots					
number	-	-	-		
weight	-	-	-		

APPENDIX 8a,b&c. Leaf area changes during 'grazing'.

(the figures are leaf area, in cm^2, in the different herbage fractions immediately before the 'bite' due on the day listed at the head of the column)

Appendix 8a : W-WET

Treatment 2

		Prior	Day 3	Day 6	Day 10	CV%	LSD 5% / 1%
Mature herbage	2nd ¼	368	395			18.0	119 / 180
	3rd ¼	175	169	196		28.6	82 / 119
	4th ¼	40	90	128	141	46.3	71* / 100
	Residue	-	14	-	-		
New shoots	Basal	1	-	15	50	30.2	17 / 25**
	Stubble	-	-	6	5		

Treatment 3

		Prior	Day 10	Day 15	Day 20	Day 25	Day 30	S.E.#	LSD 5% / 1%
Mature herbage	2nd ¼	328	423					1.3	165 / 252
	3rd ¼	103	152	238				1.7	122 / 207
	4th ¼	15	19	49	59			2.7	39* / 60
	Residue	6	-	-	-				
New shoots	Basal	3	47	122	229			1.9	115 / 165**
	Stubble	-	17	16	32			1.7	19 / 28
	total leaf area after each of the three 2 cm 'bites'				9	31	37	2.1	23 / 29**

\# analysis performed on logarithm transformations

Appendix 8b : W-DRY

Treatment 2

		Prior	Day 3	Day 6	Day 10	CV%	LSD 5% / 1%
Mature herbage	2nd ¼	102	117			35.6	67 / 102
	3rd ¼	101	158	65		30.8	51 / 74**
	4th ¼	90	122	112	84	31.1	49 / 69
	Residue	12	19	29	15	90.7	26 / 37
New shoots	Basal	46	57	60	116	33.8	36 / 51**
	Stubble	4	16	17	29	49.7	12 / 17**

Treatment 3

		Prior	Day 10	Day 15	Day 20	Day 25	Day 30	CV%	LSD 5% / 1%
Mature herbage	2nd ¼	81	107					13.6	22* / 33
	3rd ¼	102	85	152				18.0	32 / 47**
	4th ¼	91	87	96	97			30.2	43 / 61
	Residue	18	16	18	8				
New shoots	Basal	23	58	67	85			25.4	23 / 32**
	Stubble	1	9	6	8				
total leaf area after each of the three 2 cm 'bites'					36	57	87	18.4	18 / 25**

Appendix 8c : COOL

Treatment 2

		Prior	Day 3	Day 6	Day 10	CV%	LSD 5% / 1%
Mature herbage	2nd ¼	490	427			15.0	119 / 180
	3rd ¼	310	315	281		12.9	62 / 89
	4th ¼	52	63	59	149	29.2	36 / 51**
	Residue	-	-	-	-		
New shoots	Basal	10	8	21	65	31.0	12 / 17**
	Stubble	4	1	7	10		

Treatment 3

		Prior	Day 10	Day 15	Day 20	Day 25	Day 30	CV%	LSD 5% / 1%
Mature herbage	2nd ¼	512	590					5.7	54* / 82
	3rd ¼	235	180	273				20.3	74* / 107
	4th ¼	50	72	109	115			16.2	22 / 30**
	Residue	-	-	-	-				
New shoots	Basal	2	20	54	126			28.3	30 / 43**
	Stubble	-	4	11	28			33.3	8 / 11**
	total leaf area after each of the three 2 cm 'bites'				21	12	28	33.7	11 / 16**

APPENDIX 9. Stubble shoot numbers as a percentage of total shoot numbers during the regrowth period.

	Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% / 1%
		W-WET			
Day 7	17.4	18.9	9.8	44.3	10.9 / 15.7
Day 14	15.2	16.5	13.5	31.4	7.6 / 10.9
Day 21	15.3	14.1	20.2	27.6	7.3 / 10.5
		W-DRY			
Day 7	16.6	9.1	4.7	43.1	7.0 / 10.0**
Day 14	14.0	12.4	4.9	45.9	7.7* / 11.0
Day 21	17.0	10.6	5.3	26.7	4.7 / 6.7**
		COOL			
Day 7	9.8	10.0	7.3	39.5	5.7 / 8.2
Day 14	11.0	15.3	2.8	26.1	4.0 / 5.8**
Day 21	10.5	14.3	6.5	37.4	6.2* / 9.0

Explanatory note to Appendices 10-24

The following tables present details of the number and weight of the different classes of basal shoots that were present at the start of 'grazing' (Prior), or arose either during 'grazing' or after 'grazing' in any of the specified five day intervals. Data on the stubble shoots follow the basal shoot results for each harvest.

All the data are expressed on a per plant basis and as the average of eight plants.

In any statistical analyses of individual basal shoot classes, subtending shoots plus any classes with fewer than 0.5 shoot/plant were not included because their contribution to total yield was so small. Nevertheless their contribution was recognised and they were included in the totals for the three main basal shoot classes and in any analyses performed on these totals.

APPENDIX 10. Shoot population studies.
W-WET : Tmt 1 - Preliminary harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)	Shoot growth rate (mg/day) ##
	Prior	2.2	13%	0.50	27%	0.23	12.8
During the regrowth period	1st 5	9.4	56%	1.25	67%	0.13	10.0
	2nd 5	4.6	27%	0.10	5%	0.02	2.5
	3rd 5	0.6	4%	0.01	1%	0.01	
Basal shoot totals		16.8		1.86			
	CV%	37.8		59.6		34.0	
	LSD 5%	1.6		0.28		0.03	
	1%	2.2		0.38		0.04	

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots #	2.7	14%	0.08	4%	0.03

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	-	1.1	1.6	-
%	-	41%	59%	-

t.s.wt. total shoot weight
t.b.s.wt. " basal shoot weight
\# the time of appearance of each stubble shoot was noted at harvest but because there were so few of them they were bulked for weighing
shoot growth rate is taken as average weight divided by number of days from labelling to Preliminary harvest

APPENDIX 11. Shoot population studies.
W-WET : Tmt.1 - Final harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	2.5	18%	1.61	28%	0.64
During the regrowth period	1st 5	8.7	62%	3.69	65%	0.42
	2nd 5	2.9	20%	0.36	6%	0.12
	3rd 5	-	-	-	-	-
Basal shoot totals		14.1		5.66		
	CV%	32.4		29.5		30.9
	LSD 5%	1.6		0.58		0.13
	1%	2.2		0.79		0.18

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	1.6	10%	0.10	2%	0.06

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	-	0.9	0.7	-
%	-	56%	44%	-

Comparison of Preliminary & Final harvest total shoot numbers:

	CV%	LSD 5%
Basal total	14.8	2.5 *
Stubble	34.7	0.8 **

APPENDIX 12. Shoot population studies.
W-DRY : Tmt.1 - Preliminary harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)	Shoot growth rate (mg/day)
	Prior	6.7	27%	0.62	49%	0.09	5.4
During the regrowth period	1st 5	10.3	41%	0.47	37%	0.05	3.8
	2nd 5	4.4	18%	0.12	10%	0.03	3.8
	3rd 5	3.9	15%	0.06	4%	0.02	
Basal shoot totals		25.3		1.27			
	CV%	46.0		61.6		30.7	
	LSD 5%	3.0		0.20		0.01	
	1%	4.0		0.27		0.02	

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	4.3	15%	0.08	6%	0.02

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	0.2	2.0	2.0	0.1
%	5%	46%	46%	2%

APPENDIX 13. Shoot population studies.
W-DRY : Tmt 1 - Final harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	6.2	30%	0.91	52%	0.15
During the regrowth period	1st 5	8.7	42%	0.71	40%	0.08
	2nd 5	4.5	21%	0.12	7%	0.03
	3rd 5	1.0	5%	0.01	< 1%	0.01
	4th 5	0.4	2%	0.01	< 1%	0.02
Basal shoot totals		20.8		1.76		
	CV%	51.2		108.7		51.3
	LSD 5%	2.7		0.49		0.03
	1%	3.7		0.66		0.04

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	2.5	11%	0.06	3%	0.02

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	0.1	1.7	0.7	-
%	4%	68%	28%	-

Comparison of Preliminary & Final harvest total shoot numbers.

	CV%	LSD 5%
Basal total	15.9	3.9 *
Stubble	47.2	1.7 *

APPENDIX 14. Shoot population studies.
COOL : Tmt 1 - Preliminary harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)	Shoot growth rate (mg/day)
	Prior	5.3	29%	1.98	53%	0.37	14.2
During the regrowth period	1st 5	9.6	53%	1.64	43%	0.17	8.1
	2nd 5	3.3	18%	0.14	4%	0.04	2.5
	3rd 5	-	-	-	-	-	-
Basal shoot totals		18.2		3.76			
	CV%	31.3		45.1		28.2	
	LSD 5%	2.0		0.59		0.06	
	1%	2.7		0.80		0.07	

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	2.3	11%	0.08	2%	0.03

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	0.3	1.2	0.8	-
%	13%	52%	35%	-

APPENDIX 15. Shoot population studies.
COOL : Tmt 1 - Final harvest.

		No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	3.9	28%	4.24	51%	1.09
During the regrowth period	1st 5	8.0	58%	3.58	43%	0.45
	2nd 5	2.0	14%	0.50	6%	0.25
	3rd 5	-	-	-	-	-
Basal shoot totals		13.9		8.32		
	CV%	30.8		36.7		24.0
	LSD 5%	1.5		1.06		0.15
	1%	2.0		1.44		0.20

	No.	No. as % of total shoots	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	1.1	7%	0.09	1%	0.08

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5
No.	0.2	0.7	0.2	-
%	18%	64%	18%	-

Comparison of Preliminary & Final harvest total shoot numbers:

	CV%	LSD 5%
Basal total	16.9	2.9 **
Stubble	41.8	0.8 **

APPENDIX 16. Shoot population studies.
W-WET : Tmt 2 - Preliminary harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep #	-	-	-	-	-
		subt'g	1.4	7%	0.04	2%	0.03
During the 'grazing' period	1st 5	- indep	3.6	18%	0.72	31%	0.20
		- subt'g	0.4	2%	0.01	-	0.02
	2nd 5	- indep	6.6	32%	1.20	51%	0.18
		- subt'g	-	-	-	-	-
During the regrowth period	1st 5	- indep	5.1	25%	0.27	11%	0.05
		- subtd'd	0.5	2%	0.03	1%	0.06
	2nd 5	- indep	0.9	4%	0.03	1%	0.03
		- subtd'd	1.9	9%	0.06	3%	0.03
	3rd 5	- indep	-	-	-	-	-
	Basal shoot totals		20.4		2.36		
		CV%	40.3		50.7		31.3
		LSD 5%	1.5		0.23		0.03
		1%	2.0		0.31		0.04
Relative contributions from the 3 main basal shoot classes		Indep	16.2	79%	2.22	94%	
		Subt'g	1.8	9%	0.05	2%	
		Subtd'd	2.4	12%	0.09	4%	

	No.	No. as % of total I&S shts ##	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	3.2	15%	0.10	4%	0.03

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	: 1st 5	2nd 5	3rd 5
No.	-	0.5	0.9	0.8	1.0	-
%	-	16%	28%	25%	31%	-

indep - independent, subt'g - subtending, subtd'd - subtended
I&S - independent & subtended shoots

APPENDIX 17. Shoot population studies.

W-WET : Tmt 2 - Final harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	1.0	6%	0.32	6%	0.32
		subt'g	0.4	2%	0.01	< 1%	0.02
During the 'grazing' period	1st 5	- indep	4.7	27%	2.69	48%	0.57
		- subt'g	0.6	3%	0.01	< 1%	0.02
	2nd 5	- indep	6.1	35%	2.13	38%	0.35
		- subt'g	-	-	-	-	-
During the regrowth period	1st 5	- indep	2.6	15%	0.29	5%	0.11
		- subtd'd	0.6	3%	0.06	1%	0.10
	2nd 5	- indep	0.6	3%	0.03	1%	0.05
		- subtd'd	0.8	5%	0.02	< 1%	0.03
	3rd 5	- indep	-	-	-	-	-
	Basal shoot totals		17.4		5.56		
		CV%	43.2		37.4		34.9
		LSD 5%	1.0		0.3		0.08
		1%	1.4		0.4		0.10
Relative contributions from the 3 main basal shoot classes		Indep	15.0	86%	5.46	98%	
		Subt'g	1.0	6%	0.02	< 1%	
		Subtd'd	1.4	8%	0.08	1%	

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	2.2	12%	0.16	3%	0.07

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	1st 5	2nd 5	3rd 5
No.	-	0.3	0.7	0.6	0.6	-
%	-	14%	32%	27%	27%	-

Comparison of Preliminary & Final harvest total shoot numbers

	CV%	LSD 5%
Basal total	13.7	2.8 *
Indep & Subtd'd	12.3	2.3 as.
Stubble	31.4	0.9 *

APPENDIX 18. Shoot population studies.
W-DRY : Tmt 2 - Preliminary harvest

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	7.9	24%	0.56	37%	0.07
		subt'g	1.5	5%	0.02	1%	0.01
During the 'grazing' period	1st 5	- indep	1.9	6%	0.18	12%	0.09
		- subt'g	-	-	-	-	-
	2nd 5	- indep	7.0	22%	0.48	32%	0.07
		- subt'g	-	-	-	-	-
During the regrowth period	1st 5	- indep	8.5	26%	0.21	14%	0.02
		- subtd'd	1.5	5%	0.02	1%	0.01
	2nd 5	- indep	2.9	9%	0.03	2%	0.01
		- subtd'd	0.4	1%	< 0.01	-	< 0.01
	3rd 5	- indep	0.6	2%	0.01	1%	0.01
	Basal shoot totals		32.2		1.51		
		CV%	50.3		58.6		42.5
		LSD 5%	2.2		0.13		0.02
		1%	2.9		0.17		0.02
Relative contributions from the 3 main basal shoot classes		Indep	28.8	89%	1.47	97%	
		Subt'g	1.5	5%	0.02	1%	
		Subtd'd	1.9	6%	0.02	1%	

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	3.8	11%	0.08	5%	0.02

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	: 1st 5	2nd 5	3rd 5
No.	-	-	0.5	2.1	1.0	0.2
%	-	-	13%	55%	26%	5%

APPENDIX 19. Shoot population studies.
W-DRY : Tmt 2 - Final harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	6.9	27%	0.66	34%	0.10
		subt'g	0.4	2%	< 0.01	-	0.01
During the 'grazing' period	1st 5	- indep	2.0	8%	0.24	12%	0.12
		- subt'g	-	-	-	-	-
	2nd 5	- indep	7.0	28%	0.66	34%	0.09
		- subt'g	-	-	-	-	-
During the regrowth period	1st 5	- indep	6.0	24%	0.31	16%	0.05
		- subtd'd	0.5	2%	0.03	2%	0.06
	2nd 5	- indep	2.2	9%	0.03	2%	0.01
		- subtd'd	0.2	1%	0.01	< 1%	0.03
	3rd 5	- indep	-	-	-	-	-
	Basal shoot totals		25.2		1.94		
		CV%	37.3		39.6		28.7
		LSD 5%	1.8		0.15		0.02
		1%	2.5		0.20		0.03
Relative contributions from the 3 main basal shoot classes		Indep	24.1	95%	1.90	98%	
		Subt'g	0.4	2%			
		Subtd'd	0.7	3%	0.04	2%	

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	2.2	8%	0.04	2%	0.02

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	:	1st 5	2nd 5	3rd 5
No.	-	-	0.4		1.6	0.2	-
%	-	-	18%		73%	9%	-

Comparison of Preliminary & Final harvest total shoot numbers:

	CV%	LSD 5%
Basal total	15.8	4.9 **
Indep & Subtd'd	15.2	4.5 *
Stubble	41.1	1.3 *

APPENDIX 20. Shoot population studies.
COOL : Tmt 2 - Preliminary harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	2.8	13%	0.80	21%	0.29
		subt'g	1.1	5%	0.02	1%	0.02
During	1st 5	- indep	2.6	12%	0.74	19%	0.28
the		- subt'g	0.2	1%	< 0.01		0.01
'grazing'							
period	2nd 5	- indep	6.2	29%	1.43	37%	0.23
		- subt'g	-	-	-	-	-
During	1st 5	- indep	5.2	24%	0.79	20%	0.15
the		- subtd'd	0.3	1%	0.04	1%	0.13
regrowth							
period	2nd 5	- indep	1.2	6%	0.02	1%	0.02
		- subtd'd	1.6	7%	0.05	1%	0.03
	3rd 5	- indep	0.4	2%	< 0.01		0.01
	Basal shoot totals		21.6		3.89		
		CV%	27.4		36.5		24.1
		LSD 5%	0.9		0.24		0.04
		1%	1.2		0.32		0.05
Relative contributions from the 3 main basal shoot classes		Indep	18.4	85%	3.78	97%	
		Subt'g	1.3	6%	0.02	1%	
		Subtd'd	1.9	9%	0.09	2%	

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	2.5	11%	0.10	3%	0.04

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	:	1st 5	2nd 5	3rd 5
No.	-	0.2	1.0		0.6	0.7	-
%	-	8%	40%		24%	28%	-

APPENDIX 21. Shoot population studies.
COOL : Tmt 2 - Final harvest.

			No.	No. as % of total basals	Tot. wt. (g)	Tot. wt. as % of t.b.s.wt.	Av. wt. (g)
	Prior	- indep	1.8	11%	0.89	11%	0.49
		subt'g	0.3	2%	0.01		0.03
During the 'grazing' period	1st 5	- indep	2.8	18%	2.06	26%	0.74
		- subt'g	-	-	-	-	-
	2nd 5	- indep	6.2	39%	4.06	50%	0.65
		- subt'g	-	-	-	-	-
During the regrowth period	1st 5	- indep	3.2	20%	0.88	11%	0.28
		- subtd'd	0.2	1%	0.05	1%	0.25
	2nd 5	- indep	0.9	6%	0.08	1%	0.09
		- subtd'd	0.5	3%	0.03	< 1%	0.06
	3rd 5	- indep	-	-	-	-	-
	Basal shoot totals		15.9		8.06		
		CV%	25.8		30.3		25.1
		LSD 5%	0.8		0.49		0.12
		1%	1.1		0.65		0.16
Relative contributions from the 3 main basal shoot classes		Indep	14.9	94%	7.97	99%	
		Subt'g	0.3	2%	0.01		
		Subtd'd	0.7	4%	0.08	1%	

	No.	No. as % of total I&S shts	Tot. wt. (g)	Tot. wt. as % of t.s.wt.	Av. wt. (g)
Stubble shoots	1.4	8%	0.14	2%	0.10

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	1st 5	2nd 5	3rd 5
No.	-	-	0.7	0.4	0.3	-
%	-	-	50%	29%	21%	-

Comparison of Preliminary & Final harvest total shoot numbers :

	CV%	LSD 5%
Basal total	17.1	3.4 *
Indep & Subtd'd	15.9	3.1 **
Stubble	33.5	0.7 **

APPENDIX 22. Shoot population studies.
W-WET : Tmt 3 - Preliminary harvest.

			No.	No. as % of total basals
	Prior	- indep	-	-
		- subt'g	1.2	4%
During the 'grazing' period	1st 5	- indep	0.2	1%
		- subt'g	2.6	9%
	2nd 5	- indep	0.5	2%
		- subt'g	3.0	10%
	3rd 5	- indep	1.0	3%
		- subt'g	1.2	4%
	4th 5	- indep	1.0	3%
		- subt'g	0.6	2%
	5th 5	- indep	2.3	8%
		- subt'g	-	-
		- subtd'd	2.0	7%
	6th 5	- indep	3.1	10%
		- subt'g	-	-
		- subtd'd	3.0	10%
During the regrowth period	1st 5	- indep	2.3	8%
		- subtd'd	6.7	22%
	2nd 5	- indep	-	-
		- subtd'd	-	-
	Basal shoot totals		30.7	
		CV%	32.1	
		LSD 5%	0.9	
		1%	1.2	

Relative contributions from the 3 main basal shoot classes

	No.	No. as % of total basals
Indep	10.4	34%
Subt'g	8.6	28%
Subtd'd	11.7	38%

	No.	No. as % of total I&S shts
Stubble shoots	3.9	11%

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5	4th 5	5th 5	6th 5	: 1st 5	2nd 5	3rd 5
No.	-	-	-	-	-	0.2	0.8	1.8	0.6	0.5
%	-	-	-	-	-	5%	21%	46%	15%	13%

Note: the following shoot population results from Treatment 3 in all three studies were accidentally destroyed; the Preliminary harvest shoot weight results & all the final harvest results.

APPENDIX 23. Shoot population studies.
W-DRY : Tmt 3 - Preliminary harvest.

			No.	No. as % of total basals
	Prior	- indep	-	-
		- subt'g	4.1	8%
During the 'grazing' period	1st 5	- indep	0.8	2%
		- subt'g	3.1	6%
	2nd 5	- indep	1.5	3%
		- subt'g	3.5	7%
	3rd 5	- indep	2.6	5%
		- subt'g	1.4	3%
	4th 5	- indep	2.1	4%
		- subt'g	0.3	1%
	5th 5	- indep	4.4	9%
		- subt'g	-	-
		- subtd'd	2.2	4%
	6th 5	- indep	5.9	12%
		- subt'g	-	-
		- subtd'd	4.1	8%
During the regrowth period	1st 5	- indep	3.8	8%
		- subtd'd	5.9	12%
	2nd 5	- indep	1.2	2%
		- subtd'd	2.6	5%
	Basal shoot totals		49.5	
		CV%	39.7	
		LSD 5%	1.2	
		1%	1.6	

Relative contributions from the 3 main basal shoot classes

	No.	No. as % of total basals
Indep	22.3	45%
Subt'g	12.4	25%
Subtd'd	14.8	30%

	No.	No. as % of total I&S shts
Stubble shoots	2.1	4%

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5	4th 5	5th 5	6th 5 :	1st 5	2nd 5	3rd 5
No.	-	-	-	-	-	-	1.1	1.0	-	-
%	-	-	-	-	-	-	52%	48%	-	-

APPENDIX 24. Shoot population studies.
COOL : Tmt 3 - Preliminary harvest.

			No.	No. as % of total basals
	Prior	- indep	-	-
		- subt'g	1.9	6%
During the 'grazing' period	1st 5	- indep	0.3	1%
		- subt'g	2.2	7%
	2nd 5	- indep	0.6	2%
		- subt'g	3.2	10%
	3rd 5	- indep	1.5	5%
		- subt'g	1.2	4%
	4th 5	- indep	1.3	4%
		- subt'g	0.5	1%
	5th 5	- indep	1.9	6%
		- subt'g	-	-
		- subtd'd	1.8	5%
	6th 5	- indep	4.4	13%
		- subt'g	-	-
		- subtd'd	2.8	8%
During the regrowth period	1st 5	- indep	1.9	6%
		- subtd'd	5.9	18%
	2nd 5	- indep	0.8	2%
		- subtd'd	1.1	3%
	Basal shoot totals		33.3	
		CV%	36.3	
		LSD 5%	0.8	
		1%	1.1	

Relative contributions from the 3 main basal shoot classes

	No.	No. as % of total basals
Indep	12.7	38%
Subt'g	9.0	27%
Subtd'd	11.6	35%

	No.	No. as % of total I&S shts
Stubble shoots	1.7	5%

Stubble shoot time of appearance:

	Prior	1st 5	2nd 5	3rd 5	4th 5	5th 5	6th 5	: 1st 5	2nd 5	3rd 5
No.	-	-	-	-	0.2	0.7	-	0.1	-	0.7
%	-	-	-	-	12%	41%	-	6%	-	41%

APPENDIX 25. Levels of phosphorus[#] and potassium[##] in soil samples taken halfway through (Preliminary harvest) and at the end (Final harvest) of the second cycle regrowth period : W-WET room only.

		Tmt 1	Tmt 2	Tmt 3	CV%	LSD 5% 1%
Preliminary harvest	P	24.8	24.3	22.5	10.5	4.0 5.8
	K	2	2	2		
Final harvest	P	24.8	22.0	24.5	10.1	3.8 5.5
	K	2	2	2		

\# Olsen test
\## Standard Ministry of Agriculture & Fisheries quick test for potassium

APPENDIX 26. Total soil nitrogen level in the W-WET and W-DRY rooms. (Average of 4 samples from each treatment in each room taken at the end of the second cycle of each treatment - expressed as a % of oven dry weight.)

W-WET	W-DRY	CV%	LSD 5% 1%
0.418	0.405	5.0	0.017 0.023

APPENDIX 27. The pattern of mature herbage removal during grazing (actual numbers from which Figure 6 was constructed - dry weights in g/m^2)

	Top half		Bottom half	
	stem wt	leaf wt	stem wt	leaf wt
Day		Treatment 2		
0	120.87	168.20	217.30	21.95
6	59.77	24.31	250.95	10.70
9	35.85	4.47	244.98	6.09
12	2.73	-	233.42	2.04
15	-	-	132.41	0.59
CV%	29.8	15.7	19.6	62.3
LSD-5%	26.12	17.88	65.23	7.94
-1%	37.54	27.07	91.49	11.13
Day		Treatment 3		
0	92.40	129.09	174.75	18.85
6	82.01	74.01	178.00	17.40
12	72.27	30.75	190.54	6.77
18	46.79	6.06	191.42	5.15
24	-	-	154.49	0.40
30	-	-	88.72	-
CV%	22.8	22.4	17.2	69.7
LSD-5%	26.76	21.47	42.42	13.31
-1%	38.47	32.51	59.50	19.14

APPENDIX 28. Leaf area changes during the grazing period (actual numbers from which Figure 7 was constructed - leaf areas in cm^2/m^2)

Day	Total leaf area	New shoot leaf area
	Treatment 2	
0	48,227	-
6	9,830	185
9	4,005	1,284
12	1,127	670
15	296	201
CV%	21.6	34.9
LSD-5%	4217	327
-1%	5914	469

Day	Total leaf area	New shoot leaf area
	Treatment 3	
0	43,234	43
6	25,810	-
12	9,965	998
18	2,616	839
24	387	331
30	645	645
CV%	30.6	57.2
LSD-5%	5355	644
-1%	7510	925

APPENDIX 29. Yield, leaf area and size of new shoots during grazing (actual numbers from which Figure 9 was constructed)

	Basal Shoots				Stubble
	Yield (DM g/m²)	leaf area (cm²/m²)	Wt/shoot (mg)	length (cm)	Shoot yield (DM g/m²)
Day			Treatment 2		
0	-	-	-	-	-
6	5.33	185	5.89	2.25	-
9	15.80	1157	9.13	3.28	1.17
12	16.16	585	10.76	3.71	0.56
15	13.81	178	8.54	2.99	0.55
CV%	30.5	29.7	16.9	23.5	91.8
LSD-5%	6.24	250	2.31	1.15*	1.21
-1%	8.97**	360**	3.33**	1.65	1.83
Day			Treatment 3		
0	0.42	43	4.52	1.56	-
6	3.40	100	6.30	2.40	-
12	15.47	967	7.76	3.65	-
18	23.47	839	12.98	4.48	0.13
24	26.68	331	11.80	3.24	0.26
30	31.10	645	13.10	3.50	0.56
CV%	21.3	57.9	22.3	14.6	106.6
LSD-5%	5.37	425	3.16	0.69	0.58
-1%	7.44**	588**	4.37**	0.95**	0.88

APPENDIX 30. Herbage yield during the regrowth period - first two cycles (actual numbers from which Figure 12 was constructed - yield in g/m^2 DM)

	Treatment 1	Treatment 2	Treatment 3
Day		1st cycle	
0	0.32	13.05	29.20
3	3.11	35.48	47.85
8	28.58	81.31	77.78
18	129.96	266.39	204.28
x	549.17	528.32	415.10
Day		2nd cycle	
0	0.22	14.36	31.66
3	3.15	31.54	44.39
8	33.57	88.31	65.17
18	115.79	231.15	137.24
x	444.43	411.29	279.43