EFFECTS OF GRAZING ON THE

GROWTH AND DEVELOPMENT OF

WHITE CLOVER (*Trifolium repens* L.)

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CHAPTER 1

REVIEW OF LITERATURE

Introduction

White Clover (Trifolium repens L.) has been a part of the pasture scene for many years (Erith 1924; Stapledon 1919-1928) and its distribution in temperate regions is world wide (Erith loc. cit.). Its value both as a legume contributing to the nitrogen cycle (Sears 1953) and as a forage for animals has long been recognised (Erith loc. cit.) and these are still the main reasons for its continued valuable contribution to temperate pastures today (Williams 1970). In the N.Z. grassland scene its continued contribution in the future has been emphasised (Watkin 1972).

Dry matter production per se is not a sufficiently accurate measure of the excellence of white clover (Cooper 1970). Particular attention in recent years has been paid to the reasons for the high nutritive value of white clover (Ulyatt 1971) which has been shown, on many occasions, to be superior to the ryegrasses in terms of liveweight gain (Joyce and Newth 1967; Ulyatt 1969) and in combination with the ryegrasses has been shown to enhance their nutritive value (Rae et al 1963; Rattray and Joyce 1969).

Although not unique to white clover one disadvantage of the species is its propensity to cause bloat particularly in cattle (Todd 1970). The oestrogenic properties of white clover are known to vary depending on several factors including variety and disease status but they are not clearly defined (Newton et al 1970).

1.1. The White Clover plant and its components.

White Clover is a stoloniferons legume which behaves more like an annual than a perennial (Williams 1945; Hollowell 1966). The plants possess a tap root system with adventitious roots arising from the nodes of stolons and the majority of nodules appear on the branches of the main and adventitious roots. The main stem is short but from its axillary buds develop stolons which grow rapidly along the ground surface and from which branches arise (Erith 1924). The axillary buds on the stolons sometimes develop into stolons or inflorescences. The development of stolons usually occurs in the spring or late summer-autumn whereas inflorescences are normally developed in mid-summer (Erith 1924) in response to a longer photoperiod (Thomas 1961).

The main stem and taproot do not appear to last longer than a year (Hollowell 1966), so that under grassland sward conditions a white clover plant normally consists of a main stolon growing forward from the apex and rotting at the basal end. This main stolon will generally bear daughter or branch stolons which will achieve physical independence when the main stolon decays (Erith 1924; Beinhart et al 1963; Hollowell

1966; Harvey 1970). Any particular part of the stolon does not appear to last longer than a year (Beinhart et al 1963) although specific reference to stolon death in cultivars other than Ladino clover were not found except for Grasslands 'Huia' where McCree and Troughton (1966) found that stolons began to die after three months in controlled environment conditions. Neither the severing of the primary stolons from the seedling plants, nor the prevention of growth of adventitious roots from the primary stolons markedly increased the longevity of the seedling and taproot (Hollowell 1966).

1.2. White Clover cultivars and experimentation.

The species White Clover (*Trifolium repens* L.) has a number of cultivars each of which has characteristics which differ from the other cultivars (Williams 1945; Harkess et al 1970). Some management systems favour the growth of certain cultivars for production and persistence and these cultivars will predominate in countries adopting such management systems. White Clover (cv. Ladino) for example, is used in the United States (Tesar and Ahlgren 1950) but in British Agriculture it has not performed well (Williams 1945; Davies 1970). Extrapolation from one cultivar to another, therefore, in response to defoliation for example, must consider cultivar differences.

A number of studies with white clover have been carried out in glass house or controlled environment conditions (Mitchell 1956; Carlson 1966b) with the hope that results from these studies may reflect responses under field conditions, but care in such extrapolation has been emphasised (Davidson et al 1970). Other experiments have involved pure stands of white clover in the field (Brougham 1958) rather than the more typical grass/clover associations, and still others have tried to simulate grazing using clipping techniques (Wolton et al 1970). These limitations must therefore be considered in any extrapolation to grazing conditions in the field.

1.3. The growth and development of White Clover.

In considering the growth of white clover as a whole it seems logical to reason that its growth will be a function of the growth of the individual components of the plant; the roots, stolons, petioles and leaves. These components and the factors influencing their growth will be dealt with in three sections. Stolons growth and development will be considered first because it is from the terminal buds of the stolons or axillary buds that leaves and petioles arise. Consideration of petiole and leaf growth and then root growth will follow. The influence of management on the growth and development of white clover will conclude the literature review.

1.3.1. Stolon growth and development.

In this section a discussion of the factors influencing the growth of a single stolon from a terminal bud is followed by a discussion of the factors which influence the growth of the axillary buds on that stolon into new stolons.

a. Stolon elongation.

Providing other factors are not limiting, the rate of elongation of a stolon is temperature dependent (Mitchell 1956; Beinhart *et al* 1963). Little stolon elongation occurs below temperatures of 5°C but in the range 20°-25°C maximum stolon elongation occurs. Rates of 0.5-0.6 cm/day have beenrecorded from primary stolons (Mitchell loc. cit.) in the spring (Beinhart *et al* loc. cit.) but during the summer, rates of elongation slowed to 0.5 cm/week probably because of moisture and temperature stresses (Beinhart *et al* loc. cit.).

Neither of the studies (Mitchell 1956; Beinhart *et al* 1963) were under sward conditions but the latter study was with spaced plants of ladino clover. No evidence of temperature stress in New Zealand causing reduction in stolon elongation has been cited.

Removing all the leaves from the stolons of young Grasslands 'Huia' seedlings caused a decrease in stem elongation (Mitchell 1956). At 72°F (22°C) the rate of stolon elongation was reduced by half from 0.5 cm to 0.25 cm/day after defoliation. The relative reduction at 53°F (12°C) after defoliation was less than at 72°F (22°C). Of the leaves, petioles and stolons defoliation caused the smallest percentage reduction in weight in the stolons at 72°F (22°C) and caused no decrease in dry weight per centimetre at 72°F (22°C) (Mitchell loc. cit.).

At 72°F (22°C) shading had a different reaction on stem elongation than at 53°F (12°C). Whereas stem elongation was reduced by shading to about 20% of that recorded under daylight intensity at 72°F (22°C), at 53°F (12°C) some stolons grew longer than under 'full light' conditions (Mitchell 1956). Little reduction in dry weight per centimetre at either 72°F (22°C) or 53°F (12°C) occurred. These experiments were done in controlled environment conditions and would probably be atypical of a grazed pasture situation because the whole plants were shaded. The mean temperature in the New Zealand summer is closer to 72°F (22°C) than 53°F (12°C).

b. Stolon branching.

The number of stolons and the length they attain vary with the age of the plant, the space allotted to it, the character of the soil and other conditions (Erith 1924). With subterranean clover stolon development was suppressed as plant density increased (Davidson and Donald 1958).

Competition for light may be the reason that fewer axillary buds develop into new stolons under conditions of high plant density (Davidson and Birch 1972), because increasing the light intensity from 1000 to 2000 ft. candles in controlled environment conditions increased the percentage branching in ladino clover (% branching = 100 x no. of primary nodes with branches/no. of primary nodes produced, Beinhart 1963).

A nearly inverse linear relationship existed between temperature and percentage branching in Beinhart's (loc. cit.) study so that at 50°F branches emerged from 71% of all primary nodes, whereas at 86°F only 14% of the buds developed branches. Beinhart (1963) also noticed in spaced plants of ladino clover that the percentage branching was greatest in the spring and early summer but decreased in summer and only increased as a result of tertiary branches in the autumn. The decreased summe branching did not appear to be because of a limited carbohydrate supply because branching increased in the autumn with a continued decline in sugar concentration, although in late autumn sugar concentration in the stolons increased.

Differences in percentage branching between strains within cultivars, however, can be genetic in origin (Beinhart et al 1963), and the propensity to branch has bee related to production and persistence (Gibson et al 1963). Greater dry matter production resulted from the greater number of growing points, and persistence was enhanced because of the greater number of plant units surviving the first generation of plants (Gibson et al loc. cit.). The lack of persistence in ladino clover has, however, also been related to high temperatures (Crowder and Craigmiles 1960), funga diseases (Grahame et al 1961), extent of flowering (Beinhart 1963; Chow 1966) and selective grazing (Taylor et al 1960).

Where defoliation results in a deeper penetration of light into the canopy axillary buds develop into new stolons (Brougham 1958), and under weekly defoliation a much branched ground cover developed in simulated subterranean clover swards (Davidson and Birch 1972). Close defoliation in ryegrass/white clover swards encouraged vigorous stolon branching (Haggar et al 1963) but once, during regrowth, the canopy closes with regard to light penetration, shading results in reduction of light intensity which in turn reduces the stolon formation and flower head formation (Zaleski 1970). After complete light interception the death of some of the newly initiated clover stolons begins and continues to occur while new stolons and their leaves are shaded (Hunt 1968). The same sort of effect of shading on the death of new tillers has been noted with short-rotation ryegrass (Mitchell and Coles 1955).

Like tillers on a grass plant, the daughter stolons are, for a time, dependent on the stolon from which they grow (Harvey 1970). Under ideal conditions of plant growth the leaves on a primary stolon synthesise sugars by photosynthesis and these contribute to a common assimilate pool in the primary stolon from which all active meristems draw and in particular these include stolon apices, expanding leaves, root apices, root nodules and flowers. The daughter stolons import less assimilate with increasing age, and when assimilate produced in the leaves of daughter stolons was traced by autoradiographic studies, very little radioactivity appeared within the parent plant (Harvey loc. cit.). In older and larger plants than were first used in Harvey's (1970) study, results suggested that, in contrast to the common assimilate pool developed in young plants (Hoshino et al 1964 cited Harvey 1970), carbohydrates move mainly towards the stolon apex. Some of the carbohydrates produced in the leaves of the main stolon are diverted downwards into the adventitious roots produced at the nodes (Chow 1966) and these adventitious roots were found mainly to support the growth of the secondary stolon produced at the same node (Chow loc. cit.). Presumably the support was with water and minerals since little export of assimilate would take place from the roots except, maybe, as a result of shading or defoliation.

This suggests that if water is a limiting factor the secondary stolons associated with adventitious roots will be those most likely to continue growth.

It is interesting to note that shading of stolon apices had no effect on their import of assimilate (Harvey 1970). Under pasture conditions, the intensity of light at the level at which stolon apices are growing is often very low (Mitchell and Calder 1958).

It is known that overgrazing of clover can result in the removal of varying proportions of the terminal growing points of clover stolons and that regrowth is then characterised by increased development of axillary meristematic zones followed by an increased number of leaves per unit area of the sward (Brougham 1966). Inhibition of the development of axillary buds, especially those close to the terminal bud, probably involves apical dominance.

Early workers in the field of apical dominance considered that it was as a result of an inadequate supply of assimilate to the buds (Goebel 1900; Loeb 1918; cited Phillips 1969). Subsequently it became clear that IAA (Indole Acetic acid) from the apex was involved and the possibility arose that IAA in some way prevented nutrients reaching the axillary buds, possibly by inhibiting vascular connections (Phillips 1969). However, in plants which show strong apical dominance, even under optimum growing conditions, it would seem likely that the supply of other hormones to the bud is the limiting factor (Woolley 1972) and that the supply of carbohydrate is not limiting (Jewiss 1972).

There is a suggestion (Harris and Brougham 1968) that the exclusion of white clover in areas of browntop pasture may be because the pasture is too dense either for the spread of stoloniferons growth into the browntop patch or because of the inability of the white clover to maintain itself within the patch of browntop. This physical density of browntop areas may cause stolons to be lifted off the ground and therefore be more susceptible to grazing.

1.4. Petiole and leaf growth.

As a stolon grows forward, leaves and sometimes flower heads are continually produced from the growing point. The leaves originate immediately behind the apices of the main stem and stolons; they are very closely crowded together encircling each other and the growing points (Erith 1924). When the leaves have fully developed within the growing point, the petiole begins to elongate, so the wave of growth occurs first in the leaf blades and then in the petioles and stem internodes (Mitchell 1956).

In undisturbed swards of white clover, leaf unfolding and petiole elongation are determined by the light environment (Brougham 1962). As sunlight passes through the clover canopy its spectral composition changes because of differential absorption of wavelengths. Infra red light and light of longer wavelengths penetrate to the base of the canopy where they stimulate cell division and elongation (Brougham loc. cit.). These processes are inhibited by red light, with a shorter wavelength, which the leaves and petioles encounter higher in the canopy.

As the petioles elongate the folded leaves are lifted into light of higher intensity. Unfolding of the laminae was found to occur in intensities between 100 and 500 ft. candles and cessation of cell expansion in both leaves and petioles occurred in light intensities of about 3000 ft. candles (Brougham loc. cit.). Petiole elongation generally continues until leaves are in a full-light environment so that earlier formed leaves are continually overtopped by those formed later (Brougham loc. cit.).

The processes of cell division and elongation are, however, temperature dependent (Brougham loc. cit.), so that an increase of $10^{\circ}F$ ($5.6^{\circ}C$) in the average daily air temperature from winter to late spring was paralleled by a graded eight fold increase in the rate of activity of these processes. The rate at which leaves appear therefore, the area and weight they attain, and the height in the canopy to which they are lifted depends on the season, and in particular on the temperature and light environments.

In the winter, in undisturbed swards of white clover, Brougham (1962) found that the rate of initiation of main leaf primordia (those leaves originating from terminal buds) to maintain an LAI (Leaf area index - one side only) of 1.5 was $2.5/ft^2$/day, and the average area and weight of these leaves was about 5 cm^2 and about 22 mg respectively. Corresponding figures for rate of bud initiation, leaf area and weight in the spring were 13 buds/ft^2/day, about 20-25 cm^2 and 85-100 mg respectively and in summer they were 10 buds/ft^2/day, 12 cm^2 and 40-50 mg respectively. In spring the LAI that was maintained at an initiation rate of 13 buds/ft^2/day from main leaf primordia, was about 6.4. The length of life of main bud leaves from marking to death in winter was about 56-66 days, twice the length of time that those in spring lasted. The reason given for the decreases which occurred during the summer was that "drier" conditions prevailed (Brougham 1962).

In these same undisturbed swards the area of leaf developing from axillary buds was 0.5 LAI in winter, three times the value at other times of the year. Exactly the opposite situation occurred for leaves developing from terminal buds (Brougham 1962).

For any particular stolon, at temperatures between 20-25°C, the rate of leaf appearance was about 1-1½ leaves/week (Mitchell 1956; Beinhart et al 1963; Carlson 1966a), whereas at temperatures of 5°-8°C the rate of leaf appearance slows to 0.3-0.6 leaves/week (Mitchell 1960; Brougham 1962).

Under moisture deficit and high temperature stress the rate of leaf appearance fell from 1.4 to 0.6 leaves/stolon/week (Beinhart et al 1963).

In controlled environment conditions the rate of leaf appearance from a main stolon and elongating axillary stolon were found to be similar (Mitchell 1956). On newly initiated stolons, or those which were not elongating their internodes, leaves were smaller in area than on main stolons (Mitchell 1956; Brougham 1958).

1.4.1. The influence of defoliation on leaf area development.

In a pure white clover sward defoliation to half an inch caused an increase in the rate of bud initiation (Brougham 1958) but the area of the leaves first formed were only half the area of those formed at ceiling LAI twenty days later. In controlled environment conditions removing all the leaves from white clover seedlings retarded the rate of leaf appearance from 1.3 to 1 leaf/week/primary stolon at 72°F (22°C) (Mitchell 1956), although in another experiment the rate of leaf appearance was about the same before and after defoliation (Carlson 1966b). In both these controlled environment experiments leaf area and weight were reduced by defoliation (Mitchell 1956; Carlson 1966b). In Carlson's (1966b) experiment where leaf removal at stage 0.9 (leaves nearly fully opened, Carlson 1966a) continued for 3 leaves from various seedling ages, the decrease in leaf area was greater the older the seedling from which leaves were first removed (Carlson 1966b). On cessation of leaf removal each succeeding leaf increased in area at a rate similar to that of non defoliated ladino clover plant seedlings (Carlson 1966c). However, the removal of one or two of the leaflets of the trifoliate leaves did not reduce the area of subsequent leaves significantly, whereas the removal of all three leaflets reduced the area of subsequent leaves. If the petiole was not removed with the three leaflets then, in a similar fashion to the partial leaf removal described, the initial decrease in the area of leaves was followed by an increase in the area of leaves. This, Carlson (1966b) suggested, may be the result of growth regulating substances influencing the utilisation of metabolites after defoliation or maintaining low level endogenous activities which may affect the production of metabolites by the developing leaf.

Two main explanations of the decrease in leaf area after defoliation have been given. One tries to relate the level of stored carbohydrate after defoliation to the areas of the subsequent leaves. However, Carlson (1966b) concluded that the level of carbohydrates did not directly influence leaf growth because a greater percentage of total available carbohydrates was present in older than younger ladino clover seedlings and also because the decrease, after defoliation, in the area of subsequent leaves was greater in the older seedlings. The other explanation for the leaf area decrease is that growth regulating substances are involved and that defoliation affects growth-regulator production (Carlson 1966c).

Defoliation reduced petiole length and weight (Mitchell 1956; Brougham 1958; Carlson 1966b) although petiole length and weight gradually increased during the regrowth of pure white clover stands in the spring to a leaf age of 27-33 days after terminal leaf bud appearance (Brougham 1958). Marked seasonal differences occurred in the heights reached by the uppermost leaves of the canopy (i.e. lengths of the longest petioles), there being a four to five fold increase in maximum petiole length from midwinter to late spring in undisturbed stands of pure white clover (Brougham 1962).

Reference has already been made to the development of axillary buds into new stolons following the increase in light intensity at stolon level as a result of defoliation (Section 1.3.1.b.) and this increased meristematic activity is associated with the production of a large bulk of axillary bud leaves (Brougham 1958). In continuously defoliated stands of white clover more of these axillary leaves are present than terminal bud leaves (Brougham 1966) although the area of each leaf is much smaller than those from terminal buds (Mitchell 1956; Brougham 1966). However, although the total leaf area present at a particular time was less for the continously defoliated swards than the undisturbed swards (Brougham 1966), in swards of subterranean clover the total net LAI harvested under a weekly defoliation treatment was greater than that for a monthly defoliated treatment which was greater than for the uncut treatment in an experiment which lasted for 16 weeks from germination (Davidson and Birch 1972). In this experiment the rapid and marked adaptation to weekly defoliation took the form of a large increase in the amount of dry matter remaining under the defoliation height (1.5 cm). This was mainly due to an increase in the stem component of the much branched ground cover that developed and was associated with a large increase in the number of sites for leaf production. This in turn was associated with rapid canopy development after defoliation to an LAI of 1 to 2, with effective light interception by small, young leaves, which are known to be more efficient photosynthetically than older leaves (Brown, Cooper and Blaser 1966). Under close defoliation therefore, secondary leaf area, (i.e. that developing from new stolons) must be relatively important. With spaced plants of ladino clover Beinhart (1963) found that the leaf area produced from primary and secondary stolons throughout the growing season showed firstly; that a majority of total harvested leaf area was from secondary stolons and secondly; that a majority of this secondary leaf area was from branches which originated from nodes early in the season. These results highlight the importance of secondary leaf area in the formation of an LAI sufficient to intercept all incident sunlight.

After defoliation and during regrowth the LAI increases, and within the limits set by moisture and temperature, a dynamic equilibrium develops between the light environment and leaf growth so that all light is intercepted by green leaf (Brougham 1958, 1962). Because of the relatively short life cycle of white clover leaves throughout the year, providing the regrowth period is sufficiently long, the maintenance of this dynamic equilibrium is associated with a continued pattern of leaf death and renewal (Brougham 1962). In pure stands of white clover the total LAI in the spring and winter at which this dynamic equilibrium occurs is approximately 7.0 and 2.0 respectively (Brougham 1962).

Rapid light extinction occurs after the development of the critical LAI (the LAI at which 95% of incident light is intercepted by the canopy foliage) in pure stands of white clover and grass/clover swards (Mitchell and Calder 1958; Stern and Donald 1962; Hunt 1968). This results in the shading of first formed leaves and leaves lower in the canopy.

1.4.2. The influence of shading on leaf area development.

Whereas with white clover seedlings under controlled environment conditions shading at both 72°F (22°C) and 53°F (12°C) reduced the rate of leaf appearance (Mitchell 1956), in ladino clover seedlings at 21-24°C the rate of leaf appearance was increased (Carlson 1966b) although shading was much more severe with the ladino clover seedlings and was also on an individual leaf basis compared with Mitchell's (1956) whole plant basis.

In general, however, shading causes etiolation in leaves and petioles (Mitchell 1956; Brougham 1965). After shading to 150 ft. candles was applied to three successive leaves of plants at various seedling ages, the first formed leaf was reduced in area but subsequent leaves increased in area at rates similar to undefoliated plants (Carlson 1966b). A steady increase in the size of successive leaves under shading occurred at 53°F in Mitchell's (1956) experiment but at 72°F shaded leaves were smaller than those in full light undefoliated plants. Leaf area was similar but leaf weight was less in white clover plants shaded by red clover than white clover in pure stands, although the lengths of the white clover petioles were longer in the red clover than in the white clover stands (Brougham 1965). Carlson (1966b) again implicates growth regulator substances as the main cause of this etiolation under shading conditions. Since shading reduces the import of assimilate into developing leaves (Harvey 1970) this may confirm Carlson's (1966b) hypothesis, because with less carbohydrate being imported and with leaves of equal or greater area being produced, unless specific leaf weight is reduced considerably, growth regulators would seem to be implicated.

Even the slight import of carbohydrates into mature white clover leaves ceased when these leaves were shaded to their compensation point (Harvey 1970) and this was suggested as the possible reason for leaf death, which is known to be accelerated under intense shading (Brougham 1962; Hunt 1968). It has been argued that, providing other factors are not limiting, complete light interception limits the net growth rate of white clover in ryegrass/white clover swards (Hunt 1968). The growth rate, when the critical LAI was reached, was limited by the efficiency of light utilisation of the canopy structure, by an increase in the rate of respiration relative to photosynthesis which results when relatively large areas of actively photosynthesing leaf rapidly become shaded, and by losses via leaf death (Hunt 1968 p.94). If the losses via leaf death are not recorded, then the net dry matter yield of subterranean clover swards for an uncut compared with a monthly cut and weekly cut treatment is found to be less for the uncut than the other two treatments (Davidson and Birch 1972). However, by theoretical calculation from rate of ^{35}S uptake, the uncut treatment can be shown to yield more than the other two treatments. The discrepancy lies in the lack of recorded leaf death.

1.4.3. The relationship of leaf growth to plant growth.

In trying to find a plant character in the selection of ladino clover plants which is correlated with plant yield, Beinhart et al (1963) suggested that leafiness would be one such character. Several measurable traits contribute to leafiness including leaf number, leaf size, stolon elongation and stolon branching frequency (Beinhart et al 1963).

Although an increase in temperature increased the rate of primary stolon leaf production but decreased stolon branching, moderate temperatures (62°F (16.7°C) and 74°F (23.3°C)) resulted in greater leaf production through a slower rate of primary leaf production but an increased branching frequency (Beinhart 1963). Over a wide range of temperature and light intensity, dry matter accumulation is proportional to leaf area in controlled environment conditions (Beinhart 1963). It is probable that if this relationship exists under sward conditions it does so only up to the stage when little leaf area has been lost by death and decay, since leaf area present at any particular time does not include a measure of leaf lost by death and decay.

1.5. Root growth.

At the end of the experiment reported in this thesis it was decided to measure the effects of the treatments on root weight distribution. The effects of defoliation, shading and moisture availability on root growth will be briefly reviewed in this section.

In hiw review, Troughton (1957) suggests that the depth to which roots penetrate during seedling growth increases rapidly and the maximum depth to which roots penetrate almost occurs within a year. In general, however, the greatest concentration of roots is in the surface layers of the soil. Quoting results from Klapp (1943), Troughton (1957) shows this distribution as in Table 1.1.

TABLE 1.1.

Percentage of roots as measured by dry weight in 10 cm soil layers under several swards.

Dominant species	Soil layer depths (cm) 0-10	10-20	20-30	30-40	40-50
Lolium perenne	80.3	9.3	4.6	3.5	2.3
Poa pratensis	61.8	28.7	4.5	4.0	1.0
Trifolium repens	82.4	5.9	8.1	2.6	1.0

By far the greatest percentage of root weight, especially in white clover, is in the top 10 cm of the soil profile.

On a weight basis, measurements on a one year old sward under moderate utilisation showed that the weight of roots to a depth of 10 cm was 1,010 lb d.m./acre for white clover and 3,200 lb d.m./acre for perennial ryegrass (Schuurman 1954 cited Troughton 1957).

1.5.1. The effects of defoliation on root growth.

The general effect of defoliation on pasture species including white clover, is to slow or stop root elongation and reduce root weight depending on the frequency and severity of defoliation (Jones 1933a; Mitchell 1956; Troughton 1957; Butler et al 1959; Carlson 1966b; Chu 1971; Evans 1971, 1972). Severe defoliation, by removing all fully expanded leaves, caused immediate gross changes in nodule colour from pink to green with visible loss of some nodules in white clover (Chu 1971), and defoliation to half an inch every 11 days resulted in the death of some older roots and nodules (Butler et al 1959). The result of defoliation therefore in young white clover plants was a decrease in the relative rate of nitrogen assimilation of the roots compared with non-defoliated plants.

Differences occur between species in their response to defoliation, the more erect growing species being more severely affected than the prostrate species (Evans 1971, 1973). It was notable that frequent defoliation caused cessation of root elongation in perennial ryegrass but not white clover and caused more roots to die in perennial ryegrass than white clover (Evans 1973). The continued root elongation of white clover was despite a greater percentage removal of lamina by defoliation to a height of 2.5 cm than in perennial ryegrass, and it was attributed to either a greater reserves storage capacity or a channelling of a greater percentage of reserves into continued root production of the clover compared with the ryegrass.

Adaptation to defoliation in terms of root growth, however, can occur even in prostrate growing species. Davidson and Birch (1972) found that with subterranean clover the effects of weekly defoliation on rate of uptake of ^{35}S became smaller and smaller. Although the immediate effect of defoliation was to reduce root weights relative to the uncut treatment the roots of both the monthly and weekly defoliated treatments soon grew as fast as those of uncut swards and final root weights were similar for all treatments (Davidson and Birch loc. cit.). This, however, may have been the result of the larger number of sites (i.e. nodes) for root initiation in the defoliated swards as is instanced by Butler et al (1959) who found that following defoliation, active regrowth of new leaves took place from the young stolons and at the same time new stolon roots grew rapidly and became heavily nodulated.

1.5.2. The effects of shading on root growth.

The visible effects of shading on root growth in pasture species and in nodule appearance in white clover appear less rapidly than those of defoliation (Butler et al 1959; Chu 1971; Evans 1971) although this depends on the extent of shading. In early seedling growth shading appeared to enhance root growth in ladino clover (Carlson 1966b), but in glasshouse conditions shading white clover plants was associated with the gradual colour change of nodules from pink to green and the browning of the corticol tissues of many roots, leading eventually to the death of roots and nodules (Butler et al 1959). In general it seems that the result of shading is an increase inthe shoot/root ratio (Troughton 1957; Evans 1971) through etiolation of the shoot.

1.5.3. The effects of soil moisture availability on root growth.

A deficiency of water results in poor growth of both roots and shoots (Troughton 1957). The addition of water to dry surface layers of soil causes rapid root proliferation in these layers (Jacques 1957; Troughton 1957; Garwood and Williams 1967) and may be accompanied by increased availability of surface nutrients to plants. (Mitchell 1957). The observation made by Erith (1924), that adventitious roots do not appear to grow from the nodes of wild white clover until the latter part of the summer, may in part, be due to the possibility that the dry and sometimes hard soil surface restricts root initiation and penetration. In ryegrass, in New Zealand, root initiation commences to fall away after October and may cease altogether during the drier part of summer (Jacques 1957), so it may be that in white clover also the lack of root initiation is of a seasonal nature.

Shoot growth was negligible and tiller numbers were depressed in ryegrass swards when 2" of water had been lost from the surface 12" of soil but many plants still survived (Garwood and Williams 1967). This was because plants could still absorb water from deeper layers. Since white clover has roots which extend just as deep as those of ryegrass (Jacques 1941) persistence under moisture stress can be expected providing moisture is available in these deeper layers.

1.6. The influence of management on the growth and development of white clover.

In practice white clover is most commonly found in association with grasses and so because of the varying degrees of competitive influence by the grasses, its response to grazing or cutting may not be the same as in pure swards. However, Harkess et al (1970) found that Grasslands 'Huia' in association with either S24 ryegrass or S48 Timothy and S215 Meadow fescue maintained its percentage contribution in the pasture over three years under a lax defoliation regime. When sown alone clover yielded more the first year compared with the clover in the clover/grass associations but in the second and third years the clover yield was lower in the so called pure clover swards compared with the clover/grass associations because of the entry of unsown grasses and dicotyledons which competed as effectively as sown companions.

Because, however, most studies on the influence of management involve pastures with both species present, they are important in the study of white clover, and in the following sub-sections emphasis is on the yield and contribution of white clover and its components to the pasture as influenced by the grazing animal. The effects of grazing or cutting, the return of dung and urine and treading on white clover will be dealt with separately.

1.6.1. The effects of grazing or cutting on white clover.

The effects of grazing involve consideration of both the frequency and intensity of defoliation. In a trial with four different frequencies and intensities of defoliation of ryegrass/white clover pastures, white clover yields were highest under frequent defoliations in all seasons (Brougham 1959). Long periods without grazing, particularly in winter when white clover grew very little, quickly resulted in its decreased contribution and yield (Jones 1933a; Brougham 1959). In the summer when temperatures were nearer the optimum for clover growth (Mitchell 1956; Brougham 1959b) and decreases in ryegrass growth occurred, frequent but less severe defoliation (i.e. from 7"-3" compared with 3"-1") increased the yield of clover (Brougham 1959; 1960). In contrast to these rotational grazing systems (Brougham 1959) where white clover displayed free running, loosely rooted stolons and a more erect habit of growth (Harris and Brougham 1968), in continuously grazed swards, more typical of hill country pastures (Suckling 1959), clover formed compact, prostrate plants. These marked differences in clover plant growth and habit were attributed to differences in the light environment of different swards and to the removal of stolons by grazing (Harris and Brougham 1968). Further, the clover node density in moderate and laxly grazed swards increased markedly in late summer because of the free growth of stolons through the grass but in the continuously grazed treatment the high grazing pressure restricted the expression of the temperature response of white clover (Harris and Brougham loc. cit.). There was also a negative correlation between the presence of Agrostis tenuis and white clover mentioned in Section 1.3.1.b. Nevertheless the clover node density relative to the percentage presence was higher in the continuously grazed sward than in the moderate and laxly grazed swards. Such continuous grazing can lead to the gradual selection of strains of clover that persist well under these conditions (Hawkins 1960).

The percentage presence of clover buds and clover bud number in established high producing sheep and dairy pastures was found to be higher than in the newly established pastures although the spread can be rapid and even through these new pastures

(Mitchell and Glenday 1958).

It is doubtful that experiments involving the measurement of white clover yield under a clipping regime can simulate those under grazing because of the ability of the animal, especially sheep, to prehend clover stolons lying close to the ground surface and the inability of the mowing or clipping machines to select or cut this component of the clover. Nevertheless clipping ladino clover and ladino clover/ orchard grass pastures down to $3\frac{1}{2}$" or 1" either two, four or six times a season resulted in greatest yields from the ladino clover clipped four times to 1" in the first year of growth (Tesar and Ahlgren 1950). In following years the treatment cut four times to $3\frac{1}{2}$" yielded the most and this was related to the weight of stolon present at the beginning of the season and to the weight of stolon at the end of the previous season. With ryegrass/white clover pastures clover regrowth was observed to be more rapid following cutting than grazing (Wolton et al 1970) suggesting that non selective defoliation by the mowing machine left clover in a stronger position to respond.

Under some systems of management, notably rotational grazing systems where grazing is less severe, grazing and clipping can yield similar results (Taylor et al 1960) but even here differences occur. For example, under clipping, yields of an orchard grass/ladino clover pasture subjected to defoliation over 1, 7 or 14 days were similar, whereas under grazing, yields were highest from pasture defoliated over 1 day than over the 7 or 14 day periods (Taylor et al loc. cit.). Ladino clover is, however, known to yield more and persist better under lenient defoliation (Brown 1939) or rotational grazing (Raguse et al 1971).

A further reason for the possible decrease in percentage contribution of white clover under grazing is that animals, particularly sheep, have a preference for this species (Hodge and Doyle 1967) and so the effects of clipping and grazing can be expected to differ.

1.6.2. The effects of dung and urine on clover growth.

Sears and Newbold (1942) demonstrated the importance of the return of dung and urine in the maintenance of soil fertility and pasture botanical composition. Both they and Watkin (1957) found that the return of dung and urine to pasture interacted to give a highly productive and well balanced grass/clover sward. However, without the inclusion of clover in the sward the pasture dry matter yield, even with the return of dung and urine, was low (Sears 1953). By including clover in the pasture but not returning dung and urine a dominantly clover pasture resulted. Jones (1933c) showed a similar dominance of white clover in plots that he grazed during the day but from which sheep were removed at night to other plots where most of the dung and urine was dropped. These night plots became grass dominant and yielded about twice as much as the day plots receiving much less dung and urine.

The return of dung alone tended to stimulate clover production and to increase pasture production (Sears and Goodall 1948; Watkin 1954). The return of urine alone also increased pasture production but the sward became grass dominant (Sears and Goodall loc. cit.; Watkin loc. cit.) and the return of both dung and urine together yielded at least as much as the additive effects of dung and urine separately, but the early stages of clover dominance were followed in later years by a progressive increase in the proportion of grass (Sears and Goodall loc. cit.). Part of the reason for these trends in botanical composition and yield is that the dung contains most of the phosphorous and calcium essential for good clover growth, whereas the urine contains approximately 70% of the returned nitrogen and 80% of the returned potash (Sears and Newbold 1942), which lead to a more rapid dry matter increase in grasses than in the clovers.

1.6.3. The influence of treading on clover growth.

In general, as the stocking rate increases the pasture production decreases through the direct effects of treading damage (Edmond 1958), but this decrease in yield is relatively small at the lower stocking rates and drier soil conditions (Edmond 1963), and is also decreased with an increase in the cover of herbage present in the winter and spring but not in the summer and autumn (Brown 1968a).

Heavy treading reduced the yield of white clover alone or with grasses in the summer but relatively more in the winter and at all stocking rates (Edmond 1964; Brown 1968b). This was due mainly to a decrease in the numbers of clover nodes (Edmond 1964). It was suggested by Edmond (1960) that active growth must reduce the treading damage which is the reason white clover is more tolerant to treading in the summer.

Conclusions.

From this review of literature it would seem that there is a lack of detailed information on white clover growth and development in a grazed pasture especially in terms of stolon growth and initiation after grazing.

Little information can be cited on the detailed pattern of stolon growth after terminal bud removal although this can in part be derived from the work of Brougham (1958, 1966). Whether or not Brougham's (1966) classification of axillary leaves is on the basis of knowledge that they were derived from axillary stolons or only on the basis of size is not certain (Brougham 1958). It has been suggested from the work of Beinhart (1963) and Davidson and Birch (1972) that a large proportion of the leaf area in defoliated swards could be of secondary origin and that it is because these axillary buds have formed stolons providing increased numbers of growing points that soon after defoliation an efficient actively photosythesising canopy develops.

CHAPTER 2

EXPERIMENTAL PROCEDURES

INTRODUCTION

The aim of the experiment was to study, in detail, the patterns of defoliation and regrowth of pure swards of N.Z. Grasslands "Huia" White Clover (*Trifolium repens* L.).

2.A. EXPERIMENTAL SITE

The experimental area was sited in the Agronomy area of Massey University's "Tuapaka" farm (Lat. 40°21'S, 61 m a.s.l.), 14 km from the campus. The soil type was a Tokomaru silt loam, of medium fertility in its natural state, but poorly drained due to the presence of a compacted horizon or fragipan within the profile at a depth of approximately 90 cm from the soil surface (Pollock pers. comm.).

The area of 0.5 ha was sown in early March 1971, after adequate cultivation, with 4.2 kg/ha of Grasslands "Huia" White Clover (*Trifolium repens* L.) and 157 kg/ha of serpentine superphosphate. "Feather-marked" white clover (Corkill 1971) was also included in the sowing at the rate of 1 viable seed/0.18 m^2 to facilitate individual plant studies. Carbetamex (May and Baker N.Z. Ltd.), a spray selective against most Graminae species, was applied late in July, and the first preparatory grazing was late in August. The third and last preparatory grazing ended on the 29th October 1971, after a paraquat application and after 204 kg of 30% potassic superphosphate had been applied in September.

2.B. EXPERIMENTAL TREATMENTS

Mixed aged ewes were allocated to the plots according to the amount of herbage present i.e. on a grazing pressure basis (X sheep/kg herbage dry matter). This was achieved by selecting two levels at which sheep would be offered herbage dry matter (henceforth d.m.), the two levels being 4% of bodyweight, an amount adequate for maintenance and growth requirements (Low pressure = LP treatment) and 2% of bodyweight (High pressure = HP treatment), an amount sufficient to meet maintenance requirements only (Coop 1961).

At each grazing pressure sheep remained on their plot for one of three grazing periods; 3 days, 6 days or 9 days. There were, therefore, six treatments (Table 2.1.)

TABLE 2.1.

	GRAZING PRESSURE	
GRAZING PERIOD	4% of bodyweight (LP)	2% of bodyweight (HP)
3 days	LP3	HP3
6 days	LP6	HP6
9 days	LP9	HP9

2.C. EXPERIMENTAL LAYOUT

The experimental area was divided into 18 plots (Fig. 2.1.) and the six treatments randomised in each of three block replicates.

2.D. EXPERIMENTAL PROCEDURES AND TECHNIQUES

2.D.1. INTRODUCTION

There were a total of four grazings over the experimental period (Fig. 2.2.) and at each grazing sheep were allocated to plots according to treatments.

Fig. 2.2.

GRAZING NO.	1	2	3	4
GRAZING BEGAN	Dec. 13th	Jan. 10th	Feb. 14th	Mar. 23rd

The first grazing began on December 13th and sheep were removed after 3, 6 and 9 days reflecting the respective grazing periods of 3, 6 and 9 days. Before each grazing sheep were weighed, divided into three groups; heavy, medium and light, the average weights of which were known, and allocated to each plot according to treatment so that the average weight/sheep on each plot was approximately equal.

2.D.2. HERBAGE DRY MATTER SAMPLING

Two to three days before each grazing 6 quadrats (30.5 x 91.5 cm^2) were cut to ground level using a Sunbeam portable shearing machine, one from each area delineated in Fig. 2.3.

FIGURE 2.1. EXPERIMENT LAYOUT

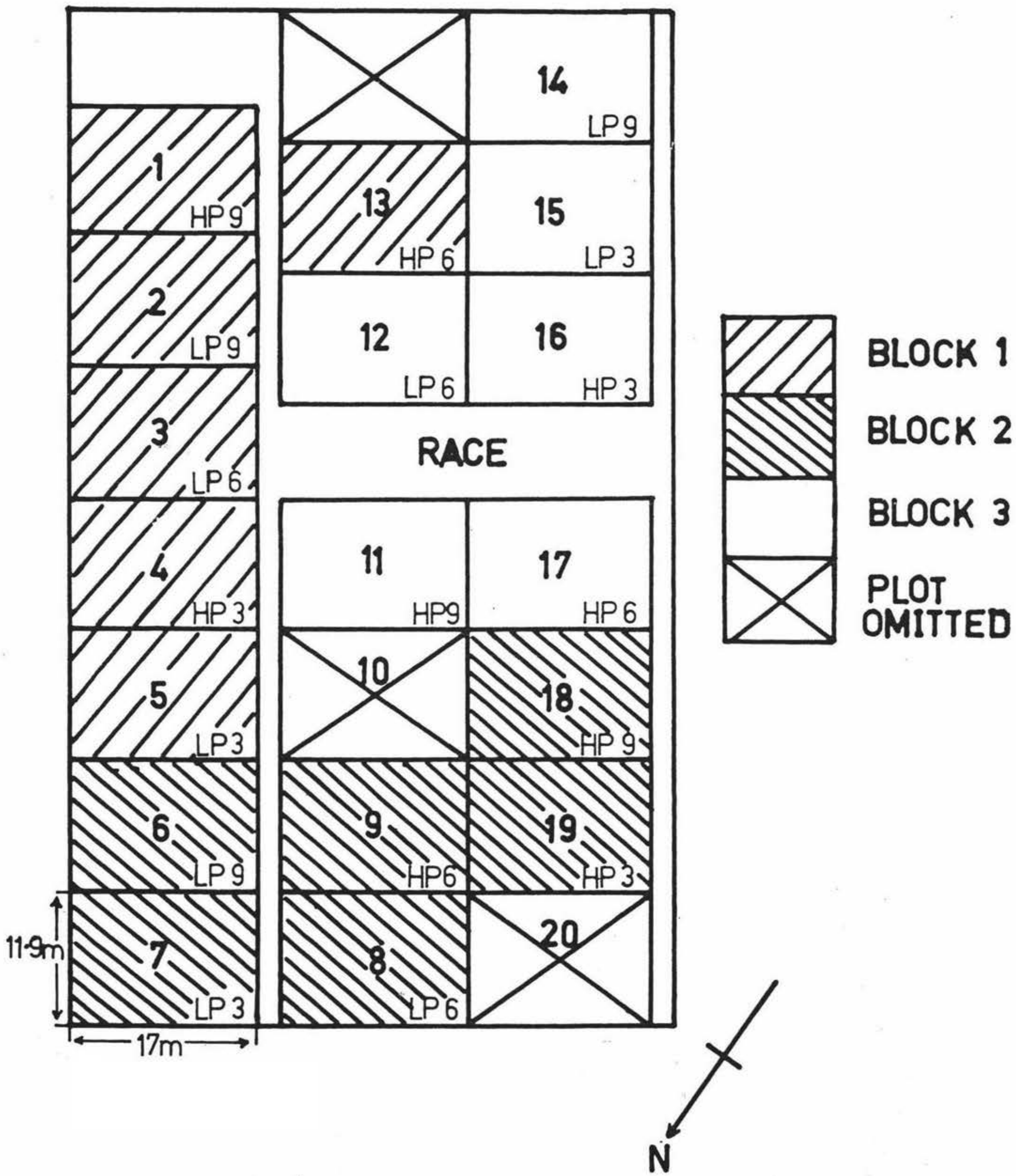
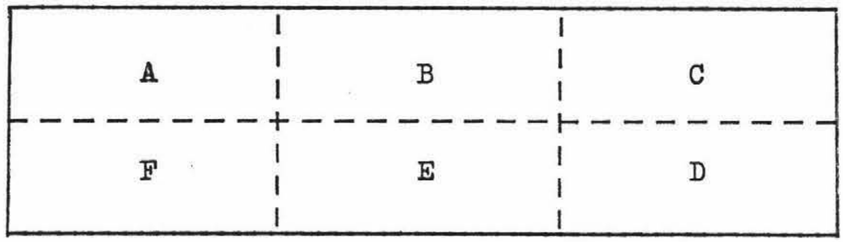


Figure 2.3. A plot divided arbitrarily into six equal parts.



The samples were bulked, weighed and subsamples (200 g) taken for botanical analysis. Herbage was dried at $80^{\circ}C$ in a Birmingham and Blackburn Unitherm oven.* The day after sheep were removed and at approximately weekly intervals until the next grazing 3 quadrats (30.5 x 91.5 cm^2) were cut from each plot (one each from AF, BE, CD as in Fig. 2.3.), weighed and dried as before. In contrast to the high pressure plots which were, in general, grazed evenly to ground level, the low pressure plots were patch grazed. A quadrat (Plate 8) was used, at some samplings, to score the number of "high patches" and "low patches" and d.m. samples were taken accordingly. Scoring with the quadrat was carried out along a transect which extended the length of the plot. No attempt was made to measure production during the grazing periods.

2.D.3. CORE SAMPLING.

A cylindrical steel core sampler (62.2 cm^2) was used to take five core samples per plot the day before and the day after each grazing,** from five of the six areas delineated in Fig. 2.3. Because of restricted sampling, each core sample was selecte to represent the clover in the area from which it came. The core samples, which included herbage attached, were stored in refrigerators at $6^{\circ}C$ and before the next grazing were dissected into leaves, petioles and stolons for detailed observations of the pre and post grazing situations on a unit area basis (Hutchinson 1967). Leaves were graded into size ranges (Williams et al 1964) for leaf area measurements, petioles into lengths (cm) and the total stolon length, number of terminal buds and number of new stolons, (arbitrarily defined as less than 1 cm in length) were recorded The three fractions, leaves, petioles and stolons for the 5 core samples were then dried and weighed. Results are quoted on a per core sample basis.

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*All d.m. samples after the second grazing were washed to remove dung and soil. Inaccuracies in weights of d.m. samples up to the second grazing are considered small because dung and soil were mostly removed by hand.

**Only four core samples were taken per plot before the first grazing.

2.D.4. INDIVIDUAL STOLON OBSERVATIONS

One to two days after each grazing, in each area as delineated in Fig. 2.3., a steel framed quadrat (929 cm^2) was placed at random, and within each quarter of the quadrat a stolon was taken randomly and measurements made (see Results section) to determine the pattern of defoliation on a per individual stolon basis. Thus measurements on 24 stolons were made per plot.

2.D.5. CLOVER PLANT TRACINGS

Three feather-marked white clover plants/plot were identified by means of a white peg 15 cm from the plant centre just before the first grazing, and shortly after the first grazing the stolon development of each plant drawn to scale. One to two days before and generally, one to three days after the second and subsequent grazings, the response of stolons in the time interval since last drawn was noted. These tracings provided information on relative rates of stolon growth/plant, new stolon initiation, extent of defoliation and rate of recovery of plants and stolons after defoliation.

2.D.6. CLOVER STOLON LENGTHS

For some plots after the second and fourth grazings and all plots after the third grazing, the average length of stolon per plot was found by measuring a stolon taken at random every 30.5 cm along a transect which stretched diagonally across the plot. Fifty stolon lengths were measured.* The idea was to see if stolon length was related to average leaf size and production.

2.D.7. ROOT SAMPLING

After the last grazing had finished, four identical root sampling devices, comprising a backing board through which 15 cm nails were driven, were used to sample the root profile down to 75 cm (Plate 10). One representative sample was taken from selected plots viz. plots 2, 3, 4, 10, 15, 16 and 18 in an attempt to measure any major effects of high and low grazing pressure on root depth and weight distribution.

2.E. THE SPLIT PLOT EXPERIMENT

Before commencing the second grazing, all the high pressure plots were split lengthwise because they were thought to have insufficient d.m. to warrant grazing. Consequently, half of each high pressure plot, taken at random, was grazed (henceforth high pressure 'grazed' treatment) and the other half left to regrow until the third

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*Initially 100 stolon lengths were measured, but the average was little different from taking 50 stolon lengths.

grazing (henceforth high pressure 'ungrazed' treatment), when sheep were again allocated to each half at the high grazing pressure. It must be clearly understood that these two treatments were the same treatment up until the beginning of the second grazing, and that the only difference between the high pressure 'grazed' treatment (HP) and the high pressure 'ungrazed' treatment (HPU) over the experimental period was that the high pressure 'ungrazed' treatment was not grazed at the second grazing. Certain alterations in sampling procedure occurred because of this split. Alterations, not similarities, are described as follows :-

2.E.1. HERBAGE D.M. SAMPLING

Before the third and fourth grazings three instead of six quadrats (30.5 x 91.5 cm^2) were cut to ground level from each half of the plot.

2.E.2. CORE SAMPLING

Five core samples, one from each of five equal areas in the plot, were taken for core sample measurements.

2.E.3. CLOVER PLANT TRACINGS

No further plants were identified. One of the three plants per plot was in either of the halves of the high pressure plots, leaving two plants in the other half

2.E.4. ROOT SAMPLING

Samples taken from the HP plots, were all from the high pressure 'grazed' half.

2.E.5. GRAZING TIMES

One week before the third grazing, 6 sheep were fitted with 'Kienzle' vibrarecorders to accustom them to these instruments before grazing. Charts were fitted the second morning after the grazing had started, and the 6 sheep were allocated, two each to plot 5, 16 (HP) and 16 (HPU). Because these were 3 day plots, sheep were removed the following day and the vibrarecorder sheep substituted for sheep of similar weight in plots 3, 11 (HPU) and 17 (HP). Charts were removed at the end of grazing.

2.F. STATISTICAL METHODS

INTRODUCTION

Two approaches to analyse the results of this experiment are to use a generalise regression analysis or a standard analysis of variance. The first requires an understanding of regression theory, from which an analysis of variance can be derived whereas the standard analysis of variance approach relies on the application of a set of rules to the data. For generalised regression analysis a generalised regression programme can be used for computor analysis whereas for analysis of variance a series of more specialised analysis of variance programmes are required. Both approaches, however, give the same result.

In the analysis of this experiment the reason for using the generalised regression analysis was to gain an understanding of the analysis of variance approach.

Analysis of the results

The analysis was done in two parts; the first being a comparison between the effects of the high pressure 'grazed' and the low pressure treatments, a randomised block design, and the second part being a comparison between the effects of the high pressure 'grazed' and high pressure 'ungrazed' treatment, a split plot design.

STATISTICAL THEORY

(a) Randomised block design

The classification model which describes the yield for an experiment of randomised block design is :-

$$y_{ij} = u + b_i + t_j + e_{ij}$$

for the plot in the ith block receiving the jth treatment where :-

y_{ij} is some yield measurement on the clover for the plot in the ith block and jth treatment.

u is the general mean effect.

b_i is the effect due to the ith block.

t_j is the effect of the jth treatment.

e_{ij} is the error which includes residual effects not incorporated in the block or treatment effects.

For the experiment here $i = 1, 2, 3$ are the three blocks

$j = 1, 2, 3$ = HP3, HP6 and HP9

$j = 4, 5, 6$ = LP3, LP6 and LP9

Each observation can be written down in terms of the model, and for any set of observations it is possible to obtain estimates of the regression coefficients such that the amount of variance of the dependent variable (y_{ij}) 'unexplained' by the parameters of the model is minimised (Appendix 4). The sums of squares associated with each estimated regression coefficient can be found (Appendix 4). These sums of squares are used in the standard analysis of variance table and the ratio of the regression mean square for an estimate and the error mean square follows an F distribution under the null hypothesis that the expectation of the estimate equals zero. This ratio is the square of the t value that is commonly used to test the null hypothesis that the expectation of the regression estimate equals zero.

(b) The split plot design

The split plot analysis was also done using regression analysis in a similar way to the randomised block analysis (Appendix 4).

Presentation of the results

The results are presented in tables, graphs and histograms.

(a) Herbage D.M. yields

Curves have not been fitted to the herbage regrowth data because insufficient points during regrowth were measured. Excluding the first regrowth period and all pregrazing cuts, regrowth cut figures have been adjusted where necessary to be at 7 day intervals from the first regrowth cut. Except for the pregrazing cuts, comparisons between treatments were made at similar stages of regrowth with respect to time after grazing.

PLATES

PLATE 1 This shows a low pressure 3 day plot immediately after the first grazing. Note the pale green areas are petioles with their leaves missing.

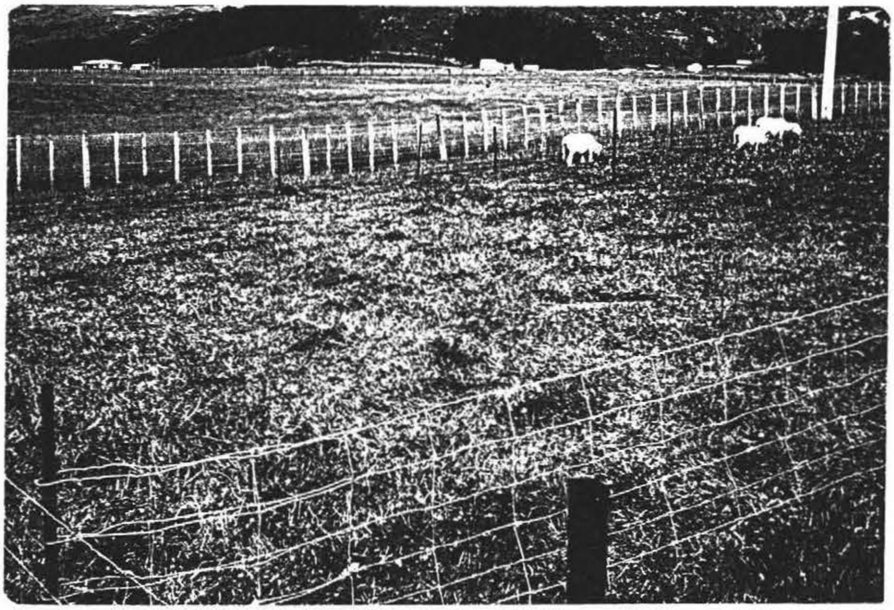


PLATE 2 This shows a high pressure 3 day plot immediately after the first grazing. The plot behind this one is a 6 day low pressure plot.

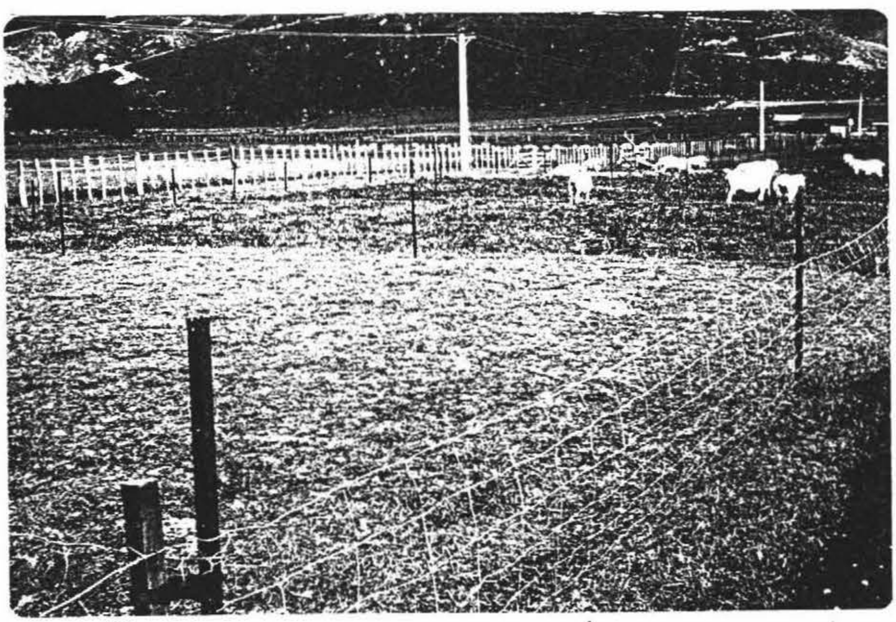


PLATE 3 A close up picture of a high pressure 3 day plot immediately after the first grazing. Very little leaf or petiole remains.

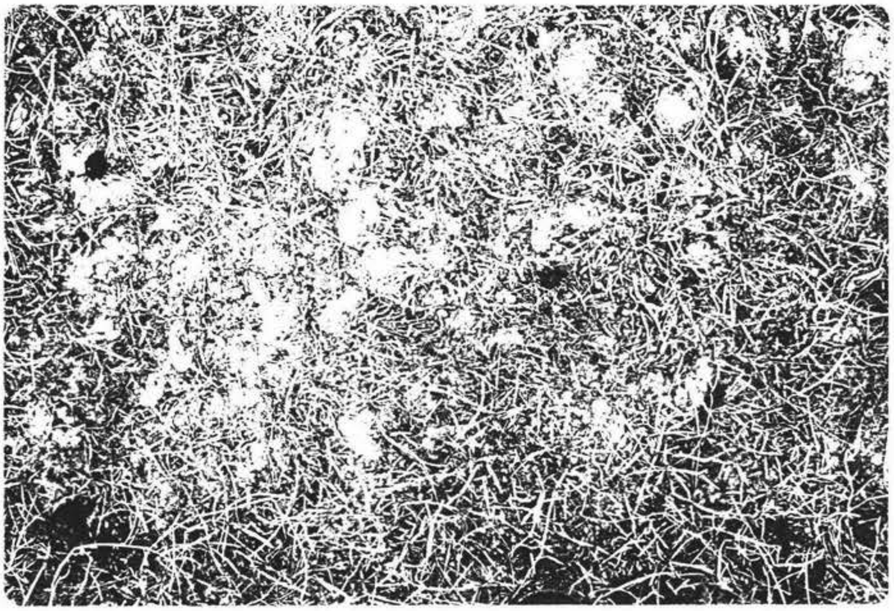


PLATE 4 A close up picture of a high pressure 'grazed' plot immediately after the second grazing.

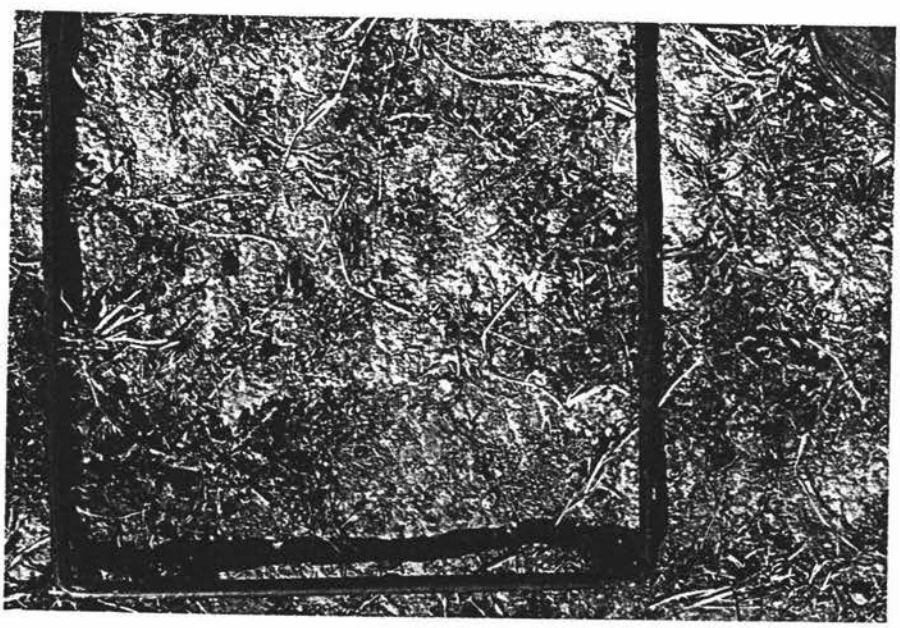


PLATE 5 A low pressure 3 day plot. Much more stolon remained after the second grazing than on the high pressure 'grazed' plot (Plate 4).

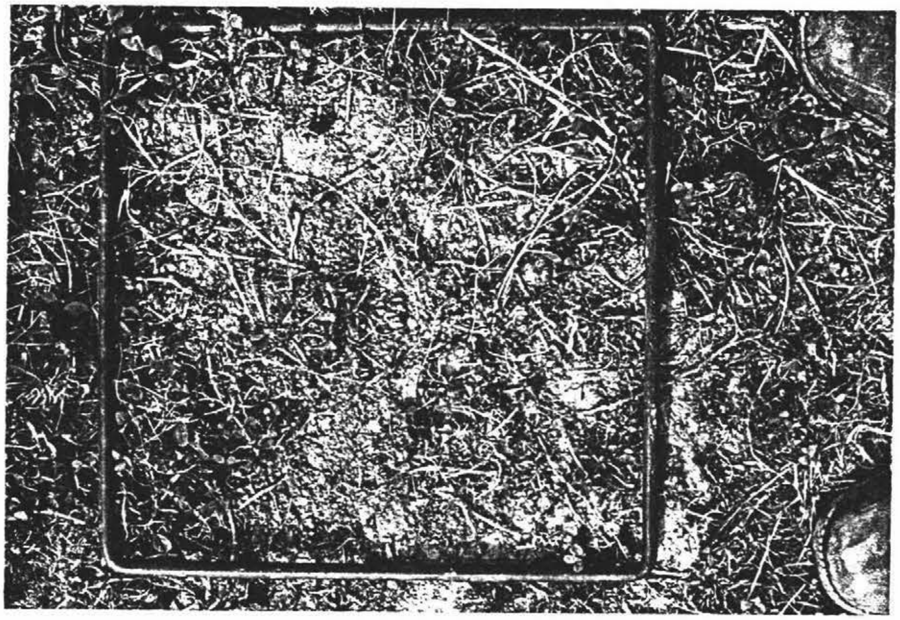


PLATE 6 During regrowth the denuded plants on the high pressure 'grazed' treatment grew again from the plant centres.

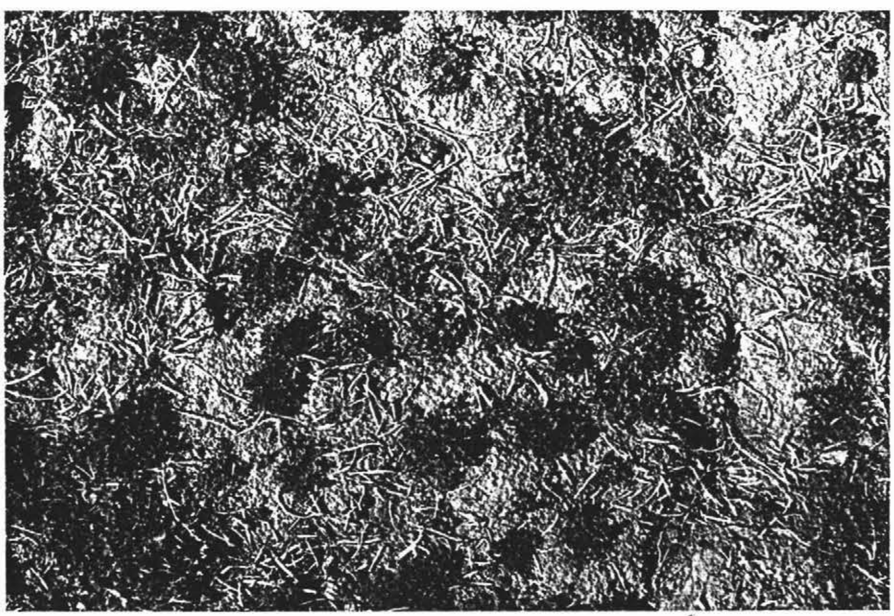


PLATE 7 54 days regrowth period for a high pressure 'ungrazed' 9 day plot.

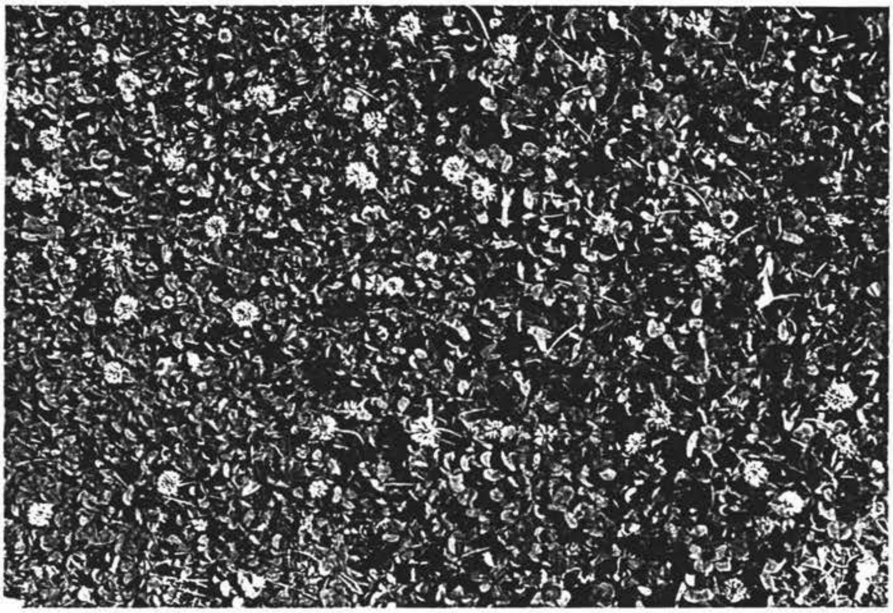


PLATE 8 Patch grazing was assessed using this quadrat.

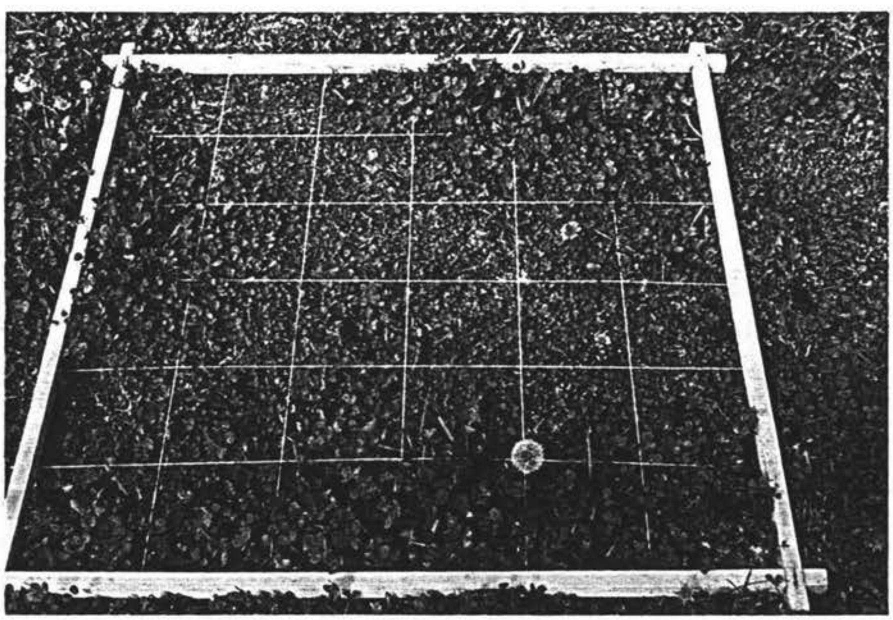
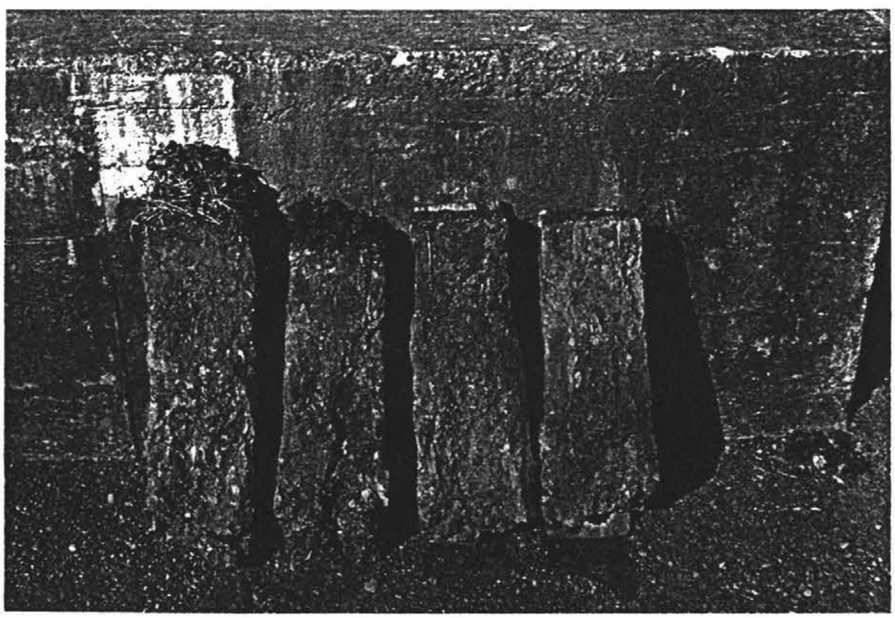


PLATE 9 The distinct feature of the feather- marked white clover plant was plainly visible.

PLATE 10 From left to right: a plot not grazed throughout the experiment, a low pressure plot and two high pressure plots. The clay fragipan is easily visible.



CHAPTER 3

RESULTS

INTRODUCTION

The terms grazing pressure, grazing period and regrowth period are used in this section. The grazing pressures (as previously defined in sections 2.B. and 2.E.) include : high pressure 'grazed' (HP), low pressure (LP) and high pressure 'ungrazed' (HPU) treatments; the grazing period refers to the period of time for grazing i.e. 3 days, 6 days or 9 days; the regrowth period is the time from the end of one grazing period until the next grazing.

Because very few treatment interactions were significant throughout the experimental period only the main effects of grazing pressure and grazing period are presented for clarity. The significant interactions recorded are presented in Appendix 2 , and the interactions considered important are marked with an asterisk.

In each section of the results the general approach has been to look firstly at the levels of the measured parameters at various times over the experimental period and at the production of the measured parameters during the regrowth periods, and secondly at the decreases in the parameters as a result of grazing. The effects of grazing pressure treatments and grazing period treatments (3, 6 and 9 days) are considered separately.

Unless otherwise stated, significant grazing period effects are linear (L) and not quadratic (Q).

All least significant differences are at the 5% level.

3.1. METEOROLOGICAL DATA

3.1.1. Rainfall

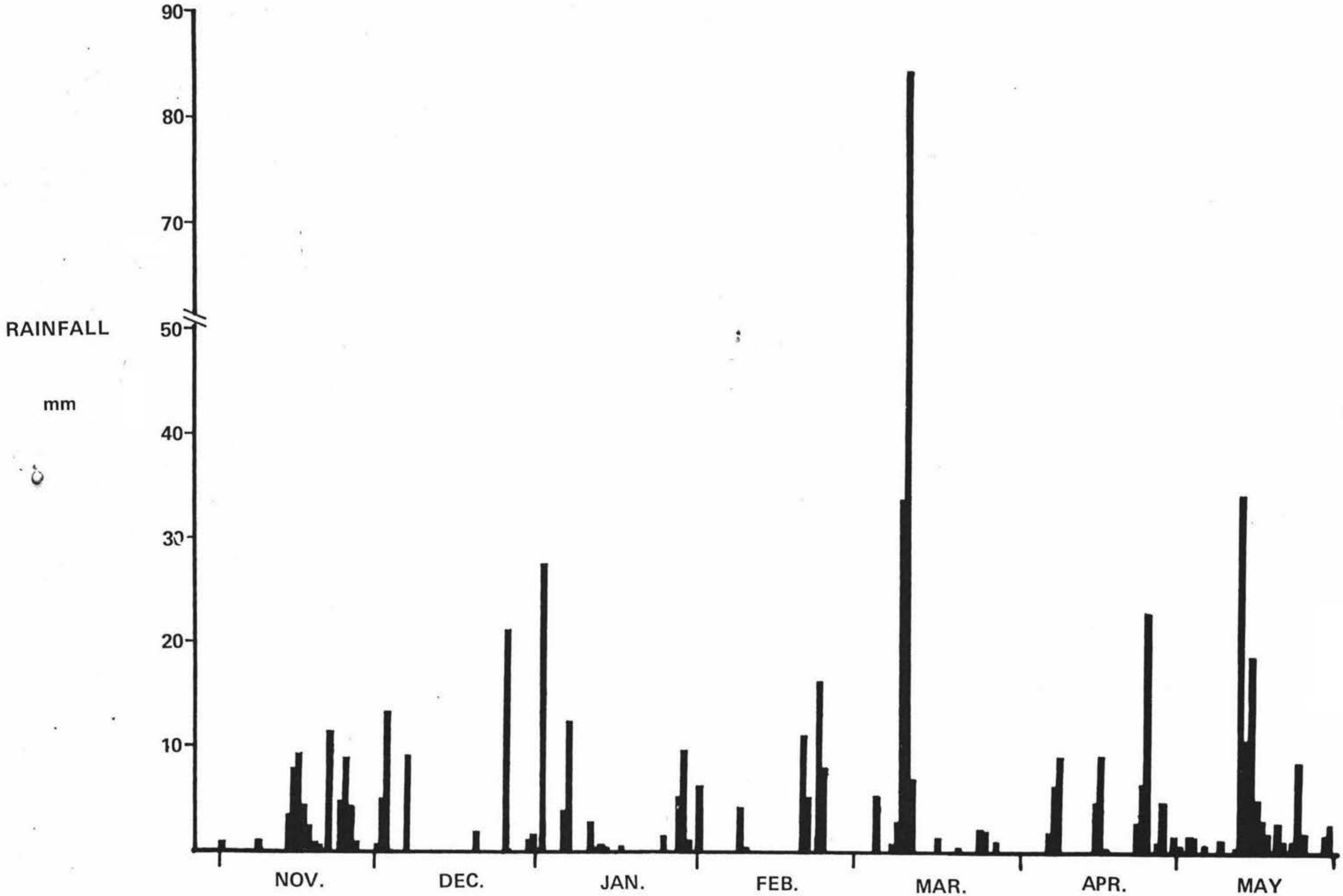
Figure 3.1.1. shows the daily rainfall over the experimental period. From the beginning of January to the end of February very little rain fell.

Monthly rainfall figures over the experimental period are shown in Appendix 1. From November until February the rainfall during the experiment was lower than the 30 year average.

3.1.2. Temperature

The mean monthly maximum, mean monthly minimum and mean monthly temperatures are shown in Appendix 1. The mean temperatures at Grasslands Division, Palmerston North, over the experimental months were very similar to the 30 year average figures.

FIGURE 3.1.1. DAILY RAINFALL OVER THE EXPERIMENTAL PERIOD



3.2. HERBAGE D.M. YIELD MEASUREMENTS

3.2.1. Total D.M. production

A. Grazing pressure treatments

The total production over the four regrowth periods is shown for the high pressure 'grazed', low pressure and high pressure 'ungrazed' treatments in Table 3.2.1.

TABLE 3.2.1.

Total production for the grazing pressure treatments. (kg/plot)

Part	Grazing pressure	Total production	Sig.
A	HP LP	62.0 49.8	*
B	HP HPU	62.0 76.3	***

Over the experimental period the high pressure 'grazed' treatment produced significantly more than the low pressure treatment (Table 3.2.1. part A), but significantly less than the high pressure 'ungrazed' treatment (Table 3.2.1. part B).

B. Grazing period treatments (3, 6 and 9 days)

Table 3.2.2. shows the total production for the 3, 6 and 9 day treatments; Part A shows the mean of the high pressure 'grazed' and low pressure treatments and Part B the mean for the high pressure 'grazed' and high pressure 'ungrazed' treatments.

TABLE 3.2.2.

Total production for the 3, 6 and 9 day treatments. (kg/plot)

Part	Total production	3 day	6 day	9 day	Sig.	L.S.D.+
A	Mean (HP&LP)	73.4	52.0	42.5	***	13.4
B	Mean (HP&HPU)	82.4	70.0	55.7	*	20.0

+L.S.D. = Least significant difference

The 3 day grazing period treatment produced significantly more d.m. over the experimental period than the 9 day treatment in both comparisons (Part A and B, Table 3.2.2.), and in Part A more than the 6 day treatment also.

3.2.2. Production during each regrowth period

A. Grazing pressure treatments

Figure 3.2.1. shows graphs of the four regrowth periods of white clover (Trifolium repens L.) for the high pressure 'grazed' and low pressure treatments. Before the treatments were applied there were no significant differences in d.m. available per plot. In all regrowth periods there was a significantly greater d.m. on the low pressure than the high pressure 'grazed' treatment. Although in the first regrowth period a decline in d.m. available took place over the first ten days for the low pressure treatment, the subsequent increase in d.m. up to the beginning of the second grazing was significantly greater than the total first regrowth period production on the high pressure 'grazed' treatment.

Figure 3.2.2. shows the same four regrowth periods for the high pressure 'grazed' treatment but also shows how, at the end of the first regrowth period, half of each high pressure plot, which was left ungrazed at the second grazing, continued to grow until the beginning of the third grazing. At the third and fourth grazing, this half plot was grazed at the high pressure. For all comparisons in the Results Section between the high pressure 'grazed' treatment and high pressure 'ungrazed' treatment during the second regrowth period (in actual fact, a continued first regrowth period for the high pressure 'ungrazed' treatment), the value of the parameter e.g. d.m. is taken to start at the end of the first regrowth period for the high pressure 'ungrazed' treatment. In the case of d.m. production over the second regrowth period therefore, this means that the high pressure 'ungrazed' treatment has a growth advantage of about 6 days over the high pressure 'grazed' treatment (Fig. 3.2.2.). In the latter half of the third and fourth regrowth periods there was a trend towards increased production of d.m. on the high pressure 'ungrazed' compared with the high pressure 'grazed' treatment. This difference reached significance in some cuts.

Table 3.2.3. shows the increases in d.m. (production) for the grazing pressure treatments in each regrowth period.

FIGURE 3.2.1. THE EFFECTS ON THE REGROWTH OF WHITE CLOVER SWARDS OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS

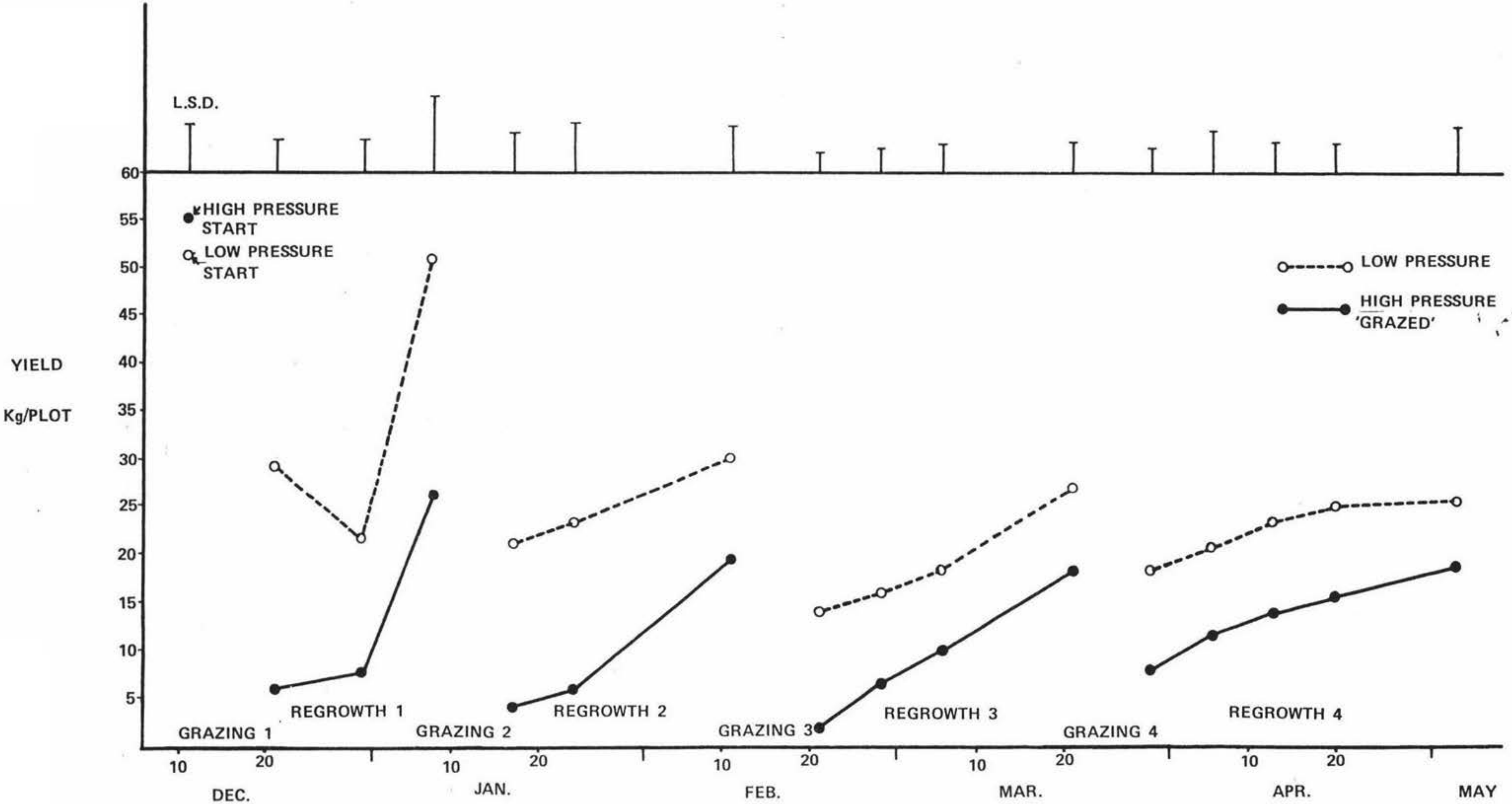


FIGURE 3.2.2. THE EFFECTS ON THE REGROWTH OF WHITE CLOVER SWARDS OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS

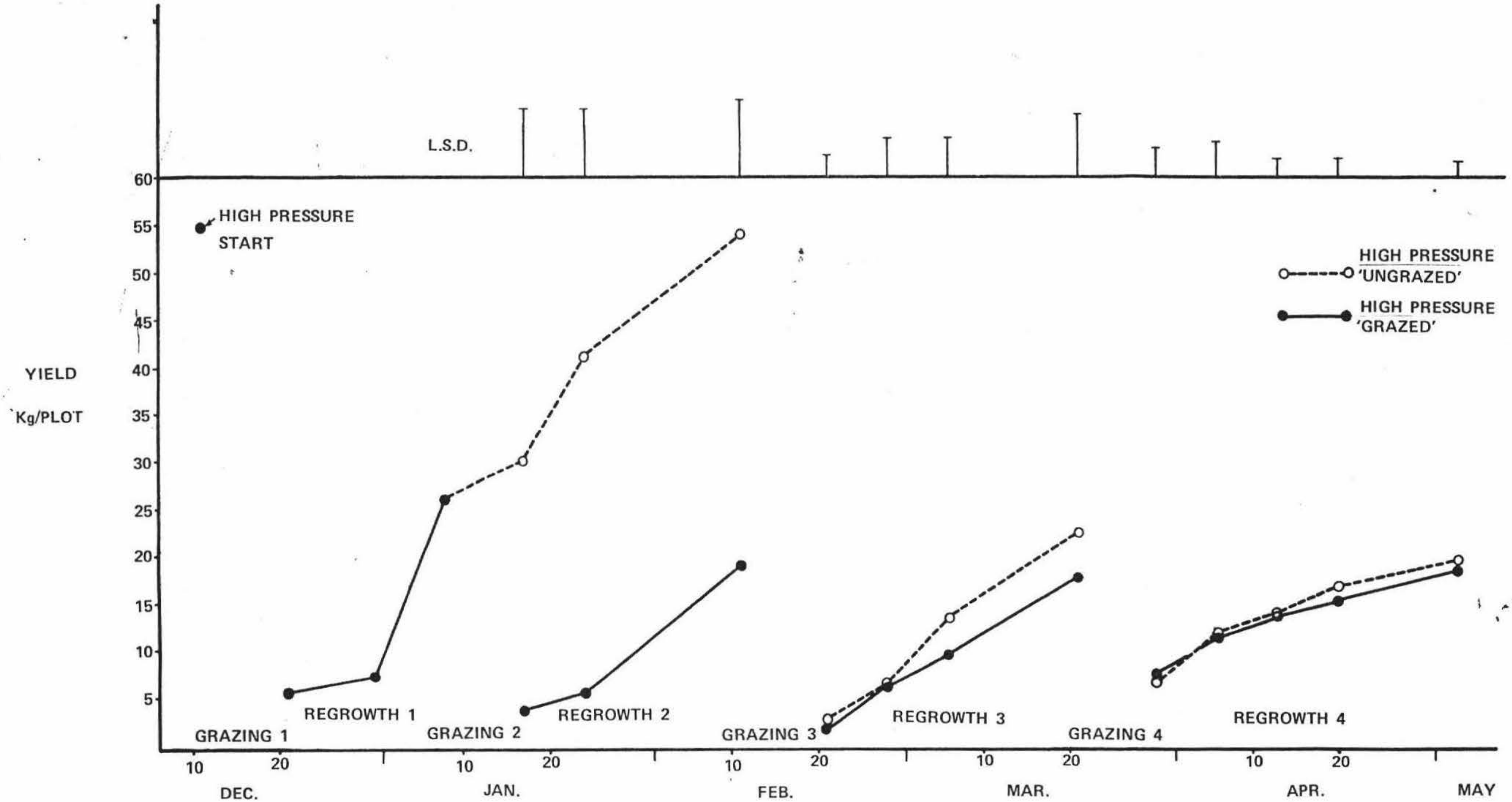


TABLE 3.2.3.

Increases in d.m. in each regrowth period for the grazing pressures. (kg/plot)

Part	Grazing pressure	Regrowth period 1	Regrowth period 2	Regrowth period 3	Regrowth period 4
A	HP LP	20.1 21.7 n.s.	15.2 7.9 **	15.9 13.0 n.s.	10.7 7.2 n.s.
B	HP HPU	20.1 20.1 n.s.	15.2 23.9 *	15.9 19.8 n.s.	10.7 12.5 n.s.

There was greater production in the first regrowth period than in the other regrowth periods for both the high pressure 'grazed' and low pressure treatments (Table 3.2.3. Part A). The increase in d.m. in the second regrowth period was significantly greater for the high pressure 'grazed' than the low pressure treatment. However, in the second regrowth period also, the high pressure 'ungrazed' treatment increased d.m. significantly more than the high pressure 'grazed' treatment (Table 3.2.3. Part B).

B. Grazing period treatments

Figure 3.2.3. shows, after each grazing, the effects of the 3, 6 and 9 day grazing periods on regrowth (mean of the high pressure 'grazed' and low pressure treatments). At the end of the first, second and fourth regrowth periods the amount of available d.m. was greater on the 3 day than the 9 day treatment and at the end of the second regrowth period greater than the 6 day treatment also. The general trend, however, was for the 3 day > 6 day > 9 day in amount of herbage available.

Figure 3.2.4. shows, after each grazing, the effects of the 3, 6 and 9 day grazing periods on regrowth (mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments). Here again the general trend was for the 3 day > 6 day > 9 day treatment in the amount of herbage available. This was especially the case just before the third grazing, although for both the high pressure 'ungrazed' and the high pressure 'grazed' treatments before the second regrowth period began, there appeared to be a greater amount of d.m. available on the 3 day treatment than the 6 or 9 day treatments. This also appeared to be the case at the beginning of the fourth regrowth period.

Table 3.2.4. shows the increases in d.m. over each regrowth period for the 3, 6 and 9 day treatments.

FIGURE 3.2.3. THE EFFECTS OF THE 3, 6 AND 9 DAY GRAZING PERIODS ON THE REGROWTH OF WHITE CLOVER SWARDS MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS

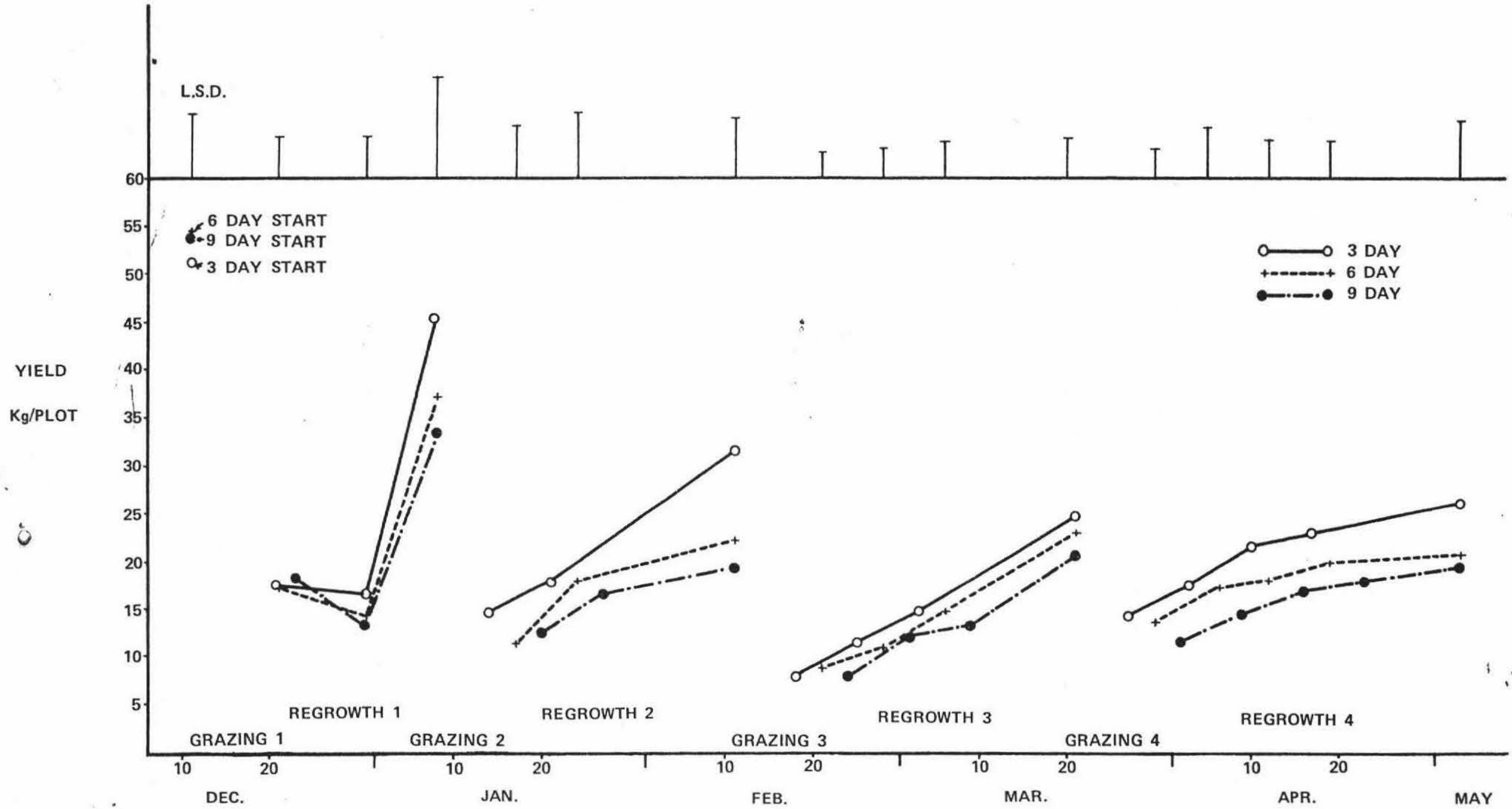


FIGURE 3.2.4 THE EFFECTS OF THE 3, 6 AND 9 DAY GRAZING PERIODS ON THE REGROWTH OF WHITE CLOVER SWARDS MEAN OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS

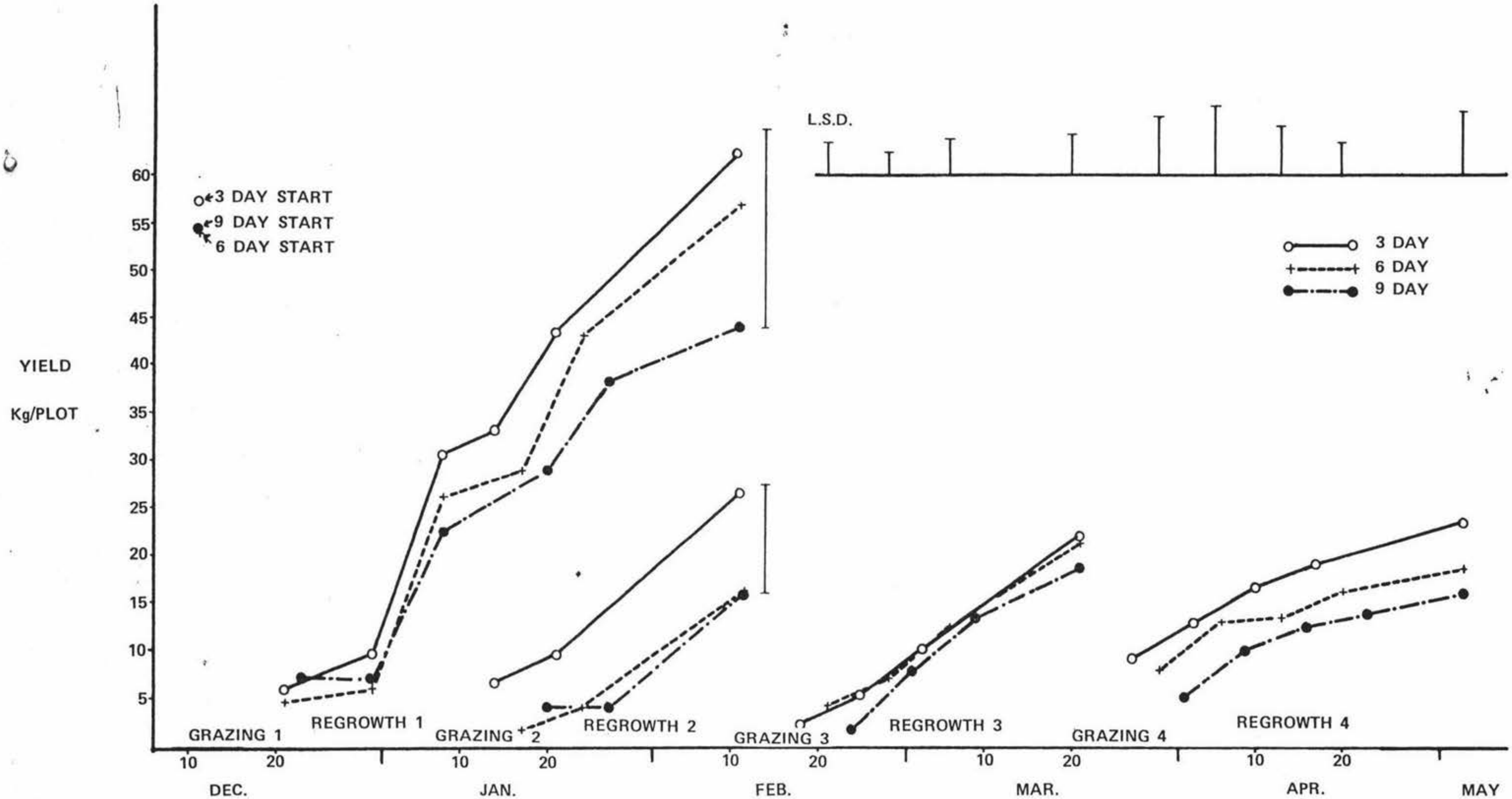


TABLE 3.2.4.

Increases in d.m. over each regrowth period for the 3, 6 and 9 day treatments. (kg/plot)

Part	Regrowth period	3 day	6 day	9 day	Sig.	L.S.D.
A	Regrowth period 1	28.0	19.7	15.1	**	8.0
Mean	Regrowth period 2	16.9	10.9	7.0	***	4.5
of	Regrowth period 3	16.7	14.2	12.6	n.s.	5.7
(HP&LP)	Regrowth period 4	11.8	7.2	7.8	n.s.	7.0
B	Regrowth period 1	24.3	21.1	15.1	n.s.	17.0
Mean	Regrowth period 2	24.3	21.1	13.3	*	10.1
of	Regrowth period 3	19.5	17.4	16.8	n.s.	3.7
(HP&HPU)	Regrowth period 4	14.3	10.2	10.5	n.s.	4.9

The general trend was for the 3 day > 6 day > 9 day treatment in the increases in d.m. over each regrowth period (Table 3.2.4. Part A and B). In Part A of Table 3.2.4., the 3 day treatment increased d.m. in the first and second regrowth periods more than either the 6 or 9 day treatments. In Part B of Table 3.2.4. the 3 day treatment increased d.m. significantly more than the 9 day treatment in the second regrowth period only.

3.2.3. Decrease in d.m. at each grazing

A. Grazing pressure treatments

Table 3.2.5. shows the decreases in d.m. at each grazing for the grazing pressure treatments.

TABLE 3.2.5.

Decreases in d.m. at each grazing for the grazing pressure treatments. (kg/plot)

Part	Grazing pressure	Number of Grazing								Total decrease	
		1		2		3		4			
A	HP	48.7	****	22.1	n.s.	17.2	n.s.	10.2	n.s.	98.3	**
	LP	29.5		29.4		15.1		8.9		82.9	
B	HP	48.7	n.s.+	22.1	n.a.++	17.2	****	10.2	n.s.	98.3	**
	HPU	48.7		0.0		50.7		16.0		115.4	

+ These were the same treatments at the first grazing.
++n.a. = not applicable, this was not analysed because there was no grazing on half the high pressure plot at the second grazing.

The decrease in d.m. appeared to be greater for both the high pressure 'grazed' treatment and the low pressure treatment at the first grazing than at the other grazings (Table 3.2.5. Part A). Only at the first grazing was a significantly greater quantity of herbage d.m. removed from the high pressure 'grazed' treatment than the low pressure treatment. This appeared to be reflected in the total herbage decrease in d.m. for the four grazings.

The significantly greater decrease in d.m. of the high pressure 'ungrazed' treatment compared with the high pressure 'grazed' treatment at the third grazing, reflected also in the total decrease in d.m. (Table 3.2.5. Part B), is the result of a greater available d.m. on the former treatment prior to the third grazing (Fig. 3.2.2.).

B. Grazing period treatments

Table 3.2.6. shows the decreases in d.m. for the 3, 6 and 9 day treatments at each grazing.

TABLE 3.2.6.

The decreases in d.m. at each grazing for the 3, 6 and 9 day treatments. (kg/plot)

Part	Number of grazing	3 day	6 day	9 day	Sig.	L.S.D.
A	Grazing 1	36.3	40.7	40.4	n.s.	7.5
Mean	Grazing 2	30.7	25.7	20.9	n.s.	10.2
of	Grazing 3	23.5	13.4	11.6	**	6.1
(HP&LP)	Grazing 4	10.4	9.5	9.0	n.s.	5.2
	Total decrease	100.9	89.3	81.9	**	11.1
B	Grazing 1+					
Mean	Grazing 2+					
of	Grazing 3	41.8	32.5	28.0	**	8.2
(HP&HPU)	Grazing 4	12.9	13.3	13.3	n.s.	5.4
	Total decrease+	117.3	106.5	97.1	*	17.9

+ Grazing 1 was common to both treatments because at this stage the plots were not split. The high pressure 'ungrazed' plots were not grazed at the second grazing and so figures are left out. The total decrease is a true mean for all the decreases on the high pressure 'grazed' and high pressure 'ungrazed' treatments assuming the first grazing decrease is common to both treatments.

The decreases in d.m. at each grazing showed no significant grazing period effects except at the third grazing (Table 3.2.6. Part A and B). However, the total decrease for the 3 day treatment was significantly greater than for the 9 day treatment (Table 3.2.6. Part A and B).

3.3. BOTANICAL COMPOSITION ANALYSIS

3.3.1. The botanical composition before each grazing and at the final harvest

A. Grazing pressure treatments

Figure 3.3.1. shows the effects of the high pressure 'grazed' and the low pressure treatments on the botanical composition. Before the first grazing no significant differences occurred between plots in clover, weeds or grass and dead matter percentages. Before the second grazing and at the final harvest the high pressure 'grazed' treatment had a significantly lower percentage of clover than the low pressure treatment because of a significantly higher dead matter percentage before the second grazing and at the final harvest because of a significantly higher grass percentage. Before the third grazing the low pressure treatment had a significantly lower percentage of clover than the high pressure 'grazed' treatment because of the higher percentage of dead matter.

The fact that each of the high pressure plots was split in half before the second grazing and one half left to regrow until the third grazing resulted in a higher clover percentage (10%) before the third grazing on the high pressure 'ungrazed' than the high pressure 'grazed' treatment (Fig. 3.3.2.). At the final harvest there was a significantly greater grass percentage on the high pressure 'grazed' than the high pressure 'ungrazed' treatment (Fig. 3.3.2.).

Table 3.3.1. shows a comparison of the first botanical analysis with subsequent analyses for the high pressure 'grazed' and low pressure treatments (Part A). For the high pressure 'ungrazed' treatment, a comparison is made of the botanical analysis before the fourth grazing and at the final harvest with the botanical analysis before the third grazing (Table 3.3.1. Part B).

FIGURE 3.3.1. THE EFFECTS OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS ON BOTANICAL COMPOSITION

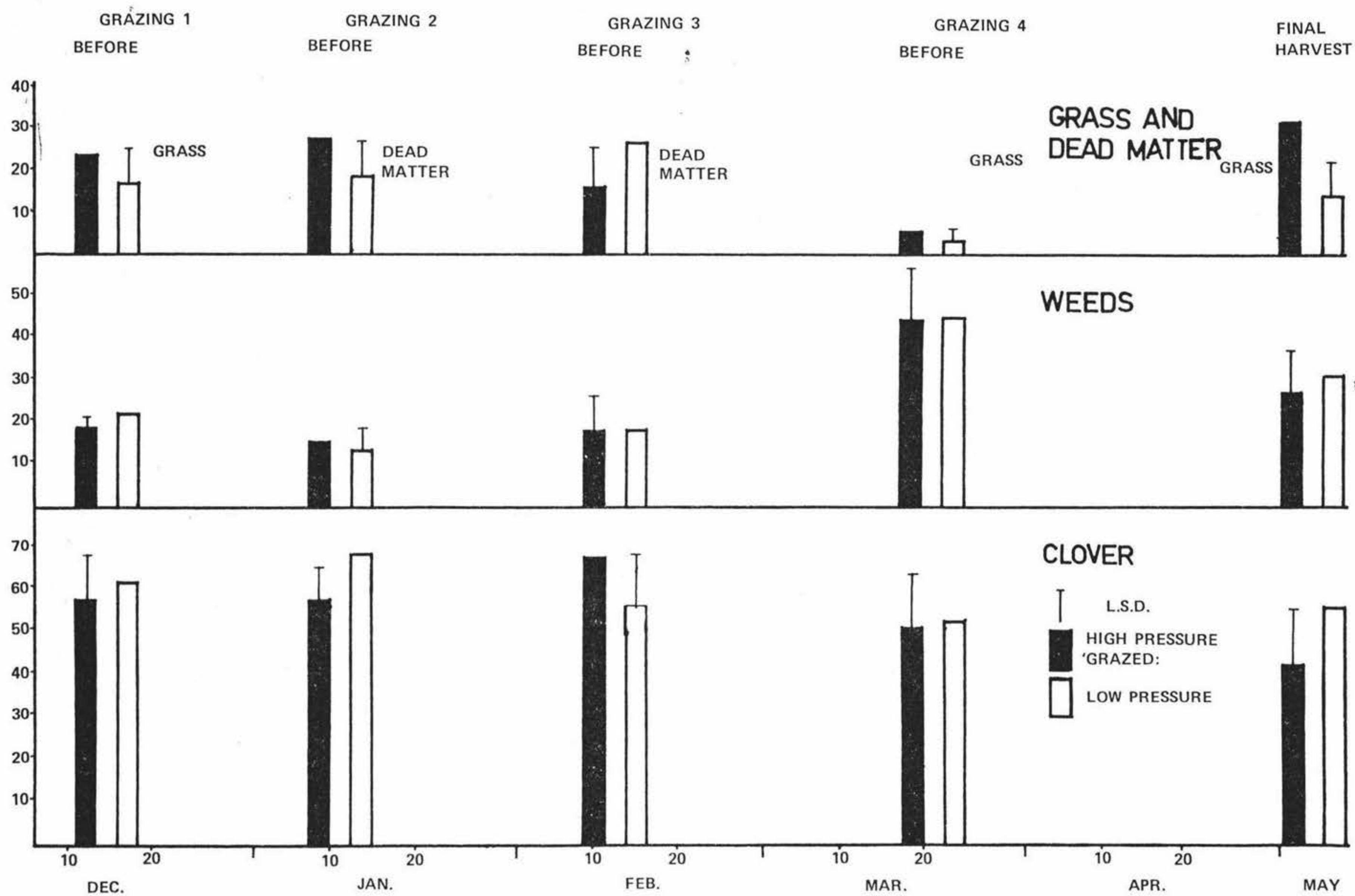


FIGURE 3.3.2. THE EFFECTS OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS ON BOTANICAL COMPOSITION

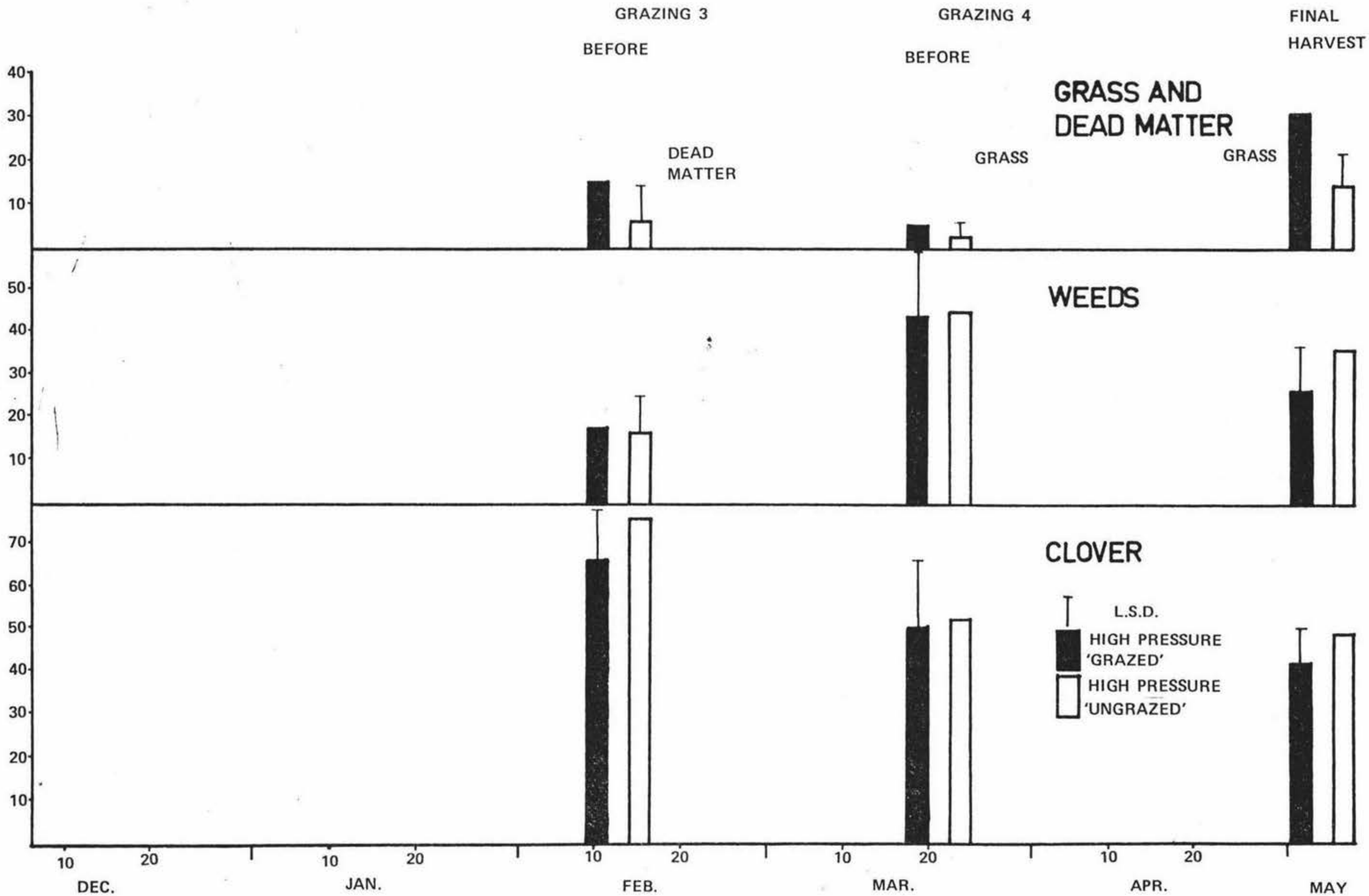


TABLE 3.3.1.

Comparisons between botanical analyses

Part	Description of herbage	Grazing pressure	No. of botanical analysis			
			No. 1 % No. 2	No. 1 % No. 3	No. 1 % No. 4	No. 1 % Final Harvest
A	White Clover	HP	58.0 n.s. 57.4	58.0 n.s. 66.7	58.0 n.s. 51.0	58.0 * 42.4
	White Clover	LP	61.7 n.s. 68.4	61.7 n.s. 50.9	61.7 n.s. 52.6	61.7 n.s. 55.7
	Weeds	HP	18.9 n.s. 15.0	18.9 n.s. 17.5	18.9 ** 43.9	18.9 n.s. 26.4
	Weeds	LP	21.4 ** 13.0	21.4 n.s. 18.0	21.4 **** 44.7	21.4 ** 30.8
B			No. of botanical analysis			
					No. 3 % No. 4	No. 3 % Final Harvest
	White Clover	HPU			76.7 *** 52.7	76.7 *** 49.0
	Weeds	HPU			17.0 *** 45.0	17.0 ** 36.1

Only at the final harvest was the percentage of clover on the high pressure 'grazed' treatment significantly lower than before the first grazing (Table 3.3.1. Part A) and this was largely due to an increase in the percentage of grass as already mentioned (Fig. 3.3.1.). Just before the fourth grazing and at the final harvest a significantly greater percentage of weeds occurred on the low pressure treatment than before the first grazing (Table 3.3.1. Part A).

The significant fall in clover percentage before the last grazing and final harvest compared with that at the third grazing for the high pressure 'ungrazed' treatment (Table 3.3.1. Part B) is compensated for by a rise in the weed percentage and, although not shown in Table 3.3.1., by a rise in the grass percentage at the final harvest also.

B. Grazing period treatments

Figure 3.3.3. shows the effects of the 3, 6 and 9 day grazing periods on botanical composition for the mean of the high pressure 'grazed' and low pressure

FIGURE 3.3.3. THE EFFECTS OF THE 3, 6 AND 9 DAY GRAZING PERIODS ON BOTANICAL COMPOSITION MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS

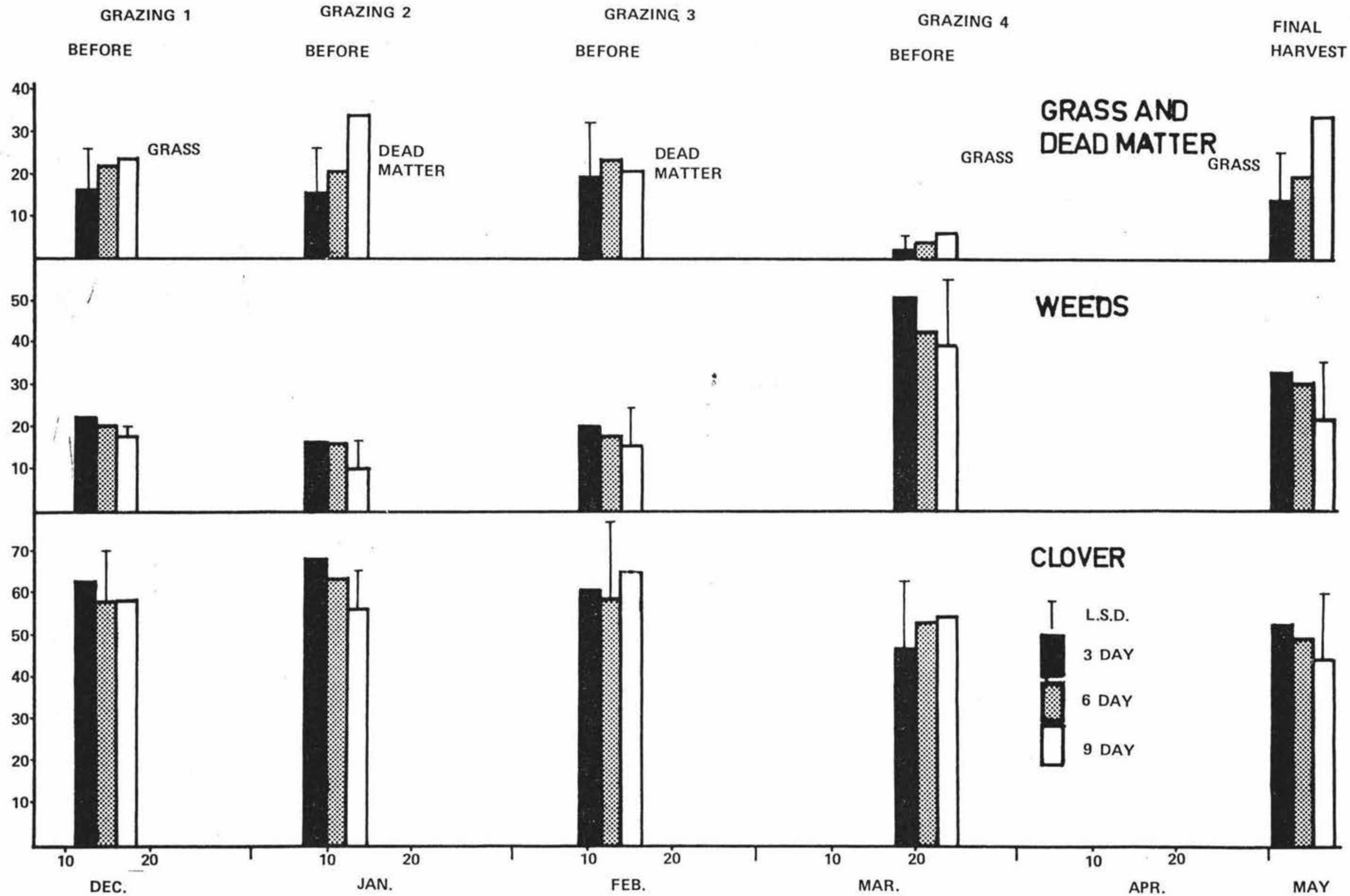
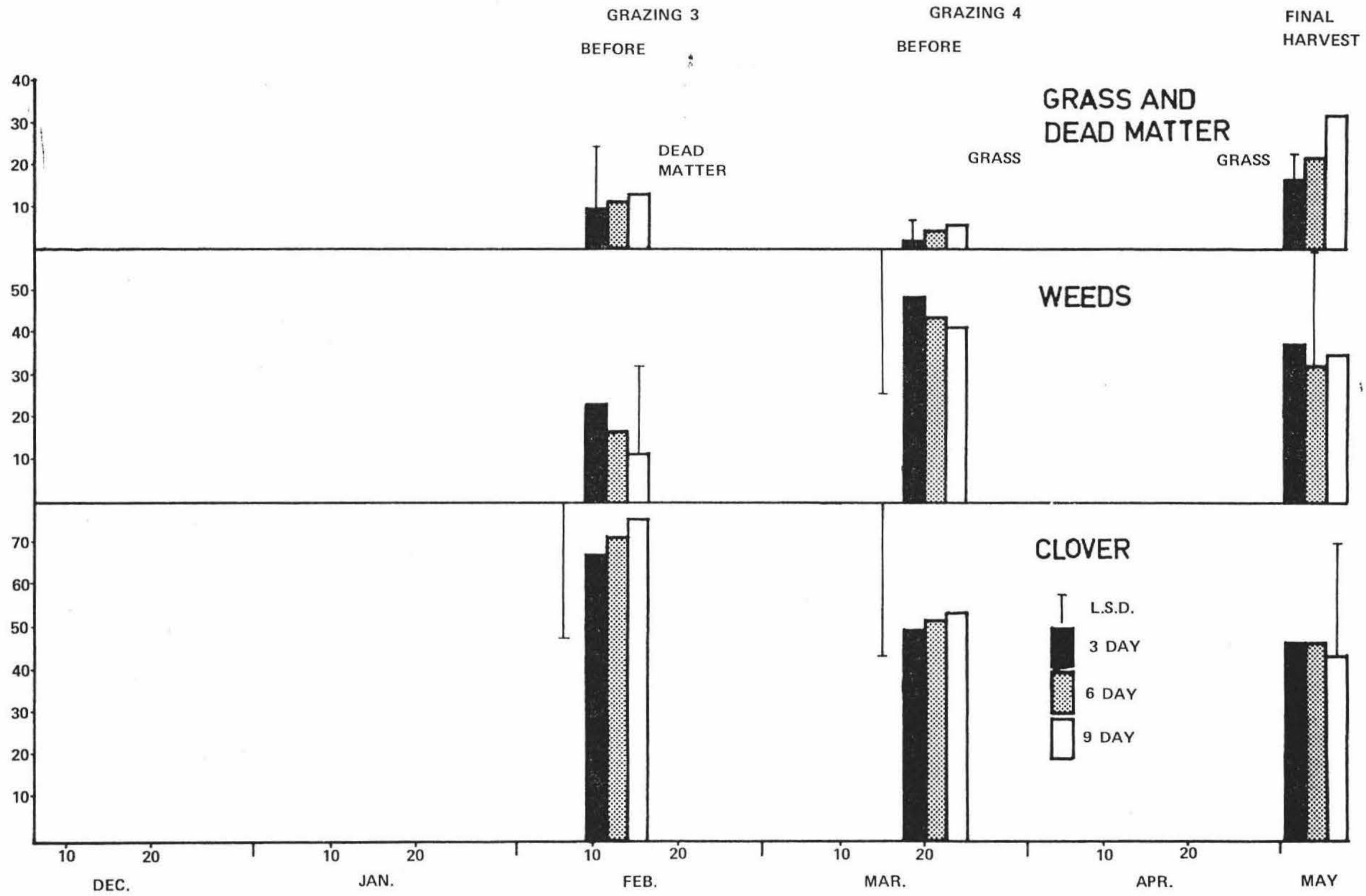


FIGURE 3.3.4. THE EFFECTS OF THE 3, 6 AND 9 DAY GRAZING PERIODS ON BOTANICAL COMPOSITION MEAN OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS



treatments.

There was no significant difference in the percentage of clover between the 3, 6 and 9 day grazing periods before each grazing, except before the second grazing, where the 3 day treatment had a significantly greater percentage of clover than the 9 day treatment. However, the 3 day treatment tended to show a higher percentage of weeds but a lower percentage of grass or dead matter compared with the 6 and 9 day grazing periods before each grazing.

Figure 3.3.4. shows the effects of the 3, 6 and 9 day grazing periods for the mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments. No significant grazing period effects occurred except at the final harvest when the grass percentage on the 9 day treatment was significantly greater than either the 3 or 6 day treatments.

3.4. WEIGHTS OF CLOVER STOLONS, PETIOLES AND LEAVES

3.4.1. The production of stolon, petiole and leaf

A. Grazing pressure treatments

Figure 3.4.1. shows the weights before and after each grazing of stolons, petioles and leaves (hereafter called fractions) for the high pressure 'grazed' and low pressure treatments. In none of the fractions was there any significant difference in weight per plot before the start of the first grazing. The general trend was for the low pressure treatment to have greater weights of all three fractions both before and after each subsequent grazing. At the start of the second, third and fourth grazings the low pressure treatment had almost the same stolon weight, 1.3 g/62.2 cm^2 (Fig. 3.4.1.). It was notable that the pregrazing weights of both leaf and petiole for the low pressure treatment at the third and fourth grazings were less than those before the first and second grazings reflecting the lower recovery in the second and third regrowth periods.

Figure 3.4.2. shows the weights of the fractions for the high pressure 'grazed' and high pressure 'ungrazed' treatments before and after the third and fourth grazings. The fact that half the high pressure plots were left ungrazed at the second grazing meant a substantial difference to the weight/unit area of the fractions at the start of the third grazing. Because both treatments were grazed at high pressure it could be expected that they would be grazed to a similar extent. Although this was so for the leaf and petiole fractions at the third grazing, more stolon remained on the high pressure 'ungrazed' treatment than high pressure 'grazed' treatment. Little difference occurred either before or after the fourth grazing

FIGURE 3.4.1. THE EFFECTS ON THE WEIGHT OF STOLONS, PETIOLES AND LEAVES OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (g/CORE)

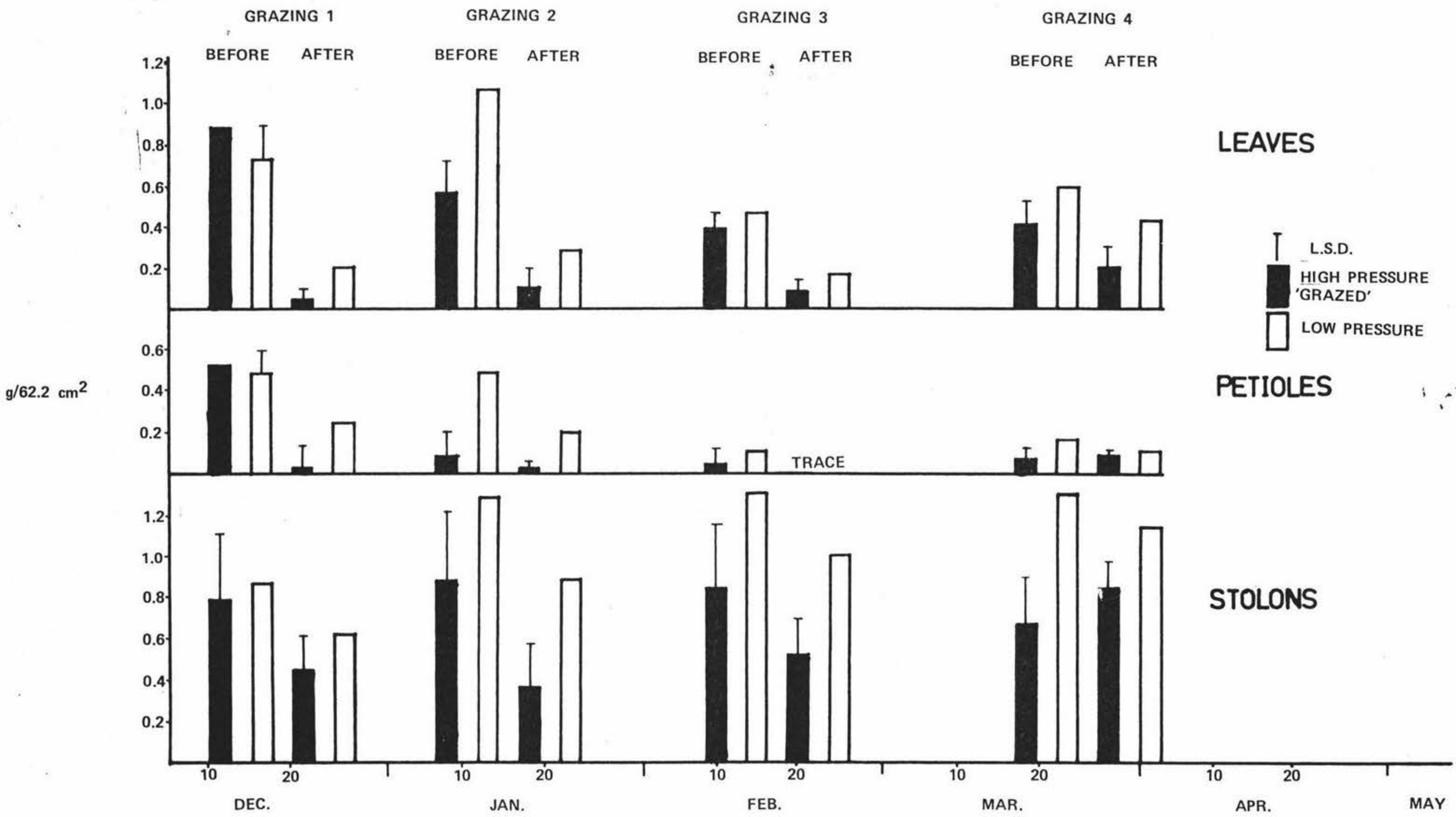
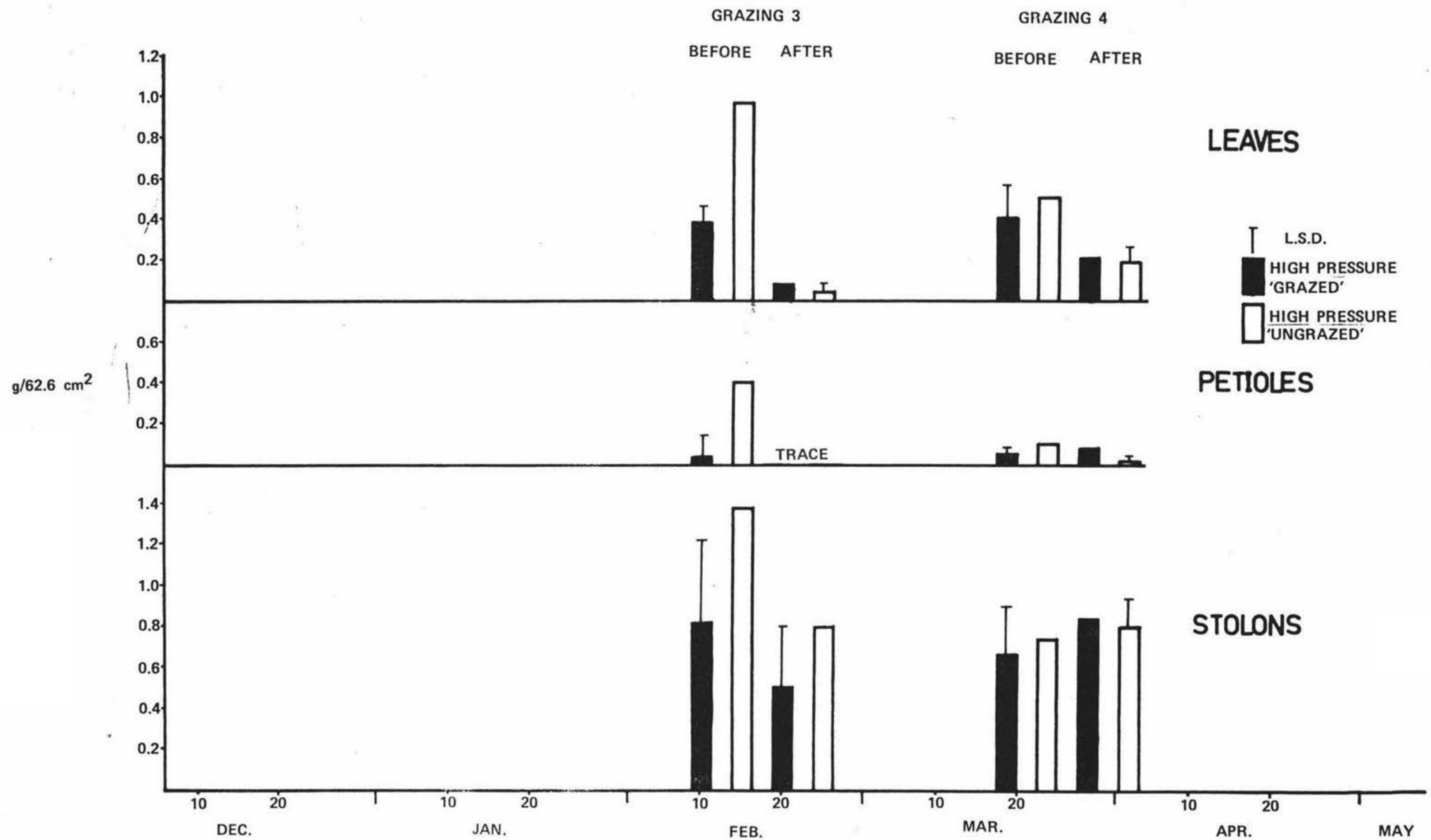


FIGURE 3.4.2. THE EFFECTS ON THE WEIGHT OF STOLONS, PETIOLES AND LEAVES OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS (g/CORE)



between treatments in the weights of the three fractions.

It is notable that the weight/unit area of all three fractions was similar for the high pressure 'ungrazed' treatment at the beginning of the third grazing to that of the low pressure treatment at the beginning of the second grazing (Fig. 3.4.2. and 3.4.1.).

Table 3.4.1. shows the increases in weight of stolons, petioles and leaves for the high pressure 'grazed', low pressure and high pressure 'ungrazed' treatments for the first three regrowth periods.

TABLE 3.4.1.

The increases in fraction weights for the grazing pressure treatments for the first three regrowth periods. ($g/62.2\ cm^2$)

Part	Description of fraction	Grazing pressure	Regrowth period			Total+ Regrowth
			1	2+	3	
A	Leaves	HP LP	0.54 0.86 ***	0.28 0.20 n.s.	0.32 0.42 n.s.	1.14 1.48 ***
	Petioles	HP LP	0.08 0.26 ***	0.04 -0.08 **	0.06 0.16 **	0.18 0.34 ***
	Stolons	HP LP	0.44 0.58 n.s.	0.44 0.42 n.s.	0.14 0.30 n.s.	1.02 1.30 n.s.
B	Leaves	HP HPU		0.28 0.38 n.s.	0.32 0.46 *	1.14 1.38 **
	Petioles	HP HPU		0.04 0.36 ***	0.06 0.10 n.s.	0.18 0.54 ***
	Stolons	HP HPU		0.44 0.52 n.s.	0.14 -0.06 *	1.02 0.90 n.s.

+ The increases in weight of the three fractions for the high pressure 'ungrazed' treatment in the second regrowth period have been taken to start from the end of the first regrowth period. The total regrowth for this treatment also includes the first regrowth period increases common to both the high pressure 'grazed' and 'ungrazed' treatments. Similar comments apply throughout the Results Section to Tables of increases in growth.

Stolon weight increased for both the high pressure 'grazed' and low pressure treatments in each regrowth period (Table 3.4.1. Part A), although the differences between these treatments were not significant. In the first regrowth period the low pressure treatment increased petiole and leaf weight/unit area significantly more than the high pressure 'grazed' treatment, and this was reflected in the total regrowth for these two fractions. A decrease in petiole weight was shwon to occur in the second regrowth period for the low pressure treatment but the increase in the weight of this fraction/unit area in the third regrowth period was significantly greater than for the high pressure 'grazed' treatment.

The high pressure 'ungrazed' treatment tended to increase the weights of stolon, petiole and leaf more than the high pressure 'grazed' treatment during the second regrowth period (Table 3.4.1. Part B), although only in the petiole fraction did this reach significance.

The increases in weight in the stolon and petiole fractions over the second regrowth period for the high pressure 'ungrazed' treatment are similar to the increases in weight of these fractions on the low pressure treatment during the first regrowth period (Table 3.4.1. Part A and B). However, the corresponding increase for the low pressure leaf weight was more than double that of the high pressure 'ungrazed' treatment for the same comparison.

During the third regrowth period there was a recorded decrease in weight/unit area of stolon on the high pressure 'ungrazed' treatment. In the same regrowth period a significantly greater leaf weight increase occurred for this treatment than for the high pressure 'grazed' treatment. The total regrowth showed significantly more leaf and petiole weight/unit area for the high pressure 'ungrazed' than the high pressure 'grazed' treatment.

B. Grazing period treatments

Figure 3.4.3. shows the weight/unit area of the fractions before and after each grazing for the 3, 6 and 9 day grazing periods (mean of the high pressure 'grazed' and low pressure treatments). Before the first grazing there were no significant differences in fraction weights between grazing periods, but before each subsequent grazing there was a tendency for the 3 day treatment to have a greater weight/unit area of all three fractions compared with the 6 and 9 day treatments. This trend was not reflected after grazing.

Figure 3.4.4. shows the weight/unit area of the three fractions before and after the third and fourth grazings for the 3, 6 and 9 day grazing periods (mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments). Before the third grazing the 3 day treatment appeared to have greater weights of

FIGURE 3.4.3. THE EFFECTS ON THE WEIGHT OF STOLONS, PETIOLES AND LEAVES OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (g/CORE)

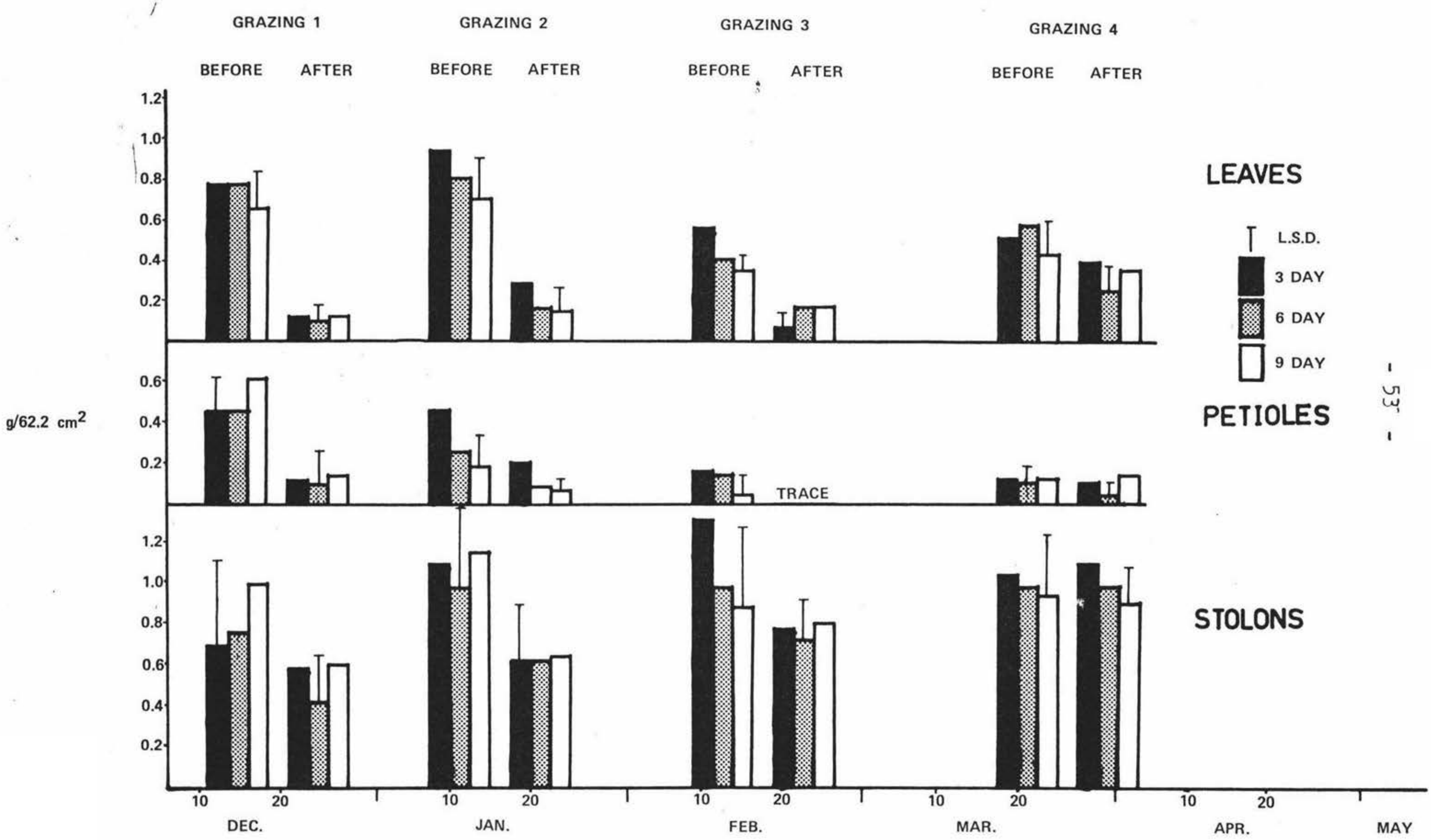
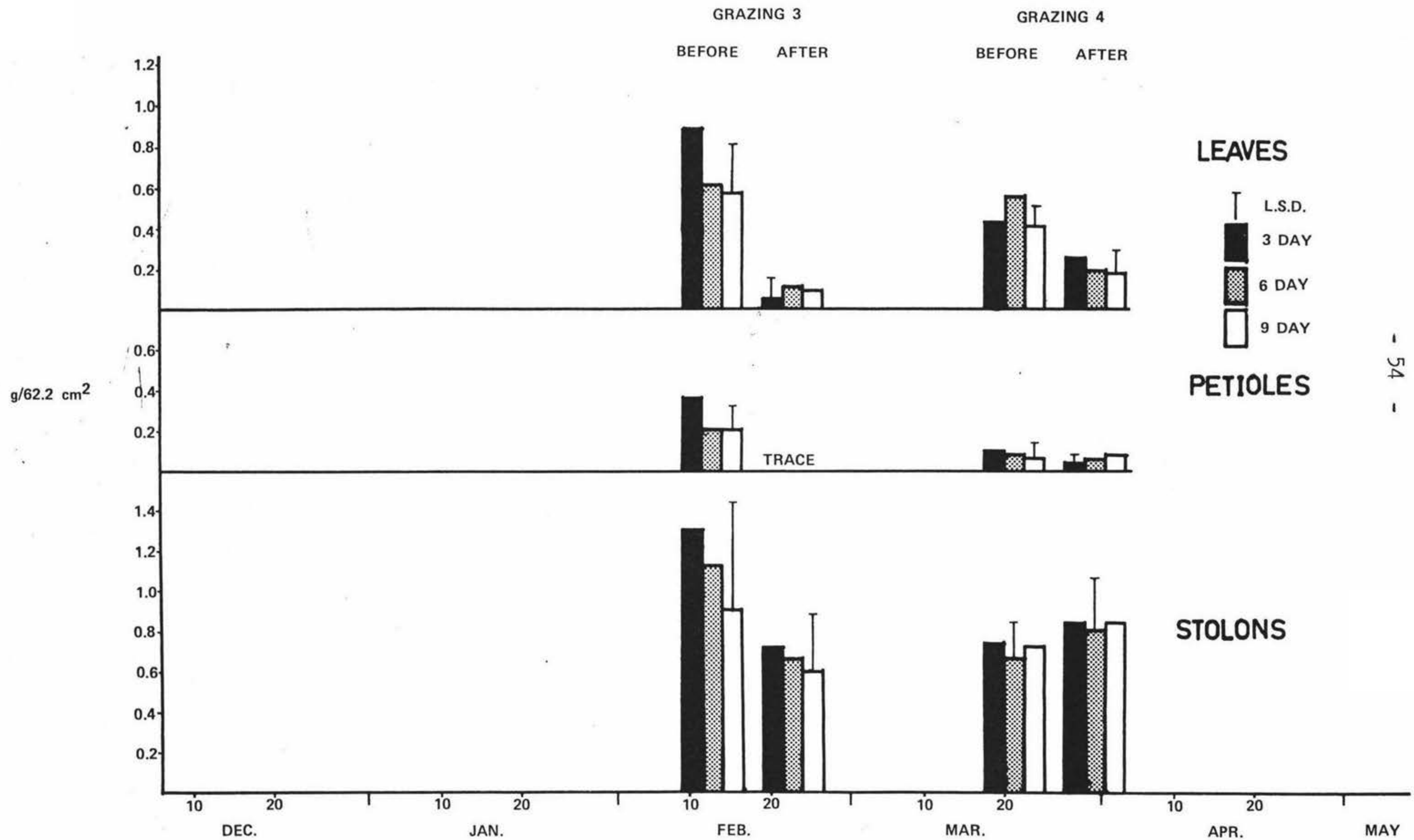


FIGURE 3.4.4. THE EFFECTS ON THE WEIGHT OF STOLONS, PETIOLES AND LEAVES OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS (g/CORE)



stolon, petiole and leaf, significant for only the petiole and leaf fractions, than either the 6 or 9 day treatments. Treatment differences subsequently were not apparent.

Table 3.4.2. shows the increases in weight of the fractions in each regrowth period for the 3, 6 and 9 day treatments.

TABLE 3.4.2.

Increase+ in fraction weights in the first, second and third regrowth periods for the 3, 6 and 9 day grazing periods. (g/62.2 cm^2, L.S.D. in brackets)

Part	Description of fraction	Grazing period (days)	Regrowth period 1	Regrowth period 2	Regrowth period 3	Total Regrowth
A Mean of (HP&LP)	Leaves	3	0.82	0.30	0.44	1.56
		6	0.70 * (0.16)	0.24 n.s.	0.44 * (0.16)	1.38 *** (0.18)
		9	0.62	0.20	0.26	1.08
	Petides	3	0.34	-0.02	0.12	0.44
		6	0.16 *** (0.12)	-0.04 n.s.	0.10 n.s.	0.22 **** (0.10)
		9	0.04	-0.04	0.12	0.12
	Stolons	3	0.54	0.72	0.26	1.52
		6	0.56 n.s.	0.36 * (0.40)	0.26 n.s.	1.18 * (0.62)
		9	0.44	0.24	0.14	0.82
B Mean of (HP&HPU)	Leaves	3		0.44	0.40	1.54
		6		0.30 n.s.	0.44 n.s.	1.24 *** (0.12)
		9		0.26	0.34	1.04
	Petioles	3		0.27	0.09	0.48
		6		0.16 * (0.10)	0.08 n.s.	0.32 ** (0.12)
		9		0.16	0.08	0.26
	Stolons	3		0.64	0.02	1.10
		6		0.66 n.s.	-0.02 n.s.	1.08 n.s.
		9		0.16	0.12	0.72

+ These increases were obtained by subtracting the weights of fractions (found from core samples) after one grazing from those before the next grazing. Since core samples were not taken at the final harvest no figures for the fourth regrowth period were obtained. Similar comments apply throughout the Results Section to Tables of increases.

The 3 day treatment increased leaf and petiole weight/unit area significantly more than the 9 day treatment and petiole weight more than the 6 day treatment also in the first regrowth period (Table 3.4.2. Part A). The 3 day treatment increased stolon weight in the second regrowth period and leaf weight in the third regrowth period significantly more than the 9 day treatment. In all three fractions the 3 day treatment was greater than the 9 day treatment in total regrowth but in the petiole fraction greater than the 6 day treatment also.

In the second regrowth period (Table 3.4.2. Part B) the trend in the leaf and petiole fractions was for the 3 day > 6 day > 9 day treatments although only in the petiole fraction was the effect significant. This trend is reflected in the leaf, petiole and stolon fractions in the total regrowth (Table 3.4.2. Part B).

3.4.2. The decreases in stolon, petiole and leaf weight at each grazing

A. Grazing pressure treatments

Table 3.4.3. shows the decreases in the weights of the fractions at each grazing for the grazing pressure treatments.

TABLE 3.4.3.

The decreases in fraction weights at each grazing for the grazing pressure treatments (g/62.2 cm^2)

Part	Description of fraction	Grazing pressure	Number of grazing 1	2	3	4	Total decrease
A	Leaves	HP	0.84 **	0.48 **	0.30 n.s.	0.20 n.s.	1.82 n.s.
		LP	0.52	0.78	0.32	0.18	1.80
	Petioles	HP	0.52 *	0.08 ***	0.04 n.s.	0.04 n.s.	0.68 n.s.
		LP	0.24	0.30	0.10	0.08	0.72
	Stolons	HP	0.32 n.s.	0.50 n.s.	0.30 n.s.	-0.18 *	0.94 n.s.
		LP	0.22	0.32	0.30	0.16	1.00
B	Leaves	HP			0.30 ****	0.20 n.s.	1.82 *
		HPU			0.92	0.32	2.07
	Petioles	HP			0.04 ****	0.04 n.s.	0.68 ***
		HPU			0.44	0.06	1.02
	Stolons	HP			0.30 *	-0.18 n.s.	0.94 n.s.
		HPU			0.58	-0.16	0.84

The significantly greater decrease in leaf and petiole weight for the high pressure 'grazed' treatment than the low pressure treatment at the first grazing (Table 3.4.3. Part A), was reversed at the second grazing. At the first and second grazing it appeared that more stolon was grazed from the high pressure 'grazed' treatment than the low pressure treatment although at the fourth grazing there was a recorded increase in stolon weight for the high pressure 'grazed' treatment.

The significantly greater decrease in all three fractions for the high pressure 'ungrazed' than the high pressure 'grazed' treatment at the third grazing (Table 3.4.3. Part B), was expected since the high pressure 'ungrazed' treatment had the greater weights of all three fractions before grazing (Fig. 3.4.2.). These decreases at the third grazing are reflected for the leaf and petiole fractions in the total decrease.

B. Grazing period treatments

Table 3.4.4. shows the decreases in fraction weights for the 3, 6 and 9 day treatments; Part A is the mean for the high pressure 'grazed' and low pressure treatments and Part B is the mean for the high pressure 'grazed' and high pressure 'ungrazed' treatments.

TABLE 3.4.4.

The decreases in fraction weights at each grazing for the 3, 6 and 9 day grazing periods (g/62.2 cm^2, L.S.D. in brackets)

Part	Description of fraction	Grazing period (days)	Number of grazing 1	2	3	4	Total decrease
A Mean of (HP&LP)	Leaves	3	0.66	0.66	0.50	0.12	1.94
		6	0.68 n.s.	0.64 n.s.	0.26 ** (0.18)	0.34 *Q (0.22)	1.92 n.s.
		9	0.72	0.60	0.18	0.14	1.64
	Petioles	3	0.32	0.28	0.16	0.04	0.80
		6	0.36 n.s.	0.20 * (0.12)	0.04 * (0.10)	0.06 n.s.	0.66 n.s.
		9	0.47	0.11	0.03	0.07	0.68
	Stolons	3	0.12	0.50	0.56	-0.06	1.12
		6	0.34 n.s.	0.36 n.s.	0.26 * (0.36)	0.00 n.s.	0.96 n.s.
		9	0.40	0.40	0.08	0.04	0.92
B Mean of (HP&HPU)	Leaves	3			0.86 **L	0.20	2.27
		6			0.50 *Q	0.36 *Q (0.12)	1.90 * (0.42)
		9			0.50 (0.18)	0.24	1.68
	Petioles	3			0.36	0.06	1.00
		6			0.20 n.s.	0.06 n.s.	0.74 n.s.
		9			0.20	0.06	0.84
	Stolons	3			0.58	-0.10	0.90
		6			0.46 n.s.	-0.14 n.s.	1.10 n.s.
		9			0.30	-0.14	0.74

The decreases in stolon, petiole and leaf weight at the third grazing were significantly greater for the 3 day than the 9 day treatment, and in the leaf and petiole fractions greater than the 6 day treatment also (Table 3.4.4. Part A). This probably resulted from the greater weights of these fractions on the 3 day treatment than the 6 or 9 day treatments before the third grazing (Fig. 3.4.3.).

The 3 day treatment appeared to be decreased at the third grazing more than the 6 or 9 day treatments in all three fractions (Table 3.4.4. Part B), although only in the leaf fraction was this significant. This was reflected in the total decrease for this fraction.

3.5. LENGTH OF STOLON, NUMBER OF TERMINAL BUDS AND NEW STOLONS

3.5.1. Production of length of stolon, terminal buds and new stolons

A. Grazing pressure treatments

Figure 3.5.1. shows the total length of stolon, the numbers of terminal buds and the numbers of new stolons (hereafter called parameters) before and after each of the four grazings for the high pressure 'grazed' and low pressure treatments. No significant differences occurred in the levels of the parameters before the first grazing.

At each grazing the length of stolon/62.2 cm^2 was decreased by about half on the high pressure 'grazed' treatment (Fig. 3.5.1.), except at the fourth grazing. Only at the third grazing was the length of stolon and the numbers of terminal buds decreased markedly for the low pressure treatment. Before each of the grazings two, three and four, the low pressure treatment had similar lengths of stolon/unit area, 70-75cm/62.2 cm^2, and also similar numbers of terminal buds 6-7/62.2 cm^2. For the high pressure 'grazed' treatment there appeared to be a greater length of stolon after than before the fourth grazing which although difficult to explain may be accounted for by the noticeable increase in the number of new stolons at this grazing (Fig. 3.5.1.).

Figure 3.5.2. shows the levels of the parameters before and after the last two grazings for the high pressure 'grazed' and high pressure 'ungrazed' treatments. Before the third grazing there was a significantly greater length of stolon and number of terminal buds but significantly smaller number of new stolons on the high pressure 'ungrazed' compared with the high pressure 'grazed' treatment. After the fourth grazing there was a greater length of stolon and number of new stolons on both treatments than before the fourth grazing.

The levels of the parameters for the high pressure 'ungrazed' treatment at the start of the third grazing were almost the same as those of the low pressure treatment at the same time (Figs. 3.5.2. and 3.5.1.) and these levels were 60-70 cm of stolon, 6-7 terminal buds and 20 new stolons/62.2 cm^2.

Table 3.5.1. shows the increases in the parameters for the grazing pressures in the first, second and third regrowth periods.

FIGURE 3.5.1. THE EFFECTS ON THE LENGTH OF STOLON, NUMBERS OF TERMINAL BUDS AND NEW STOLONS OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (per Core)

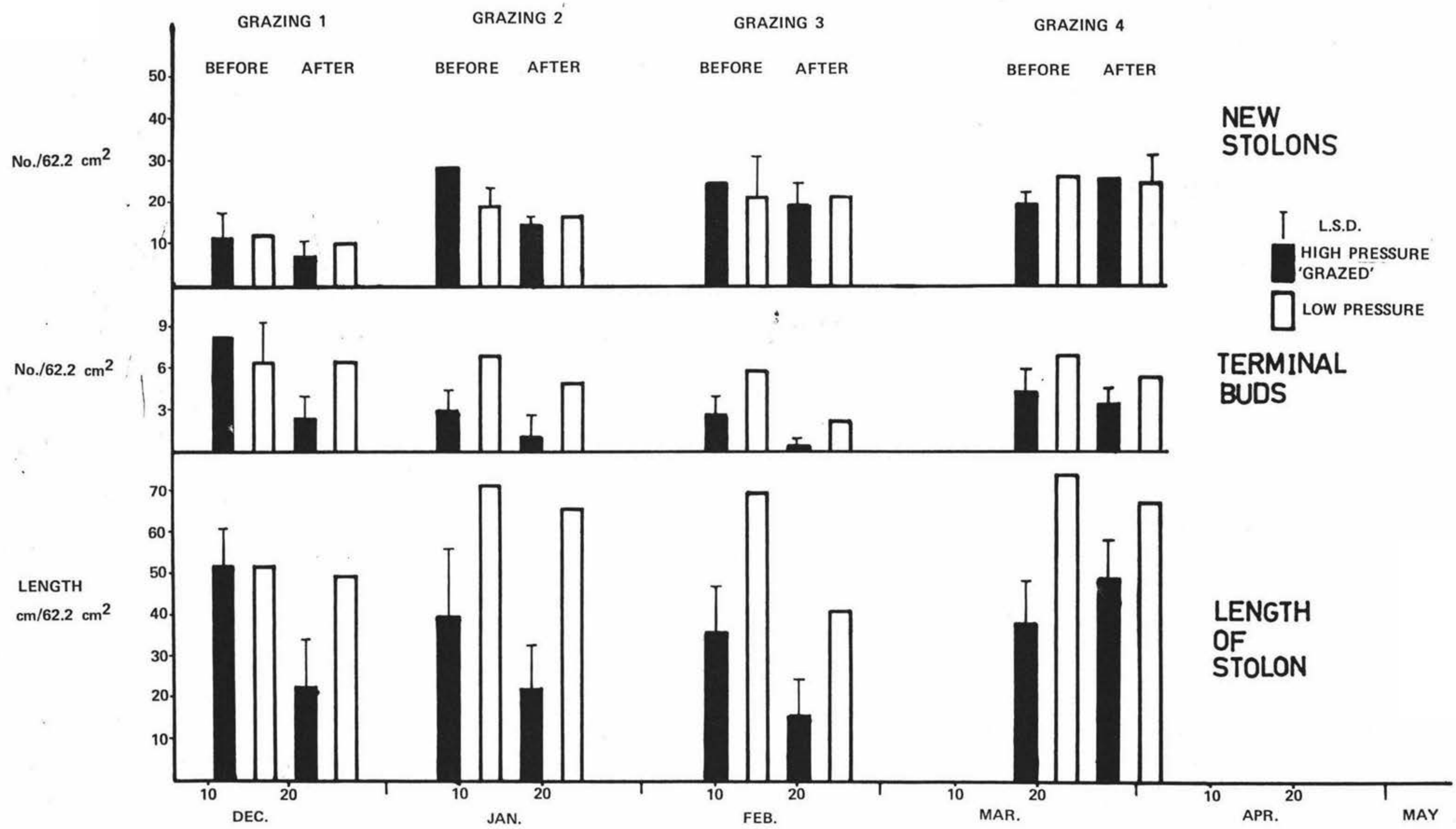


FIGURE 3.5.2. THE EFFECTS ON THE LENGTH OF STOLON, NUMBERS OF TERMINAL BUDS AND NEW STOLONS OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS (per Core)

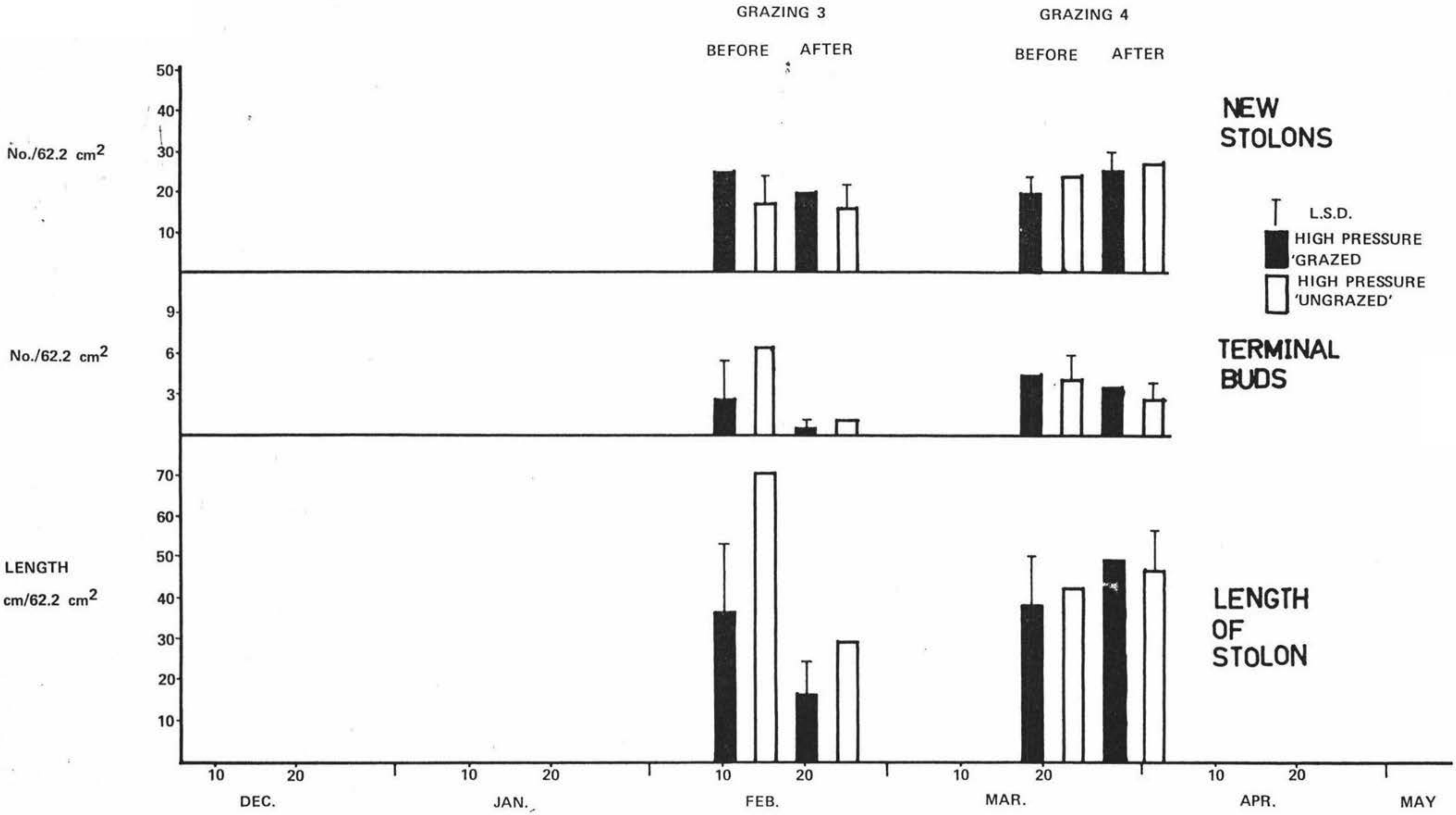


TABLE 3.5.1.

The increases in the parameters in the first, second and third regrowth periods for the grazing pressures (Length of stolon in cm)

Part	Description of parameter	Grazing pressure	Regrowth period			Total regrowth
			1	2	3	
A	Length of stolon	HP LP	16.7 23.7 n.s.	14.1 3.8 n.s.	21.9 32.7 *	52.6 60.1 n.s.
	Nos. of terminal buds	HP LP	0.5 0.4 n.s.	1.7 0.9 n.s.	3.9 4.8 n.s.	6.1 6.1 n.s.
	Nos. of new stolons	HP LP	21.2 8.4 ***	11.0 4.4 *	0.4 5.2 n.s.	32.6 18.0 ***
B	Length of stolon	HP HPU		14.1 30.9 *	21.9 13.6 n.s.	52.6 61.1 n.s.
	Nos. of terminal buds	HP HPU		1.7 3.5 n.s.	3.9 3.0 n.s.	6.1 7.0 n.s.
	Nos. of new stolons	HP HPU		11.0 -11.7 ****	0.4 7.7 **	32.6 17.1 ***

There was a significantly greater increase in the numbers of new stolons on the high pressure 'grazed' compared with the low pressure treatment in both the first and second regrowth periods reflected also in the total increase in this parameter (Table 3.5.1. Part A). The numbers of new stolons which formed in the first regrowth period for both treatments were greater than in the second and third regrowth periods. In the third regrowth period the low pressure treatment appeared to increase length of stolon, numbers of terminal buds and new stolons (only significant for length of stolon) more than the high pressure 'grazed' treatment.

Table 3.5.1. Part B, shows that there was a significantly greater increase in the length of stolon for the high pressure 'ungrazed' treatment than the high pressure 'grazed' treatment in the second regrowth period, although there was a recorded death of new stolons for the former treatment. This death was reflected in the total numbers of new stolons formed which were significantly greater on the high pressure 'grazed' than the high pressure 'ungrazed' treatment. The increase in the numbers of new stolons over the third regrowth period was significantly greater for the high pressure 'ungrazed' than the high pressure 'grazed' treatment.

B. Grazing period treatments

Figure 3.5.3. shows the length of stolon, numbers of terminal buds and new stolons before and after each grazing for the 3, 6 and 9 day grazing periods (mean of the high pressure 'grazed' and low pressure treatments). The 9 day plots had a significantly greater length of stolon before the first grazing period than either the 3 or the 6 day plots. No significant grazing period effects occurred either before or after the second, third or fourth grazings in the length of stolon and numbers of terminal buds, except at the beginning of the third grazing when the 3 day treatment had significantly more terminal buds and significantly greater length of stolon than either the 6 or 9 day treatments (Fig. 3.5.2.). Both before and after the second grazing the 9 day treatment had a significantly greater number of new stolons than either the 3 or 6 day treatments.

Figure 3.5.4. shows the effects on the parameters of the 3, 6 and 9 day grazing periods before and after the third and fourth grazings (mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments). The 3 day treatment had a significantly greater length of stolon before the third grazing than the 9 day treatment (Fig. 3.5.4.).

Table 3.5.2. shows the increases in the parameters for the 3, 6 and 9 day grazing periods during the first, second and third regrowth periods.

FIGURE 3.5.3. THE EFFECTS ON THE LENGTH OF STOLON, NUMBERS OF TERMINAL BUDS AND NEW STOLONS OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (per Core)

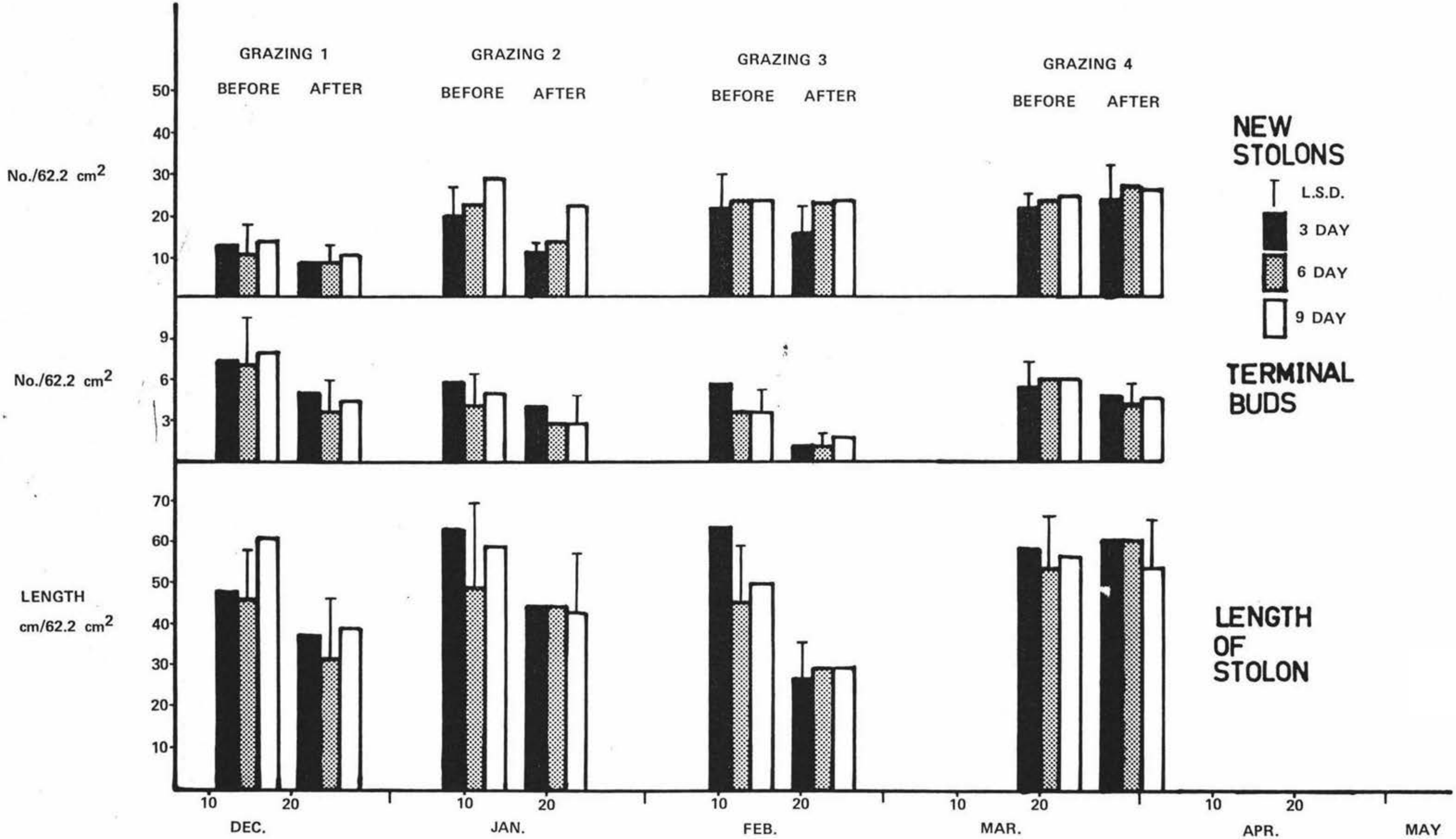


FIGURE 3.5.4. THE EFFECTS ON THE LENGTH OF STOLON, NUMBERS OF TERMINAL BUDS AND NEW STOLONS OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS

(per Core)

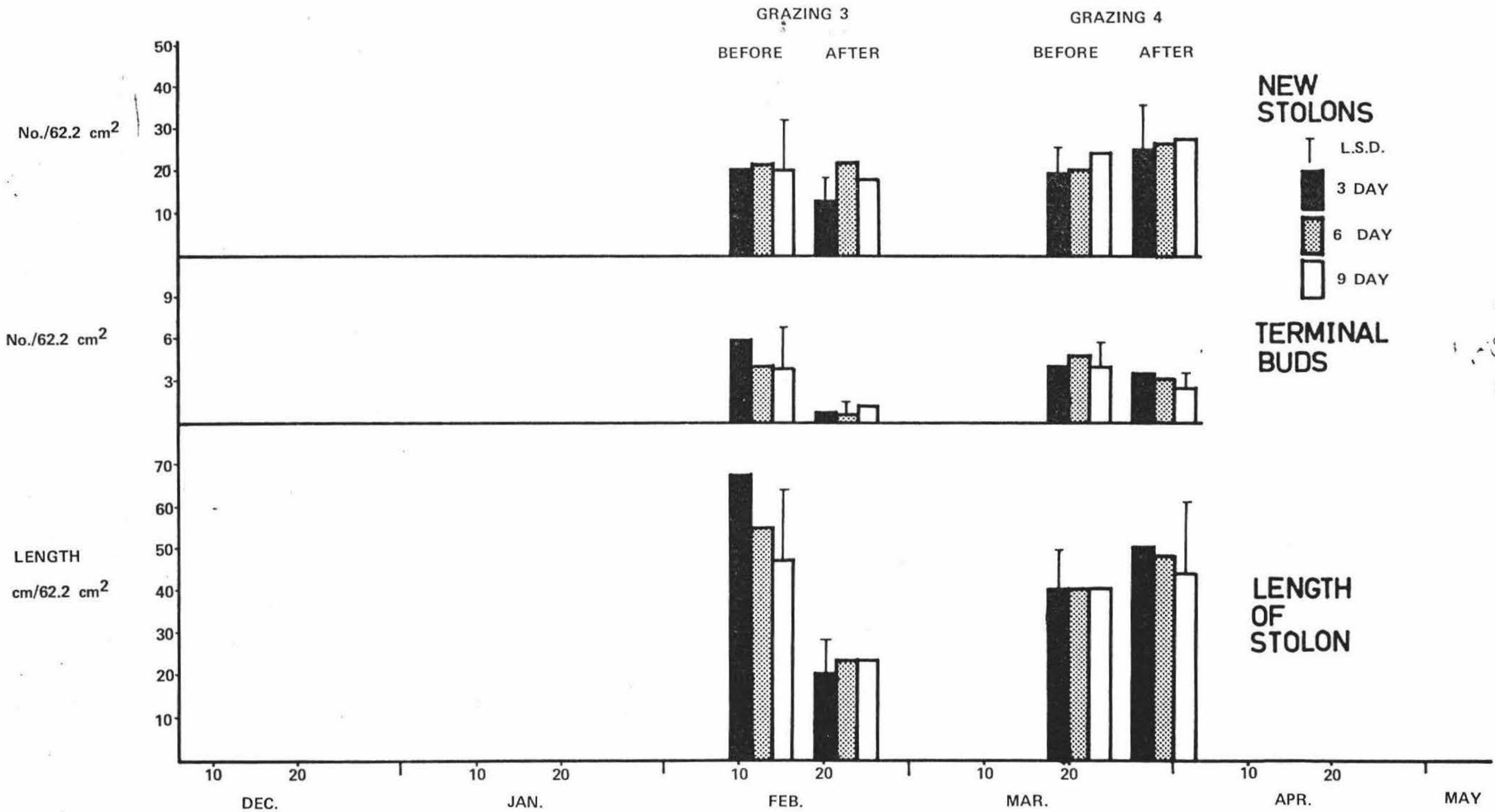


TABLE 3.5.2.

The increases in the parameters for the 3, 6 and 9 day grazing periods (Length of stolon in cm/62.2 cm^2, L.S.D. in brackets)

Part	Description of parameter	Grazing period (days)	Regrowth period			Total regrowth
			1	2	3	
A	Length of stolon	3	21.0	19.5	31.4	71.8
Mean		6	20.0 n.s.	1.0 n.s.	24.1 n.s.	45.1 n.s.
of		9	19.6	6.4	26.4	52.3
(HP&LP)	Nos. of terminal buds	3	0.7	1.8	4.2	6.6
		6	0.4 n.s.	1.3 n.s.	4.9 n.s.	6.5 n.s.
		9	0.2	0.9	4.1	5.2
	Nos. of new stolons	3	11.8	11.2	6.4	29.3
		6	14.3 *	10.0 *	0.9 n.s.	25.1 *
		9	18.3 (6.30)	2.0 (6.80)	1.2	21.6 (7.30)
B	Length of stolon	3		24.0	19.6	59.8
Mean		6		31.3 n.s.	16.9 n.s.	64.1 *
of		9		12.2	16.8	46.8 (10.10
(HP&HPU)	Nos. of terminal	3		2.9	3.4	6.9
		6		3.0 n.s.	4.3 *Q	7.8 n.s.
		9		2.0	2.7 (1.30)	5.1
	Nos. of new stolons	3		2.3	6.8	28.7
		6		2.2 n.s.	-1.1 n.s.	20.6 n.s.
		9		-5.6	6.4	25.3

There was a trend for the 3 day treatment increases in length of stolon to be greater than for the 6 and 9 day treatments in each regrowth period (Table 3.5.2. Part A). In the first regrowth period the 9 day treatment had a significantly greater increase in the numbers of new stolons than the 3 day treatment but this situation was reversed in the second regrowth period and in the total regrowth.

For all three parameters in the second regrowth period the 3 and 6 day treatments tended to be greater than the 9 day treatment (Table 3.5.2. Part B). For the length of stolon this effect became significant in the total regrowth (Table 3.5.2. Part B).

3.5.2. The decreases in parameters at each grazing

A. Grazing pressure treatments

Table 3.5.3. shows the decreases in the parameters at each grazing.

TABLE 3.5.3.

The decreases in parameters at each grazing (length of stolon in cm)

Part	Description of parameter	Grazing pressure	Number of grazing 1	2	3	4	Total decrease
A	Length of stolon	HP	28.7	17.7	20.2	-10.6	56.0
			**	n.s.	n.s.	*	n.s.
		LP	2.5	8.0	28.2	6.5	45.2
	Nos. of terminal buds	HP	6.5	1.7	2.4	1.0	11.6
			***	n.s.	n.s.	n.s.	n.s.
		LP	0.1	2.0	3.7	1.6	7.4
	Nos. of new stolons	HP	4.2	14.4	5.6	-6.3	18.0
			n.s.	***	*	*	**
		LP	2.1	2.6	-0.9	2.1	6.0
B	Length of stolon	HP			20.2	-10.6	56.0
					**	n.s.	n.s.
		HPU			41.7	-3.8	66.6
	Nos. of terminal buds	HP			2.4	1.0	11.6
					*	n.s.	n.s.
		HPU			5.4	1.4	13.3
	Nos. of new stolons	HP			5.6	-6.3	18.0
					n.s.	n.s.	****
		HPU			1.0	-3.5	1.7

The significantly greater length of stolon removed from the high pressure 'grazed' treatment than the low pressure treatment at the first grazing was similarly accompanied by a significant reduction in terminal bud numbers. For the terminal buds this did not follow the same pattern at other grazings (Table 3.5.3. Part A).

The significantly greater decrease in both the length of stolon and numbers of terminal buds for the high pressure 'grazed' than the low pressure treatment at the first grazing did not follow the same pattern at other grazings, although the trend was still present in the total decreases for these parameters (Table 3.5.3. Part A). At both the second and third grazings there was a significantly greater decrease in the numbers of new stolons for the high pressure 'grazed' than the low pressure treatment, and this was reflected in the total decrease in new stolons. A recorded increase in the numbers of new stolons over the fourth grazing for the high pressure 'grazed' treatment may explain the recorded increase in stolon length for this treatment at the fourth grazing.

It was expected that the high pressure 'ungrazed' treatment would have a greater decrease in length of stolon and numbers of terminal buds at the third grazing than the high pressure 'grazed' treatment (Table 3.5.3. Part B) since the values of these parameters were higher at the start of this grazing for the former treatment. Nevertheless the total decrease in numbers of new stolons for the high pressure 'grazed' treatment was greater than for the high pressure 'ungrazed' treatment.

B. Grazing period treatments

Table 3.5.4. shows the decreases in the parameters at each grazing for the 3, 6 and 9 day grazing periods.

TABLE 3.5.4.

The decreases in parameters at each grazing for the 3, 6 and 9 day grazing periods
(Length of stolon in cm/62.2 cm^2, L.S.D. in brackets)

Part	Description of parameter	Grazing period (days)	Number of grazing				Total decrease
			1	2	3	4	
A	Length of stolon	3	11.0	14.3	37.0 *L	-2.1	60.1
Mean		6	13.9 n.s.	8.1 n.s.	16.0 *Q	-6.6 n.s.	31.3n.s.
of		9	22.1	16.2	19.6 (13.3)	2.5	60.4
(HP&LP)	Nos. of terminal buds	3	2.4	1.9	4.5	0.7	9.4
		6	3.6 n.s.	1.5 n.s.	2.9 **	1.9 n.s.	9.8n.s.
		9	4.0	2.2	1.8 (1.6)	1.3	9.3
	Nos. of new stolons	3	4.6	9.6	6.1	-1.7	18.5
		6	1.7 n.s.	9.1 n.s.	0.7 n.s.	-3.2 n.s.	8.3n.s.
		9	3.4	6.8	0.4	-1.4	9.2
B	Length of stolon	3			38.0	-10.5	64.2
Mean		6			31.3 *	-7.5 n.s.	59.2n.s.
of		9			23.5 (9.10)	-3.7	60.4
(HP&HPU)	Nos. of terminal buds	3			5.1	0.5	12.3
		6	—		3.9 *	1.7 n.s.	13.0n.s.
		9			2.8 (2.10)	1.4	12.0
	Nos. of new stolons	3			7.4	-5.6	16.7
		6			0.4 n.s.	-6.2 n.s.	2.0n.s.
		9			2.2	-4.5	11.0

The greater length of stolon and number of terminal buds before the third grazing in the 3 day treatment than the 6 or 9 day treatment already cited (Fig. 3.5.3.), is probably the reason for the significantly greater decrease in these two parameters at the third grazing for the 3 day than the 6 or 9 day treatments (Table 3.5.4. Part A). The same situation applies for these two parameters at the third grazing in Table 3.5.4. Part B.

3.6. PETIOLE LENGTHS

Introduction

The differences in petiole lengths between treatments were not analysed because it was felt that the differences in petiole weights between treatments (Section 3.4.) adequately measured treatment differences. In order to appreciate the differences in canopy structure, however, some results are presented.

A. Grazing pressure treatments

Developing, mature and senescing petioles were defined as those having developing, mature or senescing leaves respectively. Figure 3.6.1. shows the effects of high pressure 'grazed' and low pressure treatments on mature petiole lengths before and after each grazing.

Before the first grazing canopy structure appeared to be similar for the treatment plots (Fig. 3.5.1.a.). After the first grazing there were more petioles in the 0-3 cm and 4-6 cm ranges on the low pressure compared with the high pressure 'grazed' treatment and also the low pressure treatment canopy extended to a greater height (Fig. 3.5.1.b.). This basic pattern was reflected before and after each subsequent grazing except after the third grazing when the lengths of petiole remaining were similar between treatments.

B. Grazing period treatments

For the mean of the high pressure 'grazed' and low pressure treatments the numbers of mature petioles in each length range were similar between the 3, 6 and 9 day grazing periods although there was a slight tendency for the 3 day > 6 day > 9 day grazing period reflecting the differences in weights of petioles between treatments.

3.7. LEAF AREA MEASUREMENTS

3.7.1. The production of developing, mature and senescing leaf

A. Grazing pressure treatments

Figure 3.7.1. shows the composition of leaf area in terms of developing,

FIGURE 3.6.1. THE EFFECTS ON MATURE PETIOLE LENGTHS OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (NUMBER OF MATURE PETIOLES/ 62.2 cm²)

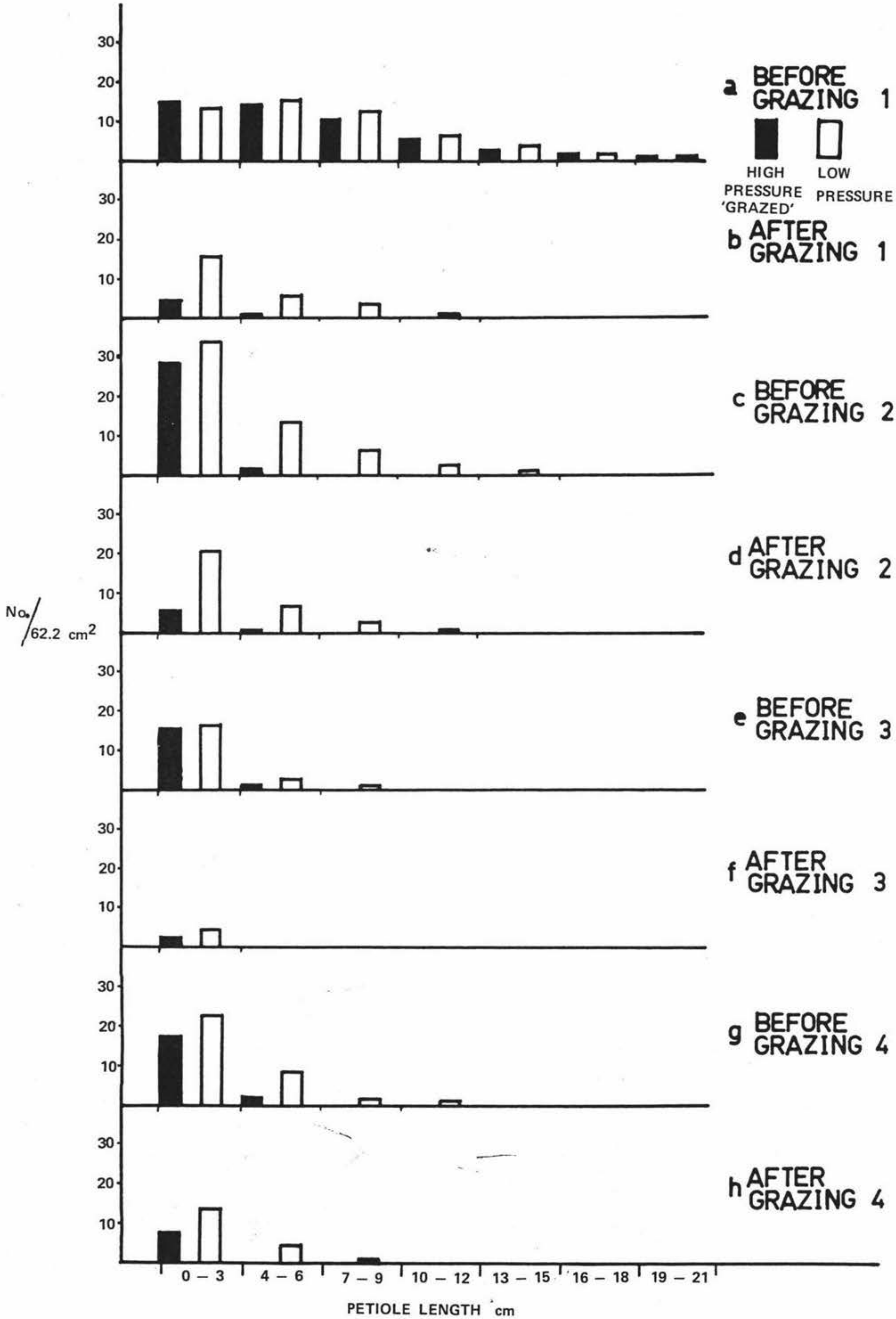
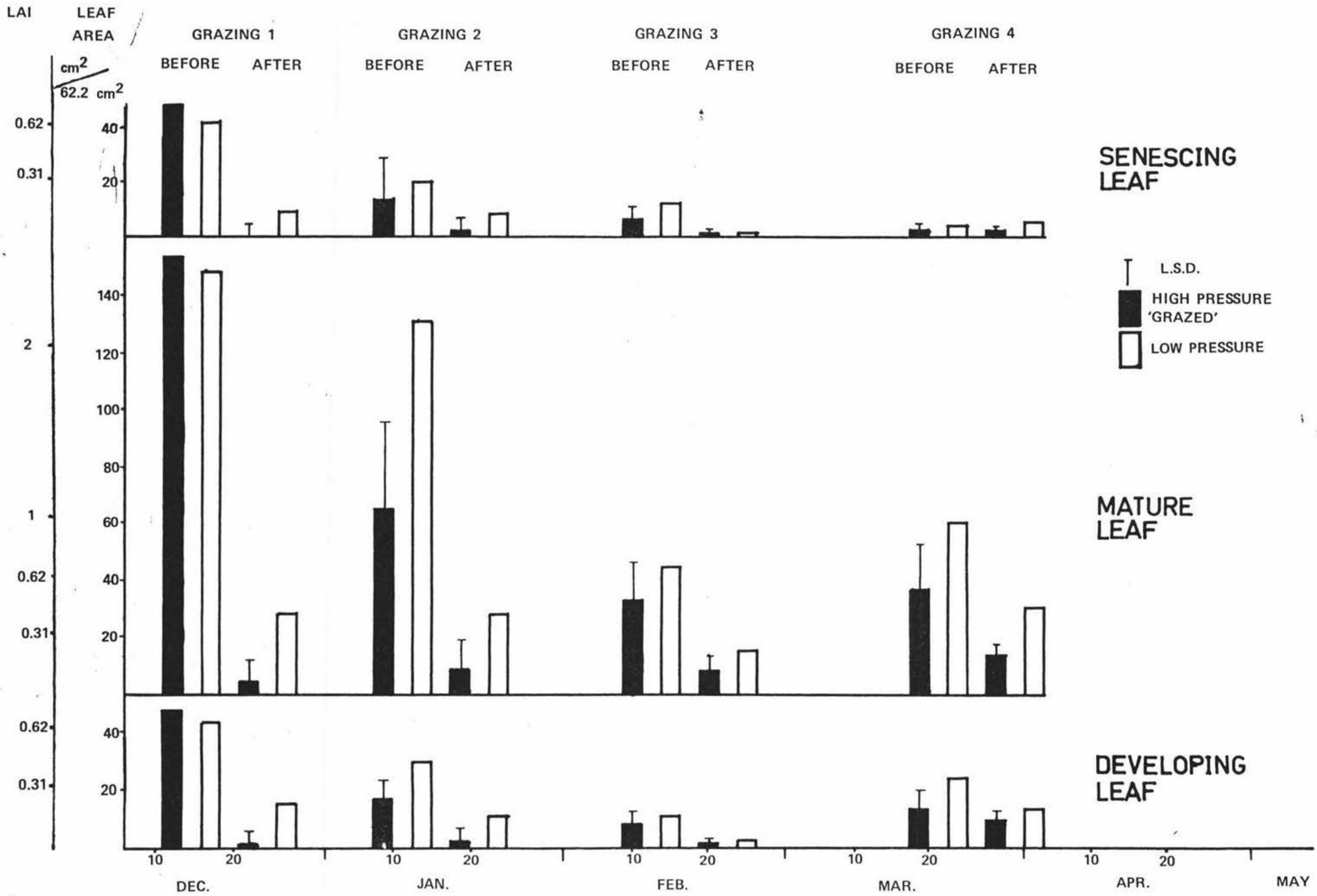


FIGURE 3.7.1. THE EFFECTS ON THE COMPOSITION OF LEAF AREA OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (per Core)



mature and senescing leaf before and after each grazing for the high pressure 'grazed' and low pressure treatments. Before treatments began there were no significant differences in the area of each category of leaf present between plots (Fig. 3.7.1.). Before and after each subsequent grazing the low pressure treatment had more of each category of leaf present than the high pressure 'grazed' treatment although the differences were much smaller before and after the third and fourth grazings.

Figure 3.7.2. shows the distribution of the total mature leaf area shown in Figure 3.7.1. in various leaf size ranges before and after each grazing. Graphs of the distribution of the total developing and senescing leaf area in size ranges are not shown because a similar pattern to the distribution of total mature leaf area occurred.

Before the first grazing there was a large area of leaf in size ranges C, D and E (Fig. 3.7.2.) and very little in size ranges A and B. At each successive pregrazing situation an increasing build up of area in leaf size ranges A and B occurred for both the high pressure 'grazed' and low pressure treatments. Just before the second grazing a significantly greater leaf area in size ranges A and B occurred on the high pressure 'grazed' than the low pressure treatment.

The very considerable range in leaf size found in clover canopies is highlighted in the following Table 3.7.1. which presents the numbers of leaves in each size group to equal 1 LAI (the area of leaf, one side only covering 62.2 cm^2).

TABLE 3.7.1.

The number of leaves in each size group to equal 1 LAI per 62.2 cm^2

Name of Group	A	B	C	D	E	LARGE
Area/leaf cm^2	0.20-0.40	0.63-1.0	1.58-2.51	3.98-6.31	10.0-15.8	20.0-25.1
No. of leaves for one LAI approx.	311-156	99-62	39-25	16-10	6-4	3-2.5

Figure 3.7.3. shows the total areas of developing, mature and senescing leaf for the high pressure 'grazed' and high pressure 'ungrazed' treatments before and after the third and fourth grazings. At the beginning of the third grazing the high pressure 'ungrazed' treatment had a greater area of developing, mature and senescing leaf than the high pressure 'grazed' treatment. Subsequently the areas of each category of leaf were similar between these two treatments.

Table 3.7.2. shows the increases in leaf area during the first, second and third regrowth periods for the grazing pressure treatments.

FIGURE 3.7.2. THE EFFECTS ON THE DISTRIBUTION OF MATURE LEAF AREA INTO LEAF SIZE RANGES OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (per Core)

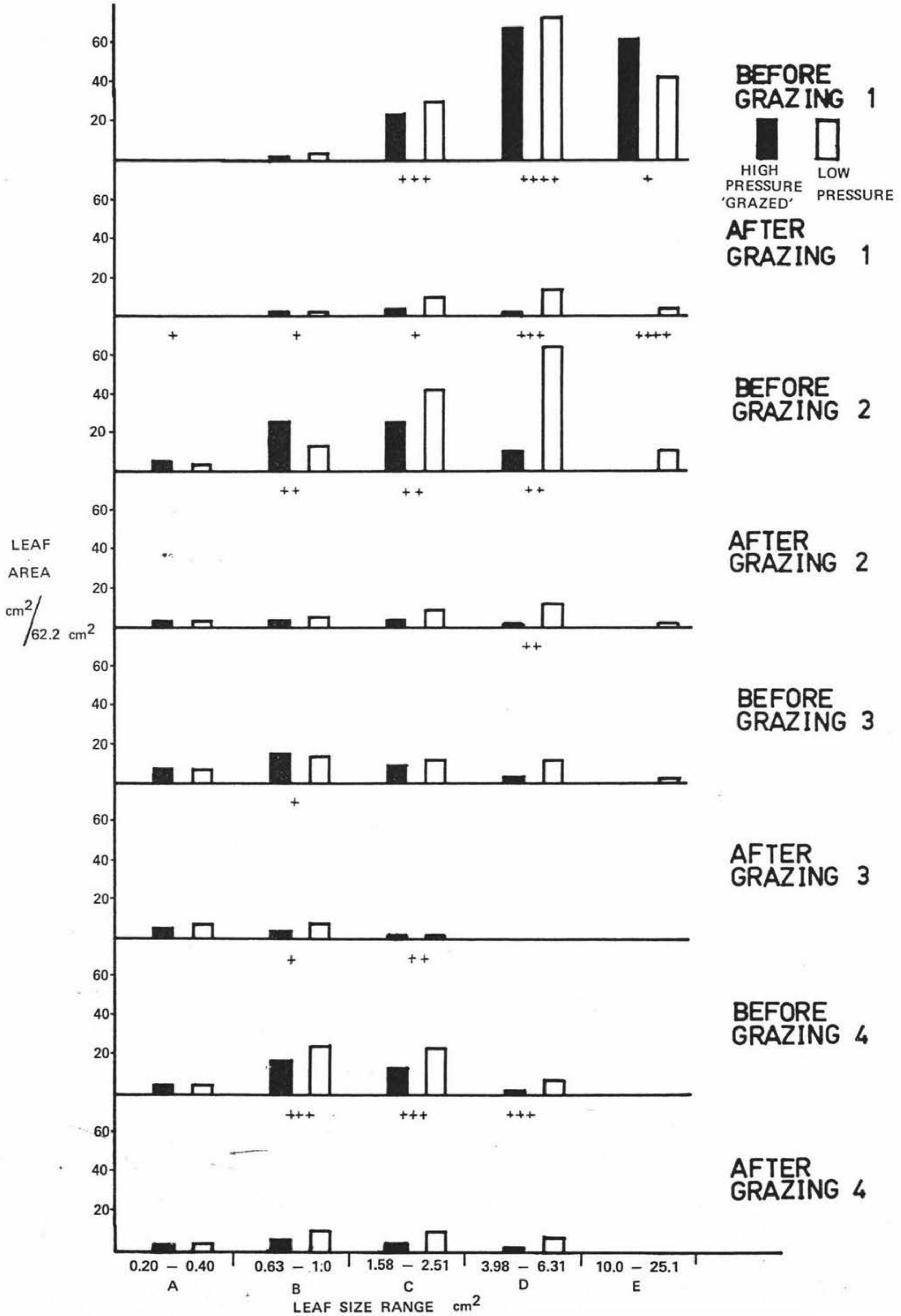


FIGURE 3.7.3. THE EFFECTS ON THE COMPOSITION OF LEAF AREA OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS (per Core)

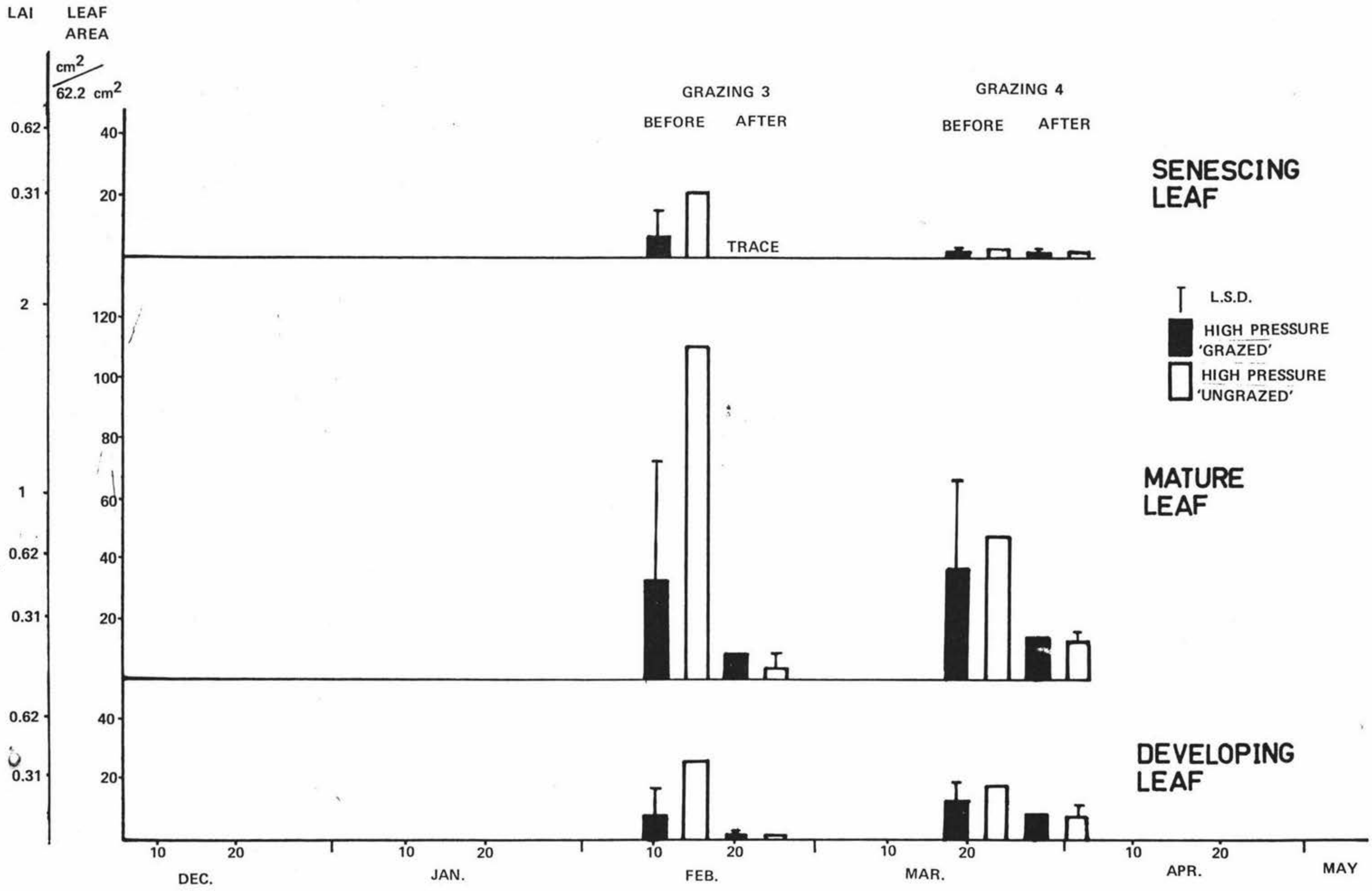


TABLE 3.7.2.

The increases in leaf area during the first, second and third regrowth periods for the grazing pressure treatments ($cm^2/62.2\ cm^2$)

Part	Description of leaf	Grazing pressure	Regrowth period 1	Regrowth period 2	Regrowth period 3	Total regrowth
A	Developing	HP LP	15.2 12.7 n.s.	5.9 -0.68 **	12.2 21.6 **	33.2 33.6 n.s.
	Mature	HP LP	60.0 103.0 *	24.7 17.2 n.s.	28.1 45.5 *	112.8 165.8 **
	Senescing	HP LP	13.3 11.2 n.s.	3.7 2.2 n.s.	1.4 2.3 n.s.	18.4 15.7 n.s.
B	Developing	HP HPU		5.9 8.9 n.s.	12.0 15.6 n.s.	33.2 39.7 n.s.
	Mature	HP HPU		24.6 46.0 n.s.	28.1 43.2 n.s.	112.7 149.2 n.s.
	Senescing	HP HPU		3.7 6.8 n.s.	1.4 2.4 n.s.	18.4 22.5 n.s.

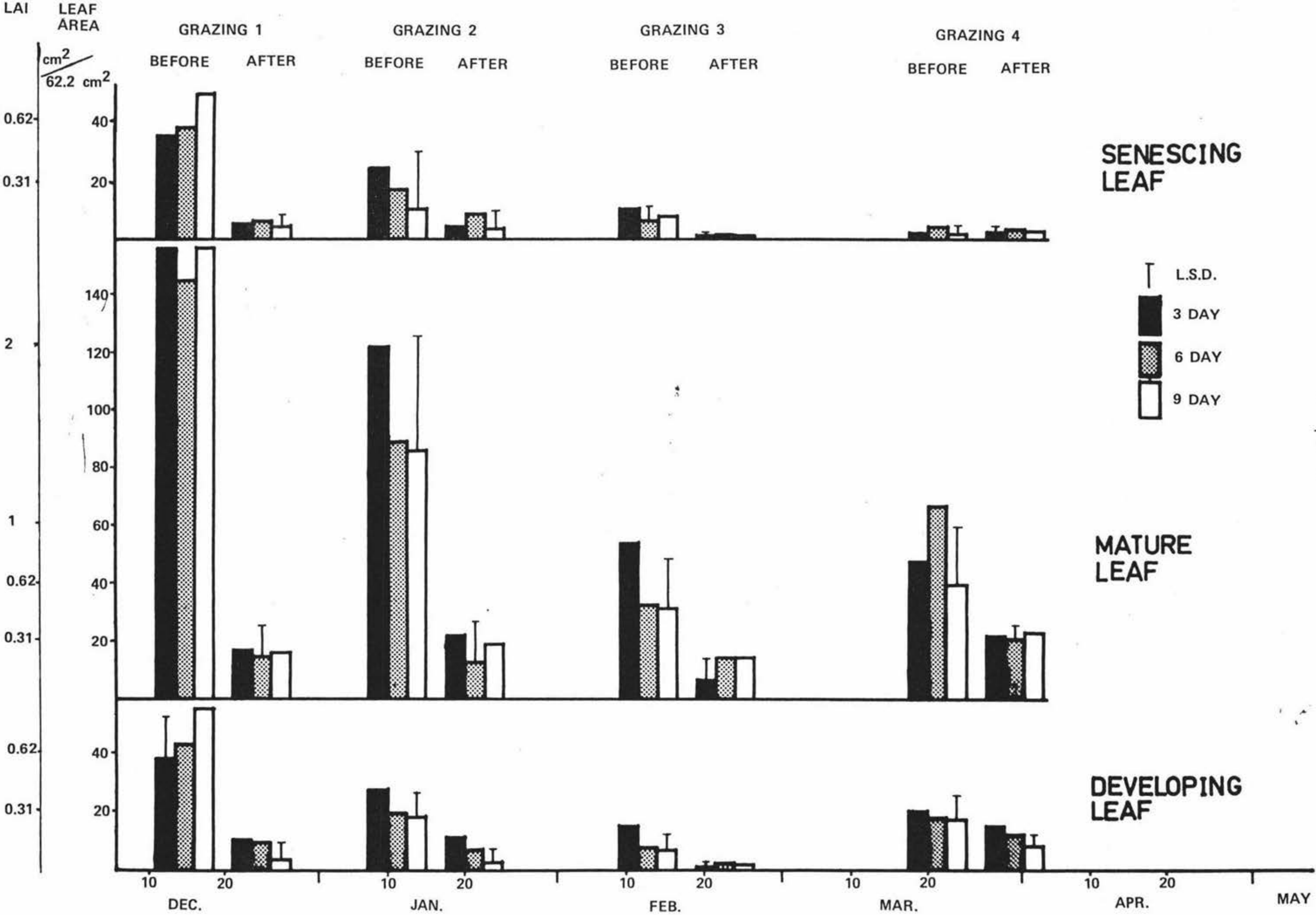
The significantly greater mature leaf area increase in the first and third regrowth periods for the low pressure treatment than the high pressure 'grazed' treatment was the main reason for the greater total regrowth for the former than the latter treatment (Table 3.7.2. Part A). The increase in leaf area for the mature and developing leaf was greater (although not significantly so for mature leaf) for the high pressure 'grazed' treatment than the low pressure treatment in the second regrowth period. The reverse was the case in the third regrowth period.

In both the second and third regrowth periods the high pressure 'ungrazed' treatment appeared to increase all three categories of leaf more than the high pressure 'grazed' treatment (Table 3.7.2. Part B); this appeared to be reflected in the total leaf area increases.

B. Grazing period treatments

Figure 3.7.4. shows the total leaf area of developing, mature and senescing leaf before and after each grazing for the 3, 6 and 9 day grazing periods (mean of the high pressure 'grazed' and low pressure treatments). The 9 day

FIGURE 3.7.4. THE EFFECTS ON THE COMPOSITION OF LEAF AREA OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS (per Core)



treatment plots had significantly more developing leaf than the 3 day treatment plots before the first grazing. Before the second and third grazings the 3 day treatment had more of each category of leaf than either the 6 or 9 day treatments although only in some cases was this difference significant.

Figure 3.7.5. shows the effects of the 3, 6 and 9 day grazing periods (mean of high pressure 'grazed' and low pressure treatments) on the distribution of leaf area by size group before and after each grazing. The same general pattern is shown in Figure 3.7.5. as in Figure 3.7.2. with larger leaves at the start of the first grazing than at the start of the fourth grazing. At the beginning of the second grazing the 3 day treatment had a significantly greater leaf area in the D and E size ranges than the 9 day treatment and similarly with the C and D size ranges at the beginning of the third grazing (Fig. 3.7.5.). The 9 day treatment had a significantly greater area of leaf in size group A than the 3 day treatment just before the second and third grazings.

Figure 3.7.6. shows the composition of leaf area for the 3, 6 and 9 day grazing periods before and after the third and fourth grazings(mean of high pressure 'grazed' and high pressure 'ungrazed' treatments). No general pattern was observed.

Table 3.7.3. shows the increases in leaf area of developing, mature and senescing leaf for the grazing periods.

FIGURE 3.7.5. THE EFFECTS ON THE DISTRIBUTION OF MATURE LEAF AREA TO LEAF SIZE RANGES OF THE 3, 6 AND 9 DAY GRAZING PERIODS
MEAN OF THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS
(per Core)

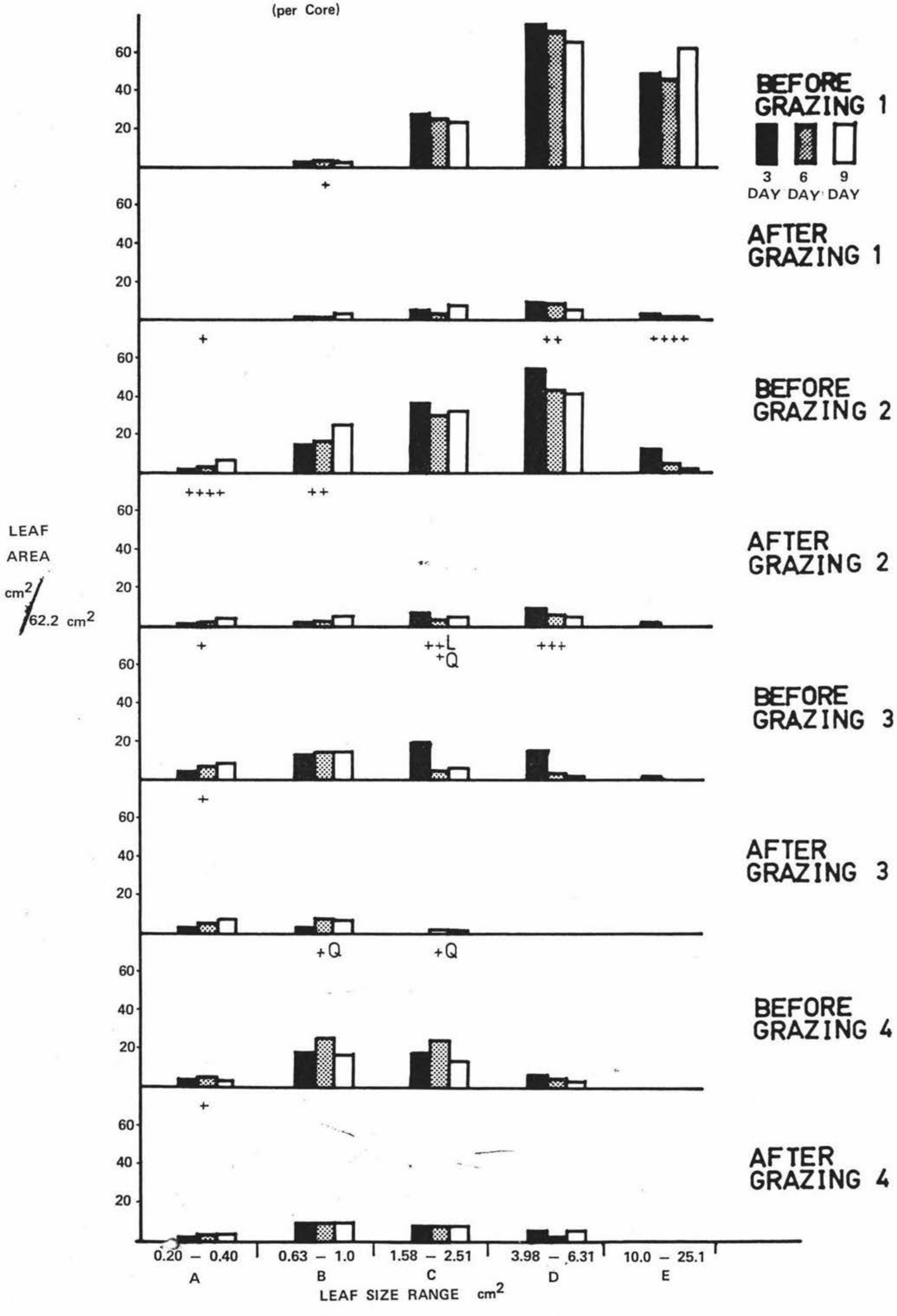


FIGURE 3.7.6. THE EFFECTS ON THE COMPOSITION OF LEAF AREA OF THE 3, 6 AND 9 DAY GRAZING PERIODS MEAN OF THE HIGH PRESSURE 'GRAZED' AND HIGH PRESSURE 'UNGRAZED' TREATMENTS (per Core)

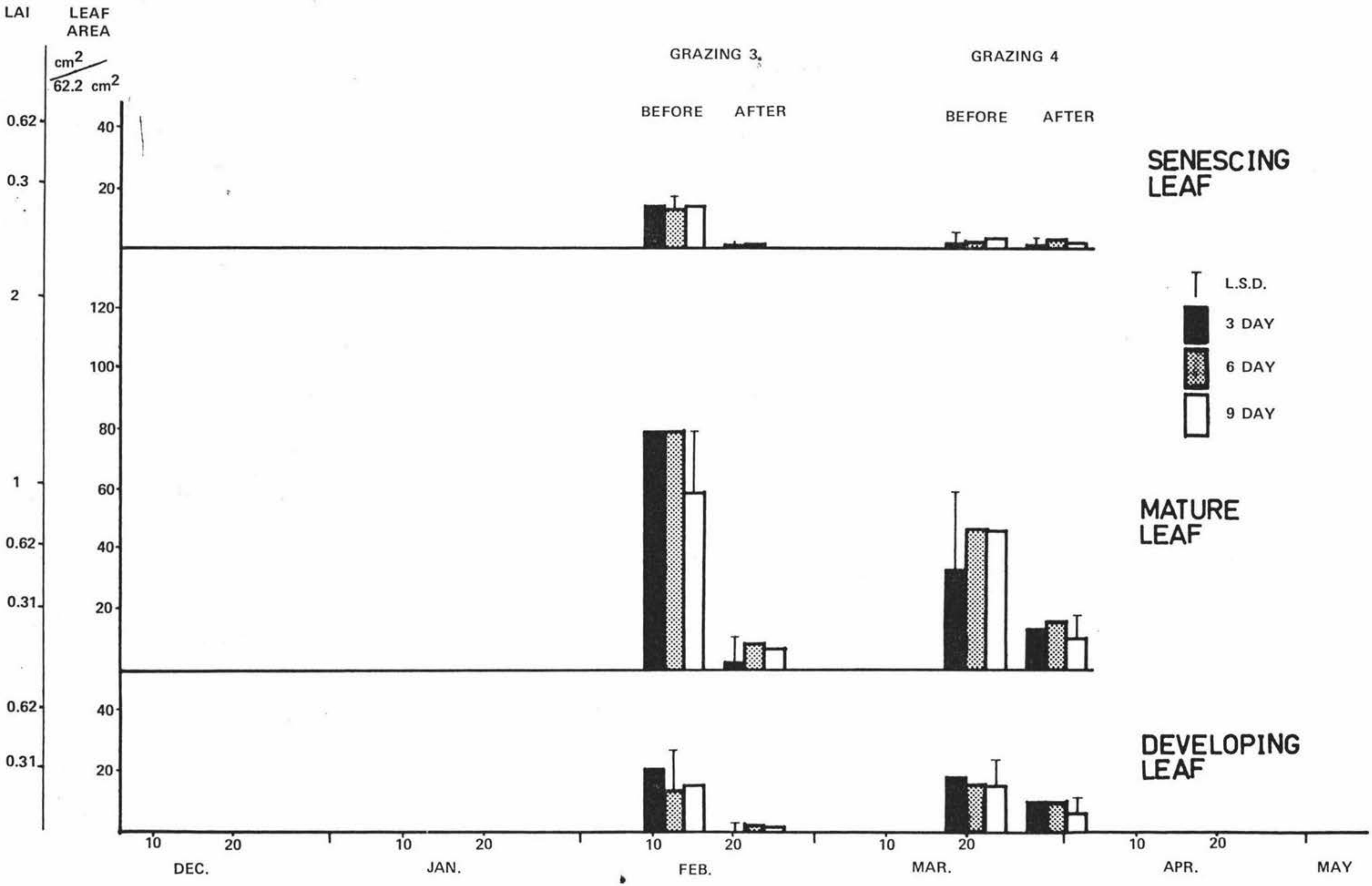


TABLE 3.7.3.

The increases in total leaf area of developing, mature and senescing leaf for the grazing periods ($cm^2/62.2\ cm^2$, L.S.D. in brackets)

Part	Description of leaf	Grazing period (days)	Regrowth period 1	Regrowth period 2	Regrowth period 3	Total regrowth
A Mean of (HP&LP)	Developing	3	17.6	3.9	19.3	40.8
		6	10.1 n.s.	0.2 *Q	15.9 n.s.	26.3 *Q
		9	14.1	3.8 (4.10)	15.3	33.1 (11.02)
	Mature	3	102.5	31.6	40.3	174.5
		6	72.7 n.s.	19.3 n.s.	45.4 n.s.	137.4 **
		9	68.5	12.7	24.6	105.8 (41.56)
	Senescing	3	19.0	7.0	1.6	27.6
		6	11.3 n.s.	-1.8 -*Q	3.2 n.s.	12.8 n.s.
		9	6.3	3.7 (6.5)	0.8	10.9
B Mean of (HP&HPU)	Developing	3		7.0	16.0	43.1
		6		6.1 n.s.	12.4 n.s.	33.3 n.s.
		9		9.0	13.0	32.9
	Mature	3		31.8	29.3	138.5
		6		47.4 n.s.	38.1 n.s.	140.1 n.s.
		9		26.8	39.6	114.2
	Senescing	3		-0.4	1.1	25.1
		6		7.0 n.s.	1.3 n.s.	16.9 n.s.
		9		9.2	3.4	19.5

Although few results were significant, the 3 day treatment generally appeared to increase all three categories of leaf more than the 6 or 9 day treatments in each regrowth period and in the total regrowth (Table 3.7.3. Part A).

No such clear general pattern can be seen in Part B of Table 3.7.3. although in the total regrowth the trend was still present.

3.7.2. The decreases in leaf area at each grazing

A. Grazing pressure treatments

Table 3.7.4. shows the decreases in developing, mature and senescing leaf at each grazing for the grazing pressure treatments.

TABLE 3.7.4.

The decreases in leaf area at each grazing (cm^2/62.2 cm^2)

Part	Description of leaf	Grazing pressure	Number of grazing 1	2	3	4	Total decrease
A	Developing	HP LP	47.5 26.9 **	14.0 16.1 n.s.	7.0 9.0 n.s.	3.9 10.4 n.s.	72.3 62.3 n.s.
	Mature	HP LP	146.1 119.4 n.s.	56.8 103.0 **	24.4 30.2 n.s.	23.4 30.2 n.s.	250.7 283.1 n.s.
	Senescing	HP LP	45.0 30.4 n.s.	12.0 12.2 n.s.	5.3 9.1 *	0.4 -1.0 n.s.	62.7 50.6 n.s.
B	Developing	HP HPU			7.0 23.3 **	3.9 9.5 n.s.	72.3 80.2 n.s.
	Mature	HP HPU			24.4 107.3 **	23.0 33.9 n.s.	250.7 287.0 n.s.
	Senescing	HP HPU			5.3 20.6 **	0.4 0.7 n.s.	62.7 66.2 n.s

The high pressure 'grazed' treatment appeared to have more of each category of leaf removed the first grazing than the low pressure treatment. (Table 3.7.4. Part A). At the second grazing a far greater area of mature leaf was removed from the low pressure than the high pressure 'grazed' treatment.

As expected, in all three classes of leaf the high pressure 'ungrazed' treatment had more of each category of leaf removed at the third grazing than the high pressure 'grazed' treatment (Table 3.7.4. Part B). This also appeared to be the case at the fourth grazing although the differences were not significant; this trend was reflected in the total decrease.

Table 3.7.5. shows the decreases in developing, mature and senescing leaf area at each grazing for the 3, 6 and 9 day grazing periods.

TABLE 3.7.5.

The decreases in leaf area for the grazing periods ($cm^2/62.2\ cm^2$, L.S.D. in brackets)

Part	Description of leaf	Grazing period (days)	Number of grazing 1	2	3	4	Total decrease
A	Developing	3	27.2	17.1	14.6	5.9	64.3
Mean		6	32.0 ** (13.7)	13.1 n.s.	4.8 ***L *Q	6.5 n.s.	56.4 n.s.
of		9	52.2	15.4	4.6 (3.6)	9.0	81.2
(HP&LP)	Mature	3	132.9	99.2	46.7 **L	25.7	304.5
		6	129.5 n.s.	74.9 n.s.	17.8 *Q	38.8 n.s.	260.9 n.s.
		9	136.6	66.0	17.3 (12.9)	15.3	235.2
	Senescing	3	32.4	20.2	10.5	-0.2	62.7
		6	33.7 n.s.	9.1 n.s.	4.9 n.s.	0.8 n.s.	48.5 n.s.
		9	47.0	7.0	6.3	-1.5	58.7
B	Developing	3			20.5	6.1	74.2
Mean		6			11.6 n.s.	4.8 n.s.	70.7 n.s.
of		9			13.5	9.2	83.9
(HP&HPU)	Mature	3			75.7	18.1	317.5
		6			70.1 n.s.	31.4 n.s.	234.5 n.s.
		9			51.8	35.9	254.5
	Senescing	3			13.4	0.5	74.5
		6			11.9 n.s.	-0.7 n.s.	41.0 n.s.
		9			13.5	1.8	77.8

At the first grazing the 9 day treatment had significantly more developing leaf removed than either the 3 or 6 day treatments (Table 3.7.5. Part A). The significantly greater 3 day developing and mature leaf area at the start of the third grazing than the 6 or 9 day treatment mentioned previously, was probably the main reason for their significantly greater decrease at this grazing. More mature leaf area appeared to be lost from the 3 day than the 6 or 9 day treatments over the experimental period (sig. 6%).

Although at the third grazing there was a trend towards a greater area of each leaf category being lost from the 3 day than the 6 or 9 day treatments, a general pattern in the last grazing and total decrease was not clear (Table 3.7.5. Part B).

3.8. INDIVIDUAL STOLON MEASUREMENTS

3.8.1. The effects of grazing on individual stolons

A. Grazing pressure treatments

Table 3.8.1. shows the levels of certain stolon parameters on the high pressure 'grazed' and low pressure treatments after each grazing.

The measurements were made on the basis that the 24 stolons cited had a growing point, a developing leaf and mature leaves present before each grazing.

TABLE 3.8.1.

The levels of certain parameters measured on the stolons cited in the quadrats for the high pressure 'grazed' and low pressure treatments after each grazing

Parameter measured	Grazing pressure	Number of grazing 1	2	3	4
a Plant centres/ 30.5^2 cm^2	HP	19.8	15.1	13.9	
	LP	19.5 n.s.	14.3 n.s.	14.7 n.s.	
b No. of growing points remaining	HP	52.5 %	42.5 %	61.2 %	84.8 %
	LP	92.1 % ****	78.0 % ****	75.7 % **	96.5 % **
c No. of stolons having any mature+ leaves remaining	HP	3.8 %	18.3 %	47.0 %	49.2 %
	LP	35.0 % ****	31.5 % n.s.	56.8 % *	67.5 % **
d No. of mature leaves these stolons had	HP	0.5	1.5	1.6	1.5
	LP	1.3 **	1.4 n.s.	1.7 n.s.	1.8 n.s.
e No. of stolons having any petioles+ remaining	HP	52.5 %	28.0 %	32.5 %	59.2 %
	LP	89.0 % ***	60.8 % ***	41.2 % *	73.6 % **
f No. of petioles these stolons had	HP	1.8	1.8	1.8	1.8
	LP	2.3 ***	2.1 n.s.	1.5 n.s.	2.0 n.s.
g No. of stolons having developing+ leaves remaining	HP	34.6 %	17.9 %	34.2 %	55.2 %
	LP	75.0 % ***	36.5 % *	40.7 % n.s.	76.2 % ***

+ c A mature leaf is one with the three leaflets unfolded and without any signs of senescence.

e Only petioles without leaves.

g A developing leaf is one with three leaflets folded on one another (Carlson 1966a).

There appeared to be a decline in the number of identifiable plant centres/quadrat especially it seems as a result of the second grazing (Table 3.8.1.a.). A plant centre is defined as the centre of an originally established white clover seedling from the main stem of which stolons grow. A significantly greater percentage of growing points were removed from the high pressure 'grazed' than the low pressure treatment at each grazing (Table 3.8.1.b.), although the margin was smaller at the last two grazings.

On the high pressure 'grazed' treatment after the first grazing only 3.8% of the stolons measured had any mature leaves remaining with an average of only 0.5 mature leaves/stolon. However, 52.5% of the stolons had a mean of 1.8 petioles remaining/stolon (Table 3.8.1.c, d, e, f). Approximately one-third (34.6%) of the stolons on the high pressure 'grazed' treatment had a developing leaf remaining (Table 3.8.1.g.).

After the first grazing therefore, all parameters in the high pressure 'grazed' treatment were significantly smaller in value than those in the low pressure treatment (Table 3.8.1.). After the second grazing there was no significant difference either in the percentage of stolons having any mature leaves or in the numbers of leaves that these stolons had between the high pressure 'grazed' and low grazing pressure treatments, although a greater percentage of developing leaves remained on the low pressure treatment (Table 3.8.1.). At the third and fourth grazing the low pressure treatment had a higher percentage of stolons with mature leaf and petiole remaining than the high pressure 'grazed' treatment. At the last grazing only a small percentage of growing points were removed from either treatment (Table 3.8.1.b.).

Because the high pressure 'grazed' and high pressure 'ungrazed' treatments were so similar in all parameters after the fourth grazing only certain relevant parameters for the third grazing are presented in Table 3.8.2.

TABLE 3.8.2.

Certain parameters measured after the third grazing for the high pressure 'grazed' and 'ungrazed' treatments

Parameter measured	Grazing pressure	Number of grazing 3
No. of growing points remaining	HP HPU	61.2 % 37.8 ** %
No. of stolons having any mature leaves remaining	HP HPU	47.0 % 17.5 ** %
No. of leaves these stolons had	HP HPU	1.6 1.0 **

A significantly smaller percentage of growing points were removed from the high pressure 'grazed' treatment and a greater percentage of stolons had mature leaves remaining on this treatment than on the high pressure 'ungrazed' treatment (Table 3.8.2.). On those stolons that had mature leaves remaining, 1.6 remained on the high pressure 'grazed' compared with 1.0 on the high pressure 'ungrazed' treatment (Table 3.8.2.).

B. Grazing period treatments

Except after the first grazing where the 3 day low pressure treatment had a significantly greater percentage of stolons with mature leaves remaining than the corresponding 6 or 9 day treatments, most other comparisons revealed no differences between grazing periods.

The 9 day treatment (mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments) had a significantly smaller percentage of growing points remaining and significantly smaller percentage of stolons having any mature leaves remaining than the 3 day treatment at the third grazing. Few other grazing period effects occurred.

3.9. INDIVIDUAL STOLON LENGTHS

3.9.1. High pressure 'grazed', low pressure and high pressure 'ungrazed' treatments

Table 3.9.1. shows the mean stolon length of the high pressure 'grazed' and low pressure treatments after the second, third and fourth grazings and for the high

pressure 'ungrazed' treatment after the third and fourth grazings. Only after the third grazing were stolon lengths (see Materials and Methods) measured on all plots.+

TABLE 3.9.1.

The mean stolon lengths after grazing for the high pressure 'grazed', low pressure and high pressure 'ungrazed' treatments (cm)

Description of parameter	Grazing pressure	Number of grazing		
		2	3	4
Stolon length	HP LP	3.3 8.9 **	2.1 6.2 **	3.3 5.2 n.s.
Stolon length	HP HPU		2.1 3.0 *	3.3 2.7 n.s.

After the second, third and fourth grazings the high pressure 'grazed' treatment had a much smaller mean stolon length than the low pressure treatment, although at the fourth grazing this did not reach significance (Table 3.9.1.).

After the third grazing the high pressure 'grazed' treatment mean stolon length was significantly less than that of the high pressure 'ungrazed' treatment (Table 3.9.1.).

3.10. CLOVER PLANT TRACINGS

The changes which took place at each defoliation and during each regrowth period for each of the 54 feather-marked clover plants initially cited (27 on the low pressure treatment and 27 on the high pressure treatment) were studied. From this a general pattern of regrowth associated with defoliation was observed and this general pattern (stated below) is illustrated by examples from the clover plant tracings made. In the illustrations, numbers occur near the plant or the stolons of the plant which is being discussed (e.g. 2a illustrates point 2(a) in this Section).

1. 15% of the traced plants in the high pressure treatment and 7% of the traced plants in the low pressure treatments died. All of these plants were small in size.

+ After the first grazing only 2 high pressure 'grazed' and 3 low pressure plots were measured. After the fourth grazing 2 high 'grazed', 4 low pressure and 3 high 'ungrazed' plots were measured.

2. The initiation of growth of new stolons off any particular stolon seems to have been stimulated under different conditions :-

   (a) On an actively growing stolon new stolons were generally initiated at nodes closer to the base than the tip of that stolon. However, the number of new stolons initiated varied considerably from stolon to stolon. Fig. 3.10.1.b.

   (b) The removal of the terminal bud generally stimulated the initiation of growth of new stolons from axillary buds, and more particularly those nearer the grazed end.

   (c) When active growth occurred after a period of slow growth, new stolons would often be initiated close together at the junction of the slow and more rapid growth. Fig. 3.10.2.b.

3. Where terminal buds were grazed off or pulled, generally they broke at a node and died back to the nearest stolon whether newly initiated or older. Fig. 3.10.2.b. and c.

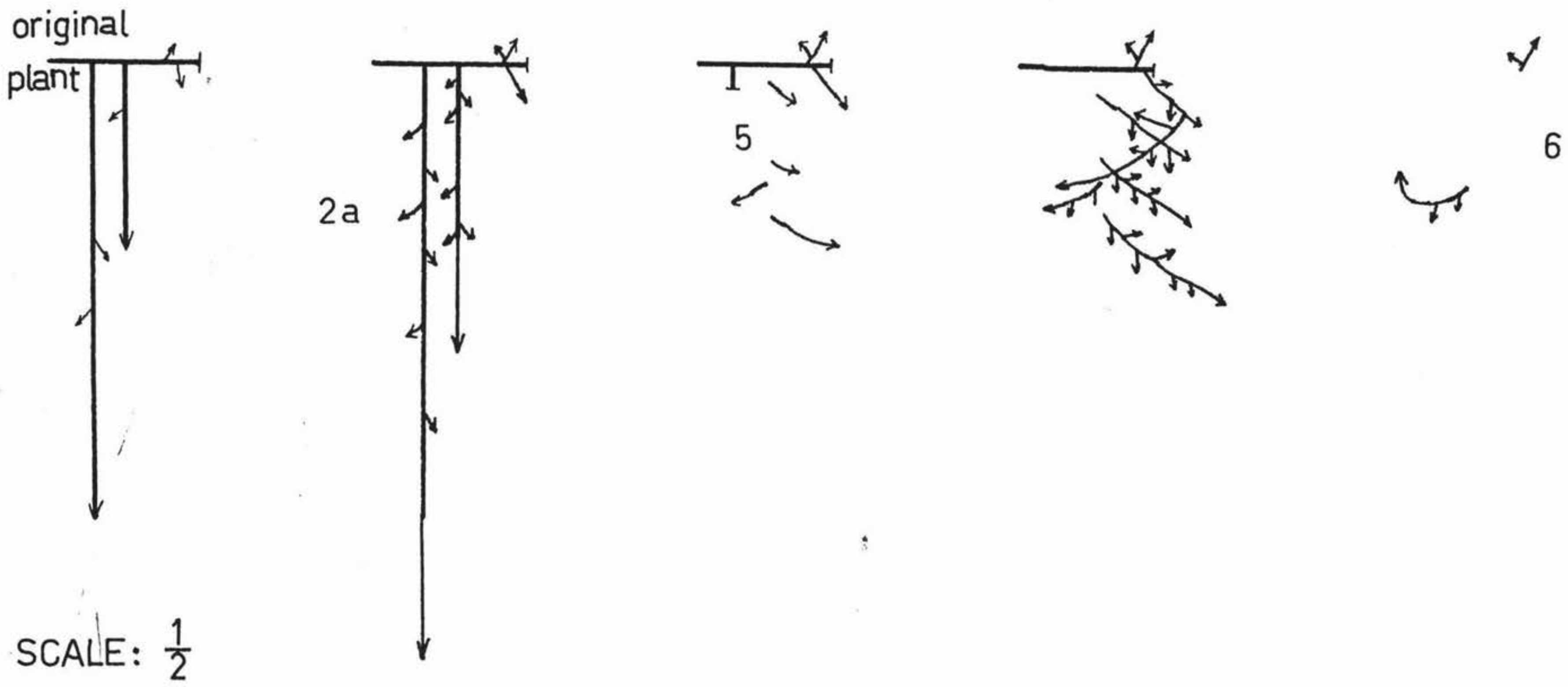
4. At times (discussed later) one or more of the smaller stolons on the traced plants died. Fig. 3.10.2.e. and f.

5. The longer the stolon the more likely it was that the terminal bud was grazed. It was observed on a number of occasions that the sheep, once it had the terminal bud in its mouth, uprooted the stolon and chewed up the length of the stolon. Where branch stolons were firmly rooted the main stolon could sometimes be completely removed leaving the branch stolons growing. Fig. 3.10.1.c.

6. As a result of grazing, initially continuous single plants were often left as several discontinuous growing units. Fig. 3.10.1.e.

7. Longer stolons generally increased their length more than shorter stolons and during rapid growth in the first regrowth period some stolons grew at the rate of up to 0.6 cm/day. Best regrowth of stolons seems to have come from those which were not damaged or affected by grazing. More rapid elongation in general, came from new stolons nearer the base than the tip of the main stolon. Fig. 3.10.3.c.

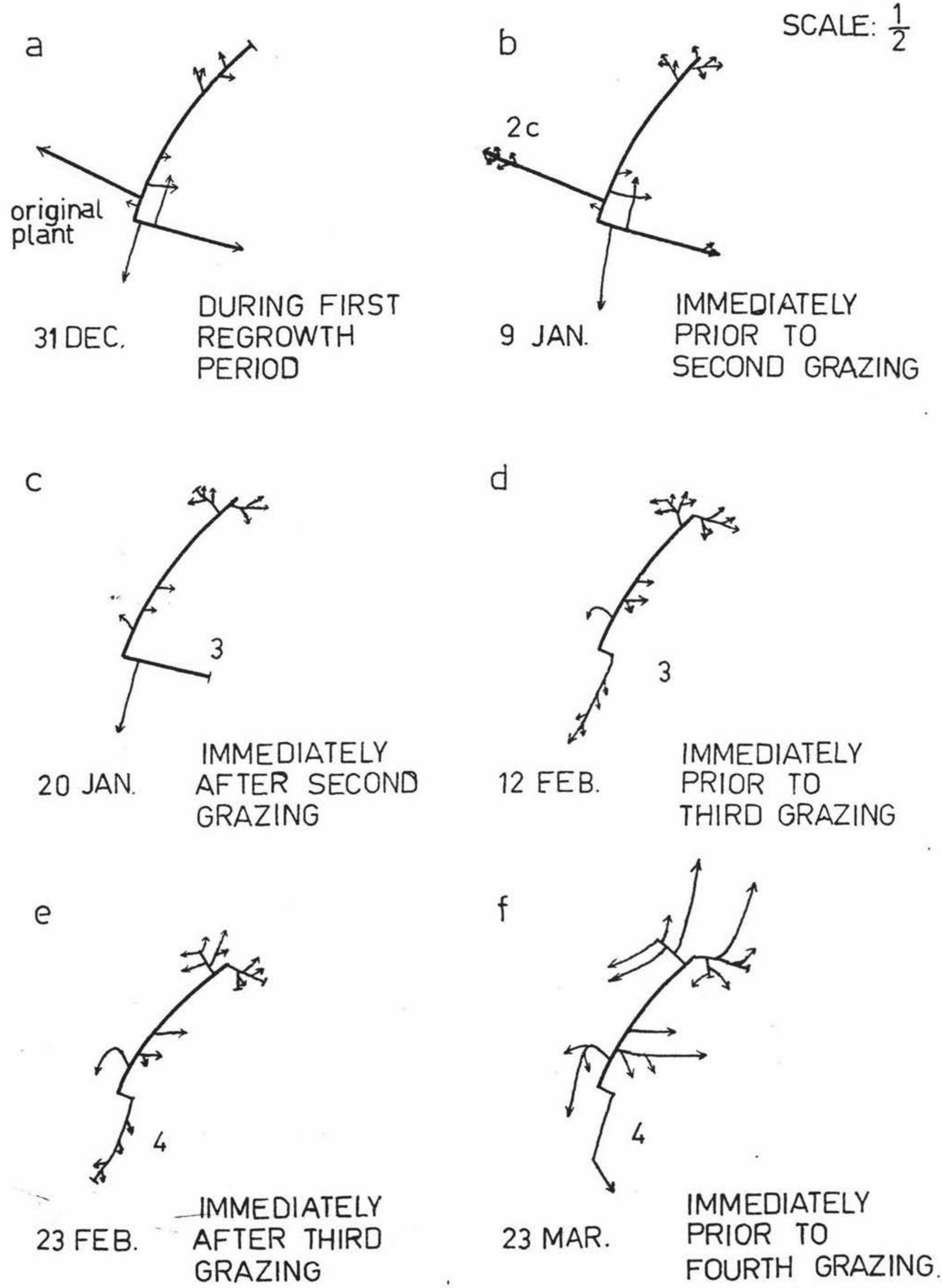
8. Even plants with stolons almost completely removed by grazing, usually survive and initiated new stolons which elongated at first slowly and then more rapidl Fig. 3.10.3.b. and c.

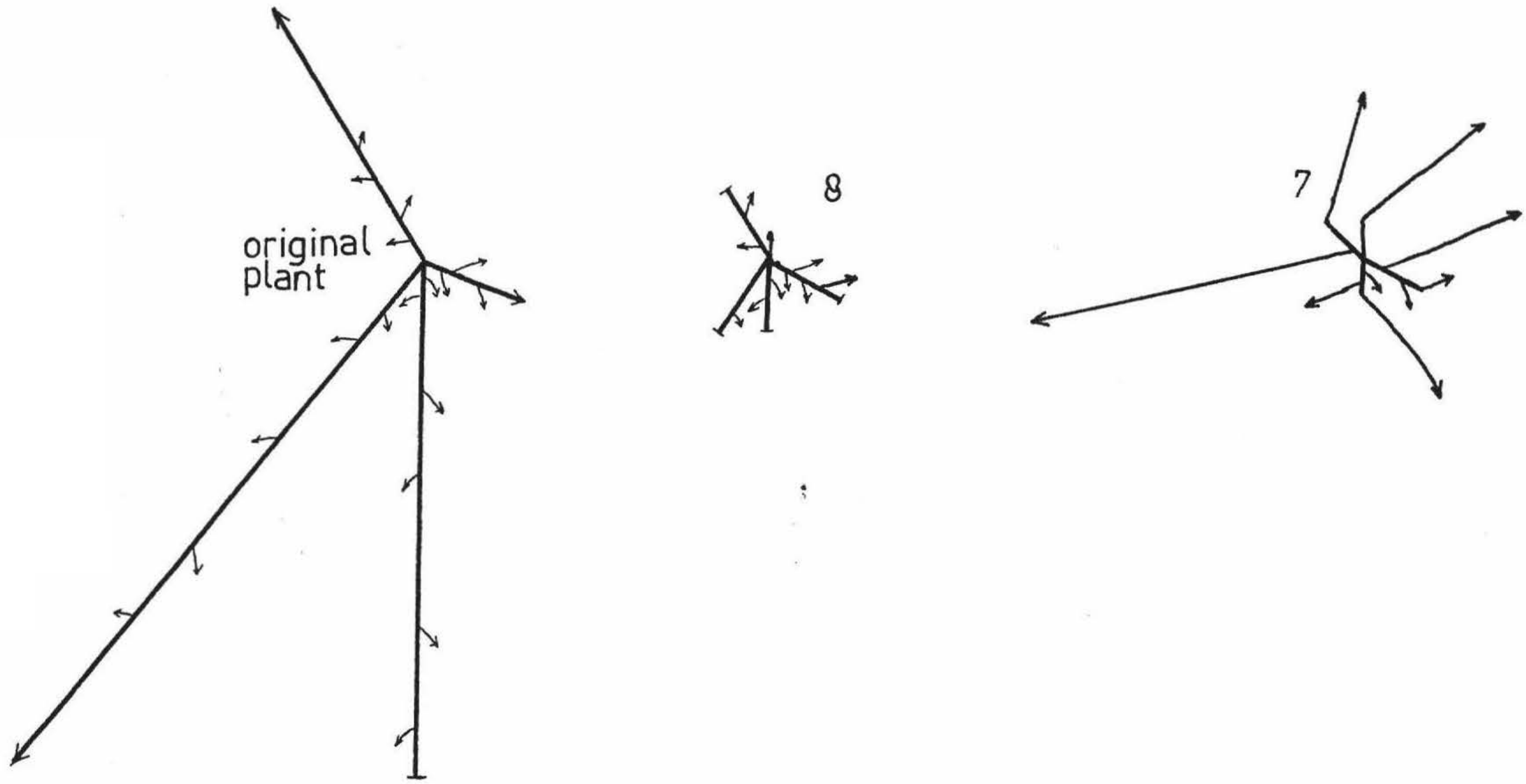


a	b	c	d	e
IMMEDIATELY AFTER FIRST GRAZING	IMMEDIATELY PRIOR TO SECOND GRAZING	IMMEDIATELY AFTER SECOND GRAZING	IMMEDIATELY PRIOR TO THIRD GRAZING	IMMEDIATELY AFTER THIRD GRAZING
28 DEC.	9 JAN.	20 JAN.	12 FEB.	23 FEB.

FIGURE 3.10.1

FIGURE 3.10.2.


SCALE: 1/2
a
original plant
31 DEC.
DURING FIRST REGROWTH PERIOD
b
2c
9 JAN.
IMMEDIATELY PRIOR TO SECOND GRAZING
c
3
20 JAN.
IMMEDIATELY AFTER SECOND GRAZING
d
3
12 FEB.
IMMEDIATELY PRIOR TO THIRD GRAZING
e
4
23 FEB.
IMMEDIATELY AFTER THIRD GRAZING
f
4
23 MAR.
IMMEDIATELY PRIOR TO FOURTH GRAZING.



SCALE: $\frac{1}{1}$

a

DURING FIRST REGROWTH PERIOD
31 DEC.

b

IMMEDIATELY AFTER SECOND GRAZING
20 JAN.

c

IMMEDIATELY PRIOR TO FOURTH GRAZING
23 MAR.

FIGURE 3.10.3.

3.11. ROOT MEASUREMENTS

3.11.1. High pressure 'grazed', low pressure treatment and plots not grazed throughout the experiment

Table 3.11.1. shows the weight of topgrowth and weight of roots down to 76 cm/400 cm^2 for the high pressure 'grazed' and low pressure treatments and for plots not grazed throughout the experiment.

TABLE 3.11.1.

The weights of topgrowth and roots down to 76 cm (g/400 cm^2)

Description of parameter	(a) HP	(b) LP	LSD (a)and(b)	(c) PLOTS NOT GRAZED	LSD (a)and(c) or (b)and(c)
Wt. topgrowth	7.5	18.5	12.6	30.4	14.1
Wt. roots0-7.6 cm	2.3	3.7	2.4	5.0	2.7
Wt. roots 7.6-30.5 cm	0.9	0.9	1.0	0.6	0.7
Wt. roots 30.5-76.0 cm	0.27	0.23	0.7	0.75	0.8

The weight of topgrowth appeared to be different between treatments although this was only significant between the high pressure 'grazed' and 'not grazed' treatments (Table 3.11.1.). This was also the case for the weight of root in the top 7.6 cm of soil but no differences between treatments below this level were found (Table 3.11.1.).

There was a great visual difference between the three treatments. The 'not grazed' treatment had a dense mass of roots in the top 7.6 cm with the low pressure and the high pressure 'grazed' treatments having progressively fewer roots respectively.

Other observations included :-

1. Most nodules were in the top 3 cm of the roots, with relatively few below this level.
2. All three treatments had roots extending below 76 cm.
3. The deepest nodule was recorded at about 38 cm, this depth representing the change in soil texture from a silty clay loam to a clay.

3.12. VIBRARECORDERS

3.12.1. High pressure 'grazed' and low pressure comparison

On the low pressure treatment the grazing time per sheep was 7.4 hours/day compared with 9.8 hours/day for the high pressure 'grazed' treatment. Whereas the grazing on the low pressure treatment took place in the morning (5 a.m. - 10 a.m.) and in the evening, on the high pressure 'grazed' treatment grazing occurred almost continuously throughout the day.

Observations made of animal behaviour on plots with a small compared with a large amount of clover suggested that the frequency of bites/minute was about 60 on the former plots and 35 on the latter plots. However intake/bite and size of bite appeared to be greater for the animals grazing the plots with a relatively large amount of clover.

3.13. SOIL MOISTURES AND SOIL TEMPERATURES

3.13.1. Soil moistures

Figure 3.13.1. shows the levels of soil moisture found by sampling the top 7.6 cm of soil with a 2.5 cm soil core sampler at various times during the experiment. The differences between high pressure and low pressure treatments were not analysed statistically since they differed so little.

From January 8th to February 18th very little rain fell, and this was reflected in relatively low values for soil moisture percentage at the three sampling dates over this period (Figure 3.13.1.). It is notable that this time span is approximately that of the second regrowth period. At some time in each of the first, third and fourth regrowth periods soil moisture levels, at least in the surface layers, approached field capacity.

3.13.2. Soil Temperatures

Figure 3.13.2. shows soil temperatures at 0, 7.6 and 30.5 cm at different times during the day for a high pressure and low pressure plot and also a plot not grazed during the experiment.

On the sunny day where the sun was striking the bare soil on the high pressure plot, surface temperatures were high in the middle of the day at the soil surface (Fig. 3.13.2.). At 7.6 cm depth, temperature increases were of a smaller magnitude and the higher temperatures were reached later in the day. A similar pattern, but of smaller magnitude, occurred for the low pressure plot (height of clover 5-10 cm). The plots not grazed in the experiment showed very

FIGURE 3.13.1 THE LEVELS OF SOIL MOISTURE IN THE TOP 7.6 cm OF SOIL DURING THE EXPERIMENT FOR THE HIGH PRESSURE 'GRAZED' AND LOW PRESSURE TREATMENTS

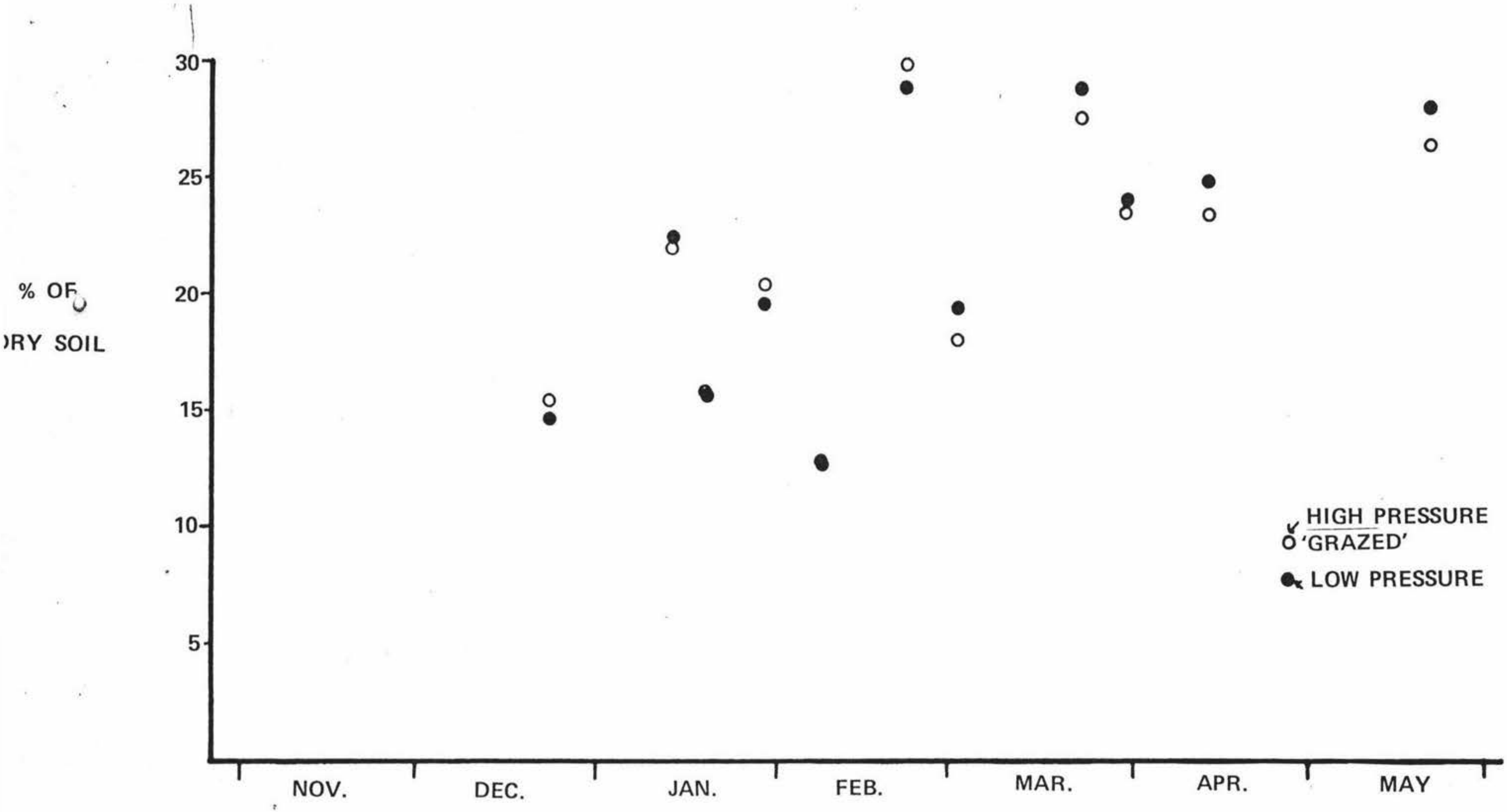
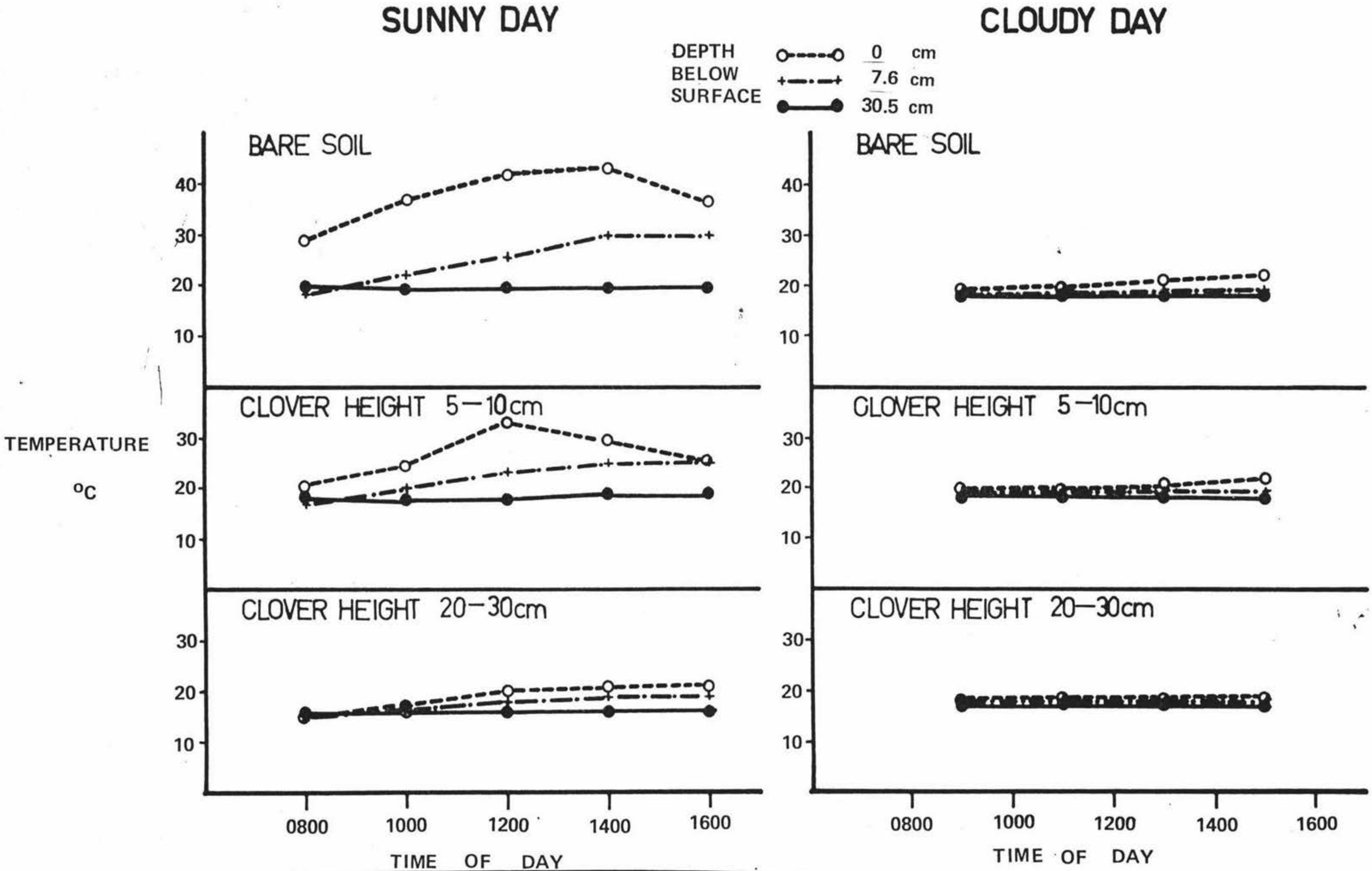


FIGURE 3.13.2. SOIL TEMPERATURES AT 0, 7.6 AND 30.5 cm FOR THREE DIFFERENT CLOVER CANOPIES



little change in soil temperatures at the three levels.

On the cloudy day very little difference occurred between the three plots at any of the levels, except perhaps for a slight increase in the surface temperature for the bare soil on the high pressure plot (Fig. 3.13.2.).

CHAPTER 4

DISCUSSION

A. DISCUSSION OF EXPERIMENTAL TECHNIQUES

Before drawing conclusions from the results the accuracy of the experimental techniques should be assessed because these may influence the validity of any conclusions drawn.

4.1. Experimental techniques

4.1.1. Herbage dry matter sampling

Especially at the first two grazings the sheep on the low pressure treatment had a large quantity of clover dry matter available to them throughout these grazings, and this enabled greater selection than on the high pressure 'grazed' treatment. This was reflected in patch grazing. The resulting variability in herbage dry matter from area to area was estimated using a grid quadrat and dry matter samples were then taken according to the number of high and low patches. A greater number of samples than were actually taken would have given more accuracy in the estimation of available dry matter on the low pressure treatment especially in the early stages of regrowth.

This patch grazing effect was enhanced by the effects which dung had upon grazing. At the first grazing this dung effect was not present because decomposition of the dung had taken place since the last preparatory grazing. At the second and subsequent grazings, however, on the low pressure treatment, it was noticeable that many of the patches left ungrazed had dung underneath them even though the clover looked palatable. At the high grazing pressure this patchiness was not evident, which suggests that the sheep were forced to eat the clover in these patches.

Thistles, especially californian thistle (Cirsium arvense L.), also affected the pattern of grazing on some plots and to a greater extent on the low pressure plots. This situation was avoided to some extent by hoeing the thistles in each plot before grazing but in thicker areas of thistle, the sheep on the low pressure plots left the clover ungrazed or only partly grazed. On the high pressure plots the sheep often grazed the thistles to quite an extent.

A further factor which affected the pattern of grazing at the second, third and fourth grazings was the presence of some Merino sheep in some plots. Insufficient Romney ewes were available at these grazings to stock all the plots, and some Merinos had to be used. They appeared to be more agitated than the Romneys, and where they predominated in numbers, the plot was generally more patchily grazed.

For the three sampling dates in the first regrowth period, including that taken just before the second grazing, dung and soil contaminated the dry matter samples. Two methods were used to estimate the quantities of dung and soil in the samples. First, dung and soil were picked from the bulked sample and weighed and secondly they were picked from the 200 g botanical analysis samples and the amounts in the bulked sample estimated and corrected. On the basis of this a constant weight was subtracted from each sample. It was felt, however, that this may have resulted in an underestimation of the dry matter on the low pressure plots and an overestimation of the dry matter on the high pressure plots.

In contrast to the first, third and fourth grazings, where D.M.% figures for each plot were used to estimate dry weight of herbage/plot, average figures for the low pressure plots and for the high pressure plots were used to estimate the dry weight of herbage on these plots at the beginning of the second grazing. This resulted in the 3 day low pressure plots, in particular, being stocked 20-25% more heavily than should have been the case and although this resulted in a heavier grazing, it was still not severe enough for many of the stolon growing points to be grazed off.

4.1.2. Botanical composition analysis

In the separation of clover in the botanical sub-samples taken from the production cuts, clover stolons were not separated from leaves and petioles. Had this been carried out, it would have been easier to correlate data from the core samples where stolon weights were measured with data from the dry matter samples. In general, however, it is considered that there was a small proportion of stolon in the samples relative to the amount remaining on the ground. This was borne out by the fact that at the end of regrowth periods the dry matter sample patches (30.5 x 91.5 cm^2) were not obvious in the plots which would have been so if much of the stolon had been removed.

4.1.3. Core Sampling technique

It has been suggested that core sampling has considerable value in ecological studies of heavily grazed pastures not only in estimating herbage available but also in detailed separation of this herbage into components such as leaf area, species composition, numbers of tillers or rooted nodes and tiller weights (Hutchinson 1967).

In this experiment it was only feasible to take 5 core samples, each of 62.2 cm^2, per plot before and after each grazing. On the basis of Hutchinson's (1967) study the variance, with such a small number of samples, could be expected to be large especially in the low pressure plots where patch grazing occurred and samples were taken as representative of defined areas in the plot. Differences between treatments therefore, can only be the result of either biassed sampling or large and real differences between treatments.

When the dry weights of leaves and petioles from the core samples were combined and multiplied by a factor to bring dry weight to a per plot basis the estimate of dry matter yield was, in general, smaller than the estimate of dry matter yield per plot obtained from the dry matter sampling technique. This suggests that core samples did not overestimate dry matter yield per plot, but two assumptions are involved; first, that little stolon was in the dry matter samples obtained to estimate dry matter yield, and secondly, that because each core sample was almost 100% clover, it was no heavier in herbage dry matter than a core sample of herbage representing the true botanical composition.

The first assumption, already discussed, appears valid. Since the dry matter percentage of leaves and petioles would generally be less than the average dry matter percentage of weeds, grass and dead matter, the second assumption also appears to be valid.

At no time did the decrease in the numbers of growing points as a result of grazing, as determined by the core samples, greatly exceed the estimate from measurements made on individual stolons using the quadrat technique (Appendix 3). However, at the fourth grazing for the high pressure 'grazed' treatment and the third and fourth grazings for the high pressure 'ungrazed' treatment the core samples did tend to underestimate the decrease in the numbers of growing points as a result of grazing compared with the quadrat technique. Because the area sampled and the number of stolons observed was much larger for the quadrat technique, this information is probably the more reliable.

4.1.4. Individual stolon observations by quadrat technique

Because these samples were taken at random in defined areas in the plots and because the stolons within each quadrat were taken at random these results should be representative of the true picture as far as individual stolons are concerned.

4.1.5. Clover plant tracings

These tracings were drawn to scale and therefore accurately defined stolon activity on a plant basis. Observation showed that the white pegs 15 cm from the plant centre did not affect the grazing of the plant.

4.1.6. Vibrarecorder measurements

Insufficient numbers of recordings were taken to give an accurate indication of the variability and mean of grazing times within a treatment. Observation of the sheep during grazing confirmed that they can lift and "rip" the stolons from the ground especially once they have the growing point or terminal bud in their mouth.

4.1.7. Root sampling

Insufficient numbers of samples were taken for a detailed study of the roots but sufficient numbers for the purposes of this experiment were taken. Some inaccuracy may have resulted from the washing technique due to loss of fine roots.

B. DISCUSSION OF RESULTS

Discussion of the results will be in two major sections. First, a discussion of the effects of the grazing pressure treatments on the growth and development of white clover, and secondly a discussion of the effects of the 3, 6 and 9 day grazing periods. In each section the total production for the treatments, discussed first, is followed by discussion of the individual grazings and their associated regrowth periods.

EFFECTS OF GRAZING PRESSURE

4.2.1. Total production of the high pressure 'grazed', low pressure and high pressure 'ungrazed' treatments.

The high pressure 'grazed' treatment produced significantly more than the low pressure treatment and significantly less than the high pressure 'ungrazed' treatment over the experimental period.

As far as the clover is concerned total production of topgrowth is a function of the production of leaf, petiole and stolon. The total production of leaf and petiole (Table 3.4.1.) showed that the low pressure treatment outyielded the high pressure 'grazed' treatment, but this was not reflected in the total herbage dry matter yield data (Table 3.2.1.). This discrepancy may have been caused largely by changes which took place in the first regrowth period. Here, the decrease in available dry matter on the low pressure treatment which took place early in the first regrowth period (Fig. 3.1.1.) was followed by a greater production of this treatment than the high pressure 'grazed' treatment over the whole first regrowth period. Taking this into account, there was no difference in total dry matter production over the experimental period between these two treatments.

Nevertheless the production of new stolons was significantly greater for the high pressure 'grazed' than the low pressure treatment over the experimental period. As found by Beinhart (1963) and Davidson and Birch (1972) production of leaf from secondary stolons can contribute significantly to total production.

The total production from the high pressure 'ungrazed' treatment was significantly greater than for the high pressure 'grazed' treatment which might have been expected since the former treatment had one less grazing than the latter. It may have also been important that the complete herbage cover during the second regrowth period of the high pressure 'ungrazed' treatment was during a time of moisture deficit.

Despite the differences in production between treatments, the total decrease in herbage dry matter, as a result of grazing, was greatest for the high pressure 'ungrazed' treatment, intermediate for the high pressure 'grazed' treatment and lowest for the low pressure treatment.

4.2.2. The first grazing and first regrowth period

Because the high pressure 'grazed' and high pressure 'ungrazed' treatments are the same treatment for the first grazing and first regrowth period they are referred to in this instance as the high pressure treatment. Subsequently they will be referred to separately.

At the first grazing the high pressure treatment was defoliated to a much greater extent than the low pressure treatment. Very little leaf or petiole remained on the high pressure treatment and 50% of the growing points, mostly terminal buds, had been grazed off, and this included half of the length of stolon (28.7 cm/62.2 cm^2) that was present before grazing. In contrast, only the top of the canopy had been grazed off the low pressure treatment and this included much of the mature leaf and about one-third of the developing leaf. Many petioles remained without their leaves (Plate 8) but only about 10% of the growing points had been grazed and this included about 2.5 cm of stolon/62.2 cm^2.

Early in the regrowth period there was a fall in the dry weight of herbage on the low pressure treatment which most probably resulted from the death of those petioles from which leaves had been removed. A separate small-scale study, confirmed that petioles senesce and die once their leaves have been removed.

The significantly greater increase in dry matter production over the latter part of the first regrowth period for the low pressure treatment than over the whole regrowth period for the high pressure treatment (Fig. 3.1.1.) was largely the result of a significantly greater increase in both clover petiole and leaf weight of the former than the latter treatment.

Brougham (1958) found that following defoliation, the first crop of new leaves form a canopy which intercepts a considerable amount of light. Leaves developing later are therefore subjected to a low light intensity and petiole elongation continues until the laminae of these leaves have penetrated the existing canopy and reached full light. On both the low pressure and high pressure 'grazed' treatments petiole elongation occurred (Fig. 3.6.1.), but greater petiole elongation and production of petiole came from the former than the latter treatment. With a total LAI of approximately 0.8 on the low pressure treatment immediately after the first grazing and a total LAI of approximately 3.0 immediately prior to the second grazing, it is probable that penetration of light into the canopy would have been restricted shortly after grazing (Brougham 1958; Davidson and Birch 1972). In contrast, the high pressure treatment had a total LAI of only approximately 1.5 just before the second grazing so the restriction to light penetration by the canopy, and therefore petiole elongation, would have taken longer.

That leaf production was greater on the low pressure than the high pressure treatment over the first regrowth period was largely the result of the greater increase in the area of mature leaf of the former than the latter treatment. A small-scale study showed that the specific leaf weight (g/cm^2) of all sizes of mature leaves was similar, so that total mature leaf weight was directly proportional to total mature leaf area and independent of the sizes of leaves comprising the mature leaf area.

There was a greater area of mature leaf occurring in the larger leaf size ranges on the low pressure than the high pressure treatment just before the second grazing, with the reverse situation occurring in the smaller leaf size ranges (Fig. 3.7.2.). It has already been highlighted that such differences involve far greater numbers of leaves in the smaller than in the larger leaf size ranges (Table 3.7.1.). In size range B for example (Fig. 3.7.2.), the high pressure treatment averaged 32 mature leaves/62.2 cm^2 compared with approximately 17 on the low pressure treatment.

The increase in developing leaf area over the first regrowth period was similar between high pressure and low pressure treatments. This partly resulted from the greater increase in the numbers of new stolons on the high pressure than the low pressure treatment, each of which would have had one developing leaf, and partly because fewer growing points had developing leaves remaining after the first grazing on the high pressure than the low pressure treatment (Table 3.8.1.).

The average size of mature leaves was 1.0 cm^2 for the high pressure treatment and 2.5 cm^2 for the low pressure treatment just prior to the second grazing. Probably two reasons for this were; first, leaves developing from new stolons were much smaller than those developing from terminal buds. Results show that for every two new stolons initiated on the low pressure treatment there were five initiated on the high pressure treatment. Increased meristematic activity after defoliation, as a result of deeper light penetration into the canopy, has been found by Brougham (1958). Secondly, severe grazing on the high pressure treatment reduced the size of leaves much more on the high pressure than the low pressure treatment. During regrowth, however, leaves gradually increased in size (Brougham 1958).

The slow production of dry matter in the first half of the regrowth period for the high pressure treatment compared with the second half may have been the result of the greater number of sites of carbohydrate utilisation, restricting supply to the main growing points, and also the result of the time taken for the newly initiated stolons to contribute significantly to production.

The situation at the start of the second grazing therefore was that the low pressure treatment had a significantly greater available dry matter than the high pressure treatment with no marked difference in botanical composition between treatments. As far as the clover was concerned the low pressure treatment had a significantly greater weight of stolon, petiole and leaf than the high pressure treatment, a fewer number of new stolons, but 7 compared with 3 terminal buds/62.2 cm^2 on the high pressure treatment.

4.2.3. The second grazing and second regrowth period

At the second grazing decreases in leaf and petiole weight were significantly greater in the low pressure than the high pressure 'grazed' treatment. At stolon level, however, there was a greater decrease in the number of new stolons in the high pressure 'grazed' than the low pressure treatment.

After the second grazing the comparison between the high pressure 'grazed' and low pressure treatments, as far as the available dry matter and clover parameters were concerned, was similar to that after the first grazing. Despite these large differences, the high pressure 'grazed' treatment unexpectedly produced significantly more herbage dry matter than the low pressure treatment over the second regrowth period.

Little change in petiole weight over the second regrowth period took place for either the high pressure 'grazed' or low pressure treatments. However, the slight increase in petiole weight for the former treatment was significantly different from the slight decrease of the latter treatment (Table 3.4.1.). Little petiole elongation on either treatment would have occurred in response to a restriction to light penetration by the canopy, because the total LAI values immediately prior to the third grazing were only approximately 1 for both the high pressure 'grazed' and low pressure treatments. The death of petioles on the low pressure treatment from which leaves had been removed at the second grazing, was probably a further reason for the negligible change in petiole weight for this treatment over the second regrowth period.

Although no significant difference in the production of mature leaf area was apparent between the two treatments over the second regrowth period, the average mature leaf size was reduced considerably. For the high pressure 'grazed' and low pressure treatments immediately before the second grazing, the average mature leaf sizes were 1 cm^2 and 2.5 cm^2 respectively. Equivalent figures immediately prior to the third grazing were 0.7 cm^2 and 1.0 cm^2. These figures include leaves from all growing points and show that during the second regrowth period the low pressure treatment was affected much more than the high pressure 'grazed' treatment in the reduction of average mature leaf size.

It was notable during the second regrowth period that rainfall (Fig. 3.1.1.) and soil moisture levels (Fig. 3.13.1.) were lower than in any other regrowth period. Reductions in leaf area and weight, and rate of initiation of leaf primorida from terminal buds because of dry conditions have been recorded by Brougham (1962). Leaf area and weight were halved in Brougham's (loc. cit.) experiment.

It may also be noted for the high pressure 'grazed' and low pressure treatments that the reduction in available dry matter from that at the end of the first regrowth period to that at the end of the second regrowth period was similar, in proportion, to the reductions in average mature leaf size.

One of the major reasons for the greater production of the high pressure 'grazed' than the low pressure treatment over the second regrowth period was probably the greater increase in developing leaf area of the former than the latter treatment. Here again the reasons seem to be first; there was a significantly greater increase in new stolons on the high pressure 'grazed' than the low pressure treatment. It is probable that these newly initiated stolons contributed significantly to production by the end of the regrowth period because observations showed that even severely defoliated plants can increase the numbers of leaves rapidly by initiating new stolons and also by increasing the area of leaves to some extent. Secondly, fewer developing leaves remained after grazing on the high pressure 'grazed' than the low pressure treatment.

Two reasons for the negligible change in developing leaf area for the low pressure treatment could be first; there was a smaller increase in the number of new growing points for this treatment compared with the high pressure 'grazed' treatment over the second regrowth period and secondly; the developing leaves that were present immediately prior to the third grazing were smaller in area than those immediately after the second grazing. There were, in fact, greater numbers of developing leaves at the start of the third grazing on the low pressure treatment than immediately after the second grazing but they were smaller in size, being mostly in size ranges A, B and C.

However, despite the greater increases in some parameters in the high pressure 'grazed' treatment during this regrowth period, actual herbage dry weight and stolon weight at the start of the third grazing was still higher in the low pressure than the high pressure 'grazed' treatment.

4.2.2.a. The high pressure 'ungrazed' treatment, second regrowth period

At the time of the second grazing, half of each high pressure plot was fenced off and left to continue growth until the third grazing. That the high pressure 'ungrazed' treatment produced more herbage dry matter than the high pressure 'grazed' treatment over the second regrowth period (in fact, the second half of the first regrowth period for the high pressure 'ungrazed' treatment) was expected for two reasons. First, the high pressure 'ungrazed' treatment had remained undefoliated over a period of approximately 57 days (the time from the end of the first grazing to the beginning of the third grazing) compared with approximately 29 days (the time from the end of the second grazing to the beginning of the third grazing) for the high pressure 'grazed' treatment. Secondly, the high pressure 'ungrazed' treatment began this so-called second regrowth period with a total LAI of 1.5 compared with an LAI of about 0.3, which was the leaf area remaining on the high pressure 'grazed' treatment immediately after the second grazing.

The dry matter production over the first regrowth period in the high pressure 'ungrazed' treatment (the same treatment as the high pressure treatment in the first regrowth period) was 990 kg/ha, a growth rate of 45 kg/ha/day. However, during the continued growth of this treatment which coincides with the second regrowth period, the production was 1180 kg/ha, a decline in growth rate to 34 kg/ha/day.

This decline in growth rate noted above, could be for several reasons. First, there appeared to be a greater moisture deficit in the second regrowth period than in the first regrowth period (Fig. 3.1.1. and Fig. 3.13.1.). Secondly, the efficiency of light utilisation of the canopy structure and photosynthetic efficiency of the leaves may have decreased. Hunt (1968) concluded similarly for a ryegrass/clover pasture after the critical LAI was reached, which was approximately 28 days and 40 days after defoliation to $\frac{3}{4}$" (2 cm) in the spring and autumn respectively. Associated with the formation of the critical LAI two further factors were considered by Hunt (1968) to cause a decrease in the net growth rate. Overtopping of clover leaves by younger leaves after the critical LAI had been reached, resulted in a considerable area of leaf being subject to intense shading, with the result that there was an increase in the ratio of respiration to photosynthesis. For the clover component as a whole this presumably meant that net photosynthesis was depressed to a lower but constant rate associated with the dynamic equilibrium attained by the clover in the sward. It is more likely in a pure clover sward, such as in this experiment, that this fairly rapid and intense shading of older leaves by younger leaves was further exaggerated because light extinction in a pure clover sward is more rapid than in a ryegrass/clover sward (Mitchell and Calder 1958). The final reason that Hunt (1968) postulated for the fall in net growth rate was the considerable loss via leaf death that began about the time the critical LAI was reached in the spring, but began sooner than this in the autumn when moisture and nutrients were limiting. It is considered, however, that moisture deficit played the largest part in the reduction of clover growth rate in the second regrowth period of this experiment, so that leaf death may have been occurring before the critical LAI was reached.

At the beginning of the second grazing the distribution of weight between stolon, petiole and leaf was 58%, 5.2% and 36.8% respectively for the high pressure 'ungrazed' treatment compared with 49.6%, 15.8% and 34.6% respectively for this treatment at the beginning of the third grazing. The weight increases of these three fractions over the second regrowth period were 57%, 450% and 72% respectively for the high pressure 'ungrazed' treatment. Whereas leaf production was the main determinant of herbage yield in the first regrowth period for the high pressure treatment, in the continued regrowth of the second regrowth period for the high pressure 'ungrazed' treatment, petiole production contributed significantly to yield, although leaf production had also increased. Because light penetration into the canopy was probably severely restricted near the end of the first regrowth period petiole elongation would have been occurring to a greater extent during the second regrowth period, extending leaves into a full light environment.

During the second regrowth period there was a recorded death of new stolons in the high pressure 'ungrazed' treatment despite the significantly greater increase in length of stolon and apparently greater increase in terminal bud numbers of this treatment compared with the high pressure 'grazed' treatment. The increase in terminal bud numbers was insufficient to account for the decrease in the numbers of new stolons (i.e. when new stolons are longer than 1 cm they become terminal buds).

It was noted by Hunt (1968) in the spring that after complete light interception the relative death rate of clover buds increased rapidly. This work appears to support this conclusion. However, he also concluded that because the relative death rate of clover buds did not decline markedly from the maximum after complete light interception that the growth of clover may depend upon the continued replacement of dying buds with new ones. This was not confirmed by the plant tracing studies made in this experiment where most of the stolons on the plants in the high pressure 'ungrazed' treatment survived and actually elongated over the second regrowth period, the period of virtually complete light interception.

It is interesting to note that 15 new stolons were recorded as dying on the ten traced plants of the high pressure 'ungrazed' treatment over the second regrowth period, an average of 1.5/plant. For the same time period, 18 new stolons died on the remaining 44 plants of the high pressure 'grazed' and low pressure treatments, an average of 0.4/plant. There would, of course, have been some areas of clover in the latter two treatments in which complete light interception occurred because of patch grazing, especially on the low pressure treatment.

The stolons that died were generally small, less than 1 cm in length, and probably the first to be shaded because of their smaller leaves and shorter petioles.

Other causes than severe shading are also thought to have resulted in the death of stolons, particularly the smaller stolons. For example, where a stolon (generally the longer stolons) had been lifted off the ground in the process of grazing, some of the adventitious roots at nodes closer to the terminal buds than the base of the stolon would have broken and this may have resulted in the death of the stolon or stolons associated with this adventitious root. Chow (1966) under greenhouse conditions found that when a primary stolon was severed at the crown of the plant and from any supply of nutrients and water from the taproot, but having the adventitious roots intact, the growth of that stolon slowed down sharply in the first and second week after treatment and ceased entirely after the third week. The growth of the branch stolon connected to this primary stolon, supported by its adventitious root, slowed down only slightly. By comparison, when the adventitious roots were removed from the nodes but the stolon was still connected to the crown and taproot, the original taproot gave its support to both main and branch stolons, but the growth of branch stolons, lacking the support from the adventitious roots, was much less than from the main stolon.

Growing conditions in the field, as in this experiment, were probably much less ideal than those of Chow (1966) so that branch stolons disconnected from their adventitious roots and their most direct supply of moisture by "ripping" up of the stolons may have resulted in their death.

It was noted after grazing that some stolons, although not grazed, were badly damaged, presumably by treading, which probably resulted in further death of stolons. This bruising of stolons seemed to occur particularly when the ground surface was hard and stolons could not be pushed into the soil by treading. Insect damage to some terminal buds on the traced plants was noted, and may have been another cause of stolon death.

At the end of the second regrowth period other differences than those already mentioned occurred between the high pressure 'grazed' and high pressure 'ungrazed' treatments. The distribution of the mature leaf area on the high pressure 'ungrazed' treatment, into size ranges, showed a pattern very similar to that of the low pressure treatment immediately prior to the second grazing (Fig. 3.7.2.), the average mature leaf size being 2.4 cm^2/leaf compared with 0.7 cm^2 on the high pressure 'grazed' treatment. Similarly the distribution of petiole lengths of the high pressure 'ungrazed' treatment at the end of the second regrowth period was like that of the low pressure treatment immediately prior to the second grazing. It is obvious from these results that severe defoliation results in considerable reduction in the area of individual leaves, but that during regrowth the area of the leaves gradually increases. It appeared that, in general, the longer the stolon, providing it was actively growing, the larger were the leaves arising from it.

Because the canopy on the high pressure 'ungrazed' treatment probably restricted light penetration to a considerable degree soon after the start of the second regrowth period (the total LAI at the start of this regrowth period was 1.5), and because intense shading of clover leaves accelerates senescence (Brougham 1958; Hunt 1968), it is not surprising that the high pressure 'ungrazed' treatment had a greater area of senescing leaf than the high pressure 'grazed' treatment at the end of the second regrowth period. Nevertheless, with the possible exception of the second regrowth period for the high pressure 'ungrazed' treatment, the critical LAI (LAI = 3.0, Brougham 1960) was not reached in any of the regrowth periods. It is considered therefore that apart from the above, little loss of dry matter would have occurred in any regrowth period because of leaf senescence and death, as is evidenced by the small areas of senescing leaf at the ends of the regrowth periods (Fig. 3.7.1.).

Although it appeared that the numbers of growing points on the high pressure 'ungrazed' treatment was fewer than on the high pressure 'grazed' treatment, the length and weight of stolon of the former treatment was greater than on the latter treatment at the start of the third grazing. The percentage of clover appeared to be greater on the high pressure 'ungrazed' than the high pressure 'grazed' treatment at the end of the second regrowth period. This may have resulted because the clover petioles elongated and lifted clover leaves above the leaves of the predominant weed dandelion (Taraxacum officinale L.) which resulted in the death of this weed.

4.2.3. The third grazing and third regrowth period

Above stolon height, there was little effective difference either in photosynthetic potential (Fig. 3.7.1.) or in structure (Fig. 3.6.1.) between the high pressure 'grazed' and the low pressure treatments after the third grazing. Nevertheless, the decrease in new stolon numbers was significantly greater on the high pressure 'grazed' than the low pressure treatment which suggests a harder grazing of the former treatment than the latter treatment. New stolons, being shorter, are more difficult for sheep to prehend than long stolons.

The difference in production between the two treatments over the third regrowth period was not significant. However, the pattern of clover development suggested a production advantage to the low pressure treatment because the increase in the area of developing and mature leaf and in the weight of petiole per unit area was greater for this treatment than the high pressure 'grazed' treatment. For the leaf area, this may have been the result of an apparently greater increase in numbers of growing points on the low pressure treatment than the high pressure 'grazed' treatment over the third regrowth period. The average area of the individual developing and mature leaves at the end of the regrowth period differed little between treatments.

In contrast to the first and second regrowth periods the increase in the numbers of new stolons for the high pressure 'grazed' treatment was negligible over the third regrowth period. It may have been that the decline in average stolon length as a result (Table 3.9.1.) of grazing meant a lack of potentially suitable nodes for stolon initiation. Hormone suppression of axillary buds may also be involved since moisture deficit was unlikely to have been a limiting factor in the third regrowth period (Fig. 3.1.1.).

Nevertheless, increases in stolon length/unit area occurred for both treatments, the low pressure treatment increase being significantly greater than that of the high pressure 'grazed' treatment. These stolon length increases appeared to be greater in this regrowth period than in either the first or the second probably because rainfall, soon after the third grazing had finished, raised the soil moisture level back to field capacity (Fig. 3.13.1.) thereby removing the moisture limitation to rapid growth.

Here again, by the end of the regrowth period the low pressure treatment was significantly greater in nearly all parameters including total yield of dry matter than the high pressure 'grazed' treatment.

4.2.3.a. The third grazing and third regrowth period for the high pressure 'ungrazed' treatment

The large quantity of herbage dry matter present on the high pressure 'ungrazed' treatment before the third grazing was associated with a large decrease in dry matter at the third grazing. A similar quantity of herbage dry matter remained on the high pressure 'ungrazed' and high pressure 'grazed' treatments immediately after grazing (Fig. 3.2.2.).

Of the 6 terminal buds/62.2 cm^2 on the high pressure 'ungrazed' treatment 5 were removed at this grazing whereas of the 17 new stolons/62.2 cm^2 on this treatment only 1 was removed as a result of grazing. This demonstrates how much more easily the longer stolons are prehendable by the sheep than the shorter stolons. Developing leaves from terminal buds are larger and petioles longer than on the smaller stolons and are therefore more easily enclosed in the sheep's mouth. The terminal bud is then easily pulled off the ground and a sharp jerk can "rip" up the stolon which generally breaks at a lower node. It was noted in the clover plant tracing studies that once the terminal bud of a stolon was grazed off, the stolon died back to the nearest growing stolon, whether newly initiated or older. A reasonable proportion of stolon may therefore have died which may have been associated with the negligible change in weight of stolon/unit area of this treatment over the third regrowth period.

Here again there was no difference in production between the high pressure 'ungrazed' and high pressure 'grazed' treatments over the third regrowth period (Table 3.2.3.). The greater increase in the numbers of new stolons of the former than the latter treatment appeared to be associated with a greater increase in leaf weight for the high pressure 'ungrazed' treatment than the high pressure 'grazed' treatment since the individual leaf sizes and therefore weights were similar between these treatments.

The clover percentage of the high pressure 'ungrazed' treatment fell from 77% just before the third grazing, to 53% just before the fourth grazing whereas the weed percentage changed from 17% to 45%. The removal of the clover canopy at grazing must have left the weed seeds and seedlings in a suitable environment for growth especially following the rainfall early in this regrowth period, and the light penetration to the base of the canopy.

At the beginning of the fourth grazing the two treatments had similar yield in nearly all parameters.

4.2.4. The fourth grazing and fourth regrowth period

Both for the high pressure 'grazed' and low pressure treatments immediately prior to the fourth grazing, there was a significant increase in the percentage of weeds compared with the proportion just before the first grazing. For the low pressure treatment this was also the case at the final harvest. It was noticeable several months after the experiment had finished how contamination with weeds and grass was greatest for the two high pressure treatments, and least for those extra plots which were not included in the experiment and remained ungrazed (Fig. 2.1.).

Immediately after the fourth grazing there appeared to be a greater weight and length of stolon/unit area and numbers of new stolons on the high pressure 'grazed' and high pressure 'ungrazed' treatments than immediately before the fourth grazing. Individual stolon observations showed, however, that 10-15% of the growing points were removed from these treatments at this grazing (Appendix 3). Core sample data showed an increase in the number of growing points over the fourth grazing. Although this discrepancy is difficult to explain, at least the core sample data lends support to the weight and length of stolon, and new stolon increases. Both techniques show a decrease in numbers of growing points over the fourth grazing for the low pressure treatment (Appendix 3) where weight and length of stolon/unit area appeared to decrease (Fig. 3.4.1. and 3.5.1.).

The production over the fourth regrowth period was not significantly different between the high pressure 'grazed' and low pressure treatments, despite the larger area and weight of leaf, greater length of stolon and number of terminal buds/unit area remaining on the low pressure treatment than the high pressure 'grazed' treatment immediately after the fourth grazing.

There was also no difference in production between the high pressure 'grazed' and high pressure 'ungrazed' treatments over the fourth regrowth period. Since there were no differences after grazing between any of the parameters of these two treatments, this result may have been expected.

EFFECTS OF GRAZING PERIODS

4.3. Total production of the 3, 6 and 9 day grazing periods (Mean of the high pressure 'grazed' and low pressure treatments)

It may be helpful to recapitulate the major differences between these three grazing period treatments at this point in the discussion. The 3 day treatment had six days longer uninterrupted regrowth in each regrowth period than the 9 day treatment, and three days longer regrowth than the 6 day treatment. For example, the length of the first regrowth period was 28 days from the start of the first grazing to the start of the second. The lengths of uninterrupted regrowth were therefore 25, 22 and 19 days for the 3, 6 and 9 day grazing periods respectively. No estimate of the growth during grazing periods was obtained.

Over the experimental period the dry matter production of the 3 day treatment was much greater than the 9 day treatment, the production from the 6 day treatment lying between the two (Table 3.2.2.). The production of leaf, petiole and stolon showed the same pattern as total herbage production (Table 3.4.2.). It is interesting that the total production of new stolons was greater for the 3 day than the 9 day treatment. The differences in total herbage production, however, were largely due to the differences in production between treatments in the first two regrowth periods.

<u>4.3.a. Total production of the 3, 6 and 9 day grazing periods</u> (Mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments.

A very similar pattern of total production occurred in this case as in section 4.3., the 3 day treatment being greater than the 6 day treatment which was greater than the 9 day treatment in the production of most parameters.

<u>4.3.1. The first grazing and first regrowth period</u> (Mean of the high pressure 'grazed' and low pressure treatments)

As a result of grazing, there was no difference between the 3, 6 and 9 day grazing periods in the reduction of available dry matter. A significant interaction effect occurred, however, (Appendix 2). For the low pressure treatment only, the reduction in dry matter appeared to be smaller for the 3 day than the 6 or 9 day grazing periods. This found support in the greater decrease of developing leaf area (Table 3.7.5.) and an apparently heavier grazing at stolon level of the 9 day treatment than the 3 day treatment. Because, after grazing, there was no difference between the 3 day and 9 day treatments in the weight of leaf remaining (Fig. 3.4.4.), some of the leaves being produced during the 9 days of the 9 day grazing period were probably grazed.

In this regrowth period the production of dry matter was greater for the 3 day treatment than for either the 6 or 9 day treatments. The greater production of petiole and leaf of the 3 day than the 9 day treatment confirms the herbage yield data.

Just before the second grazing the 3 day treatment had a significantly greater mature leaf area in leaf size ranges D and E than either the 6 or 9 day grazing periods (Fig. 3.7.5.). In contrast to this, the 9 day grazing period had significantly greater mature leaf area in leaf size range A than the 3 day treatment. This confirms the greater production of new stolons on the 9 day than the 3 day treatment, because leaves on new stolons are smaller than those from terminal buds.

At the beginning of the second grazing the greater clover percentage of the 3 day treatment than the 9 day treatment (Fig. 3.3.3.) may have reflected the more rapid closure of the 3 day than the 9 day clover canopy thereby causing greater restriction of light penetration to the weeds.

4.3.2. The second grazing and second regrowth period (Mean of the high pressure 'grazed' and low pressure treatments)

The greater quantity of available dry matter on the 3 day than the 9 day treatment at the beginning of the second grazing was probably the reason why the former treatment appeared to be more heavily grazed than the latter treatment.

Here again, however, the production over this period from the 3 day treatment was greater than for either the 6 or 9 day treatments. In contrast to the first regrowth period, however, production of new stolons was greater on the 3 day than the 9 day treatment (Table 3.5.2.), but at the end of this regrowth period, new stolon numbers were similar between treatments (Fig. 3.5.3.). The average mature leaf size appeared to be greater on the 3 day than the 9 day treatment (Fig. 3.7.5.). With the longer regrowth period, it is not surprising that the 3 day production was greater than the 6 or 9 day production.

At the beginning of the third grazing total herbage dry matter was significantly greater on the 3 day than the 6 or 9 day treatments (Fig. 3.2.3.), but there was no difference in botanical composition between treatments. The length and weight of stolon and number of terminal buds/62.2 cm^2 was also significantly greater on the 3 day than the 9 day treatment at the beginning of the third grazing.

4.3.2.a. The second regrowth period for the 3, 6 and 9 day grazing periods on the high pressure 'ungrazed' treatment

For clarity the 3, 6 and 9 day grazing period treatments are discussed for the high pressure 'ungrazed' treatment alone in this section. The separate regrowth periods are shown for these three treatments in Figure 3.2.4.

Here again, the production for the 3 day treatment appeared to be greater than the 9 day treatment over the second regrowth period. The leaf and petiole increases appeared to confirm this dry matter production data (Table 3.4.2.).

Fewer growing points were present at the end of this second regrowth period than at the beginning because of the death of approximately 10 new stolons/62.2 cm^2 on the 3, 6 and 9 day treatments. It seems probable that, had these stands of clover been left to grow for a longer period, continued death of new stolons would have taken place. However, some of the new stolons initiated after the first grazing became established sufficiently to compete successfully with terminal buds as was confirmed by the clover plant tracing studies.

At the beginning of the third grazing therefore, above stolon level, the 3 day treatment was larger in most parameters than the 9 day treatment. The average area of mature leaves was 2.6, 2.7 and 2 cm^2, and the number of growing points was 22, 23.3 and 23.9/62.2 cm^2 for the 3, 6 and 9 day grazing periods respectively.

4.3.3. The third grazing and third regrowth period (Mean of the high pressure 'grazed' and low pressure treatments)

The greater decrease from grazing in leaf, petiole and stolon of the 3 day than the 9 day treatment appeared to reflect the decreases in dry matter for these treatments. A similar situation for the 3 day and 6 day treatment applied.

After grazing the quantity of available dry matter remaining was similar for the 3, 6 and 9 day grazing periods (Fig. 3.2.3.). The 9 day treatment, however, reached this level of dry matter six days later than the 3 day treatment.

The production over the third regrowth period was similar in all parameters between the 3, 6 and 9 day grazing periods with the exception that the 3 and 6 day treatments were shown to increase the weight of leaves more than the 9 day treatment. This may have been due to the slightly larger leaves on the 3 and the 6 day treatments than the 9 day treatment and to the longer period of uninterrupted regrowth of the former treatments than the latter.

At the end of the regrowth period neither the dry matter yield measurements nor the levels of the measured clover parameters showed significant differences between treatments.

4.3.3.a. The third grazing and third regrowth period (Mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments)

The decreases in the measured parameters as a result of grazing and the production in the third regrowth period followed almost the same pattern as in section 4.3.3. Although few of the increases in the parameters during the regrowth period were significantly different between treatments, the general trend in production, however, was still for the 3 day to be greater than the 6 day which was greater than the 9 day treatment.

4.3.4. The fourth grazing and fourth regrowth period (Mean of the high pressure 'grazed' and low pressure treatments)

Before the fourth grazing began the only difference between the 3, 6 and 9 day grazing period treatments was that the 6 day treatment had a significantly greater area of mature leaf, more particularly in size ranges C and D, than the other two treatments (Fig. 3.7.5.). Grazing resulted in a greater decrease in leaf weight of the 6 day treatment than the 3 day treatment with a similar trend being reflected in the decrease in mature leaf area.

After grazing the 3 day treatment had a greater quantity of dry matter remaining than either the 6 or 9 day treatment (Fig. 3.2.3.) and this was reflected in the significantly greater weight of leaves remaining on the 3 day treatment than the 6 day treatment and greater area of developing leaf of the 3 day than the 9 day treatment.

There were no significant differences in production between treatments.

The greater percentage of grass on the 9 day than the 3 or 6 day treatment at the final harvest may reflect the fact that throughout the experimental period the 9 day treatment tended to be the last of the three treatments to restrict light penetration into the base of the canopy.

4.3.4.a. The fourth grazing and fourth regrowth period (Mean of the high pressure 'grazed' and high pressure 'ungrazed' treatments)

The 3, 6 and 9 day treatments were grazed to a similar extent, and there were no differences in production between treatments (Table 3.2.4.), although the 3 day treatment appeared to have a greater quantity of herbage remaining after grazing (Fig. 3.2.4.).

C. GENERAL DISCUSSION

4.4. The Grazing Pressure Treatments

Production in a pasture, at any one time, must be a function of the number of growing units, and the average production per growing unit. Over a time period the production function is more complex, because in this case, production is a function of the number of growing units at the beginning of the time period, the rate of increase or decrease in the number of growing units, and the average production of the average number of growing units over the time period.

Table 4.4.1. shows an attempt to relate the production of dry matter in the first three regrowth periods of the high pressure 'grazed' and low pressure treatments to the production per growing point. Several assumptions are made in this Table 4.4.1. The first assumption is that mature leaves present immediately after a grazing had either senesced or decomposed before the end of the associated regrowth period. Brougham (1958) found that mature leaves generally last for 15-20 days, a shorter period than each of the regrowth periods in the Table 4.4.1.

The area of mature leaf per 62.2 cm^2 immediately after grazing has been added to the increases in mature leaf area over that regrowth period. The reasoning for this was as follows. A stolon may have had one mature leaf remaining after grazing. At the end of the associated regrowth period that same stolon may have had 3 leaves present, but because the increase in mature leaf area was found by subtracting the area of mature leaf at the end of the regrowth period from that at the beginning, the increase in the number of leaves would have been calculated as 2 (3-1). Had the one mature leaf present after grazing sensced, which seems likely (Brougham loc. cit.), the real increase in the numbers of mature leaves should have been 3, which shows that the calculated increase in mature leaf area was underestimated. Table 3.8.1. (Results section) shows, on individual stolons measured after grazing, how many of them had mature leaves remaining and how many mature leaves/stolon there were. From this Table 3.8.1., the area of mature leaf/62.2 cm^2 remaining after grazing was calculated, and added to the underestimated increase in mature leaf area for each regrowth period.

The second assumption involved in Table 4.4.1. is that little leaf area produced during the regrowth period was lost by senescense and decay. This assumption appears valid because of the relatively short regrowth periods and the general lack of attainment of the critical LAI during the regrowth periods; the attainment of critical LAI being associated with a rapid increase in leaf senescence (Brougham 1958; Hunt 1968).

TABLE 4.4.1.

Some clover production parameters for the high pressure 'grazed' and low pressure treatments

Regrowth period	Average length of re-growth period (days)	Grazing pressure	Nos. growing points immediately after grazing (a)	Nos. growing points at end of regrowth period (b)	Average number of growing points over re-growth period (c)	Average area of individual mature leaves at end of regrowth period cm^2 (d)	Increase in mature leaf area over regrowth period cm^2 (e)	Nos. of mature leaves formed per growing point over re-growth period $\frac{e}{bd}$ (f)	$\frac{e}{cd}$ (g)
1	22	HP	10	31	20.5	1.0	60.4	2.0	3.0
		LP	17	26	21.5	2.5	127	2.0	2.4
2	29	HP	15	28	21.5	0.7	30.3	1.6	2.0
		LP	21	27	24.0	1.0	36.8	1.4	1.5
3	32	HP	19	24	21.5	0.7	36.4	2.2	2.4
		LP	24	33	28.5	1.0	57.5	1.7	2.0

The number of mature leaves produced per growing point has been calculated by two methods. The first way (column f, Table 4.4.1.) assumes that the production of new growing points occurred early in the regrowth period and therefore contributed significantly to production. The second method (column g, Table 4.4.1.) assumes that the growing points were produced more gradually and that some of them made relatively little contribution to leaf production during the regrowth period.

From the clover plant tracing studies, it appeared that new stolons were produced soon after light penetration into the base of the canopy (i.e. to stolon level) and soon after the removal of stolon growing points by grazing. Both methods of calculating the rate of leaf production are considered valid.

The general conclusion from Table 4.4.1. is that the rates of leaf production per growing point are similar between treatments. (Table 4.4.1. column f), the general tendency is for the high pressure 'grazed' treatment to show a faster rate of leaf production than the low pressure treatment.

If production from the clover is as defined at the beginning of the discussion (section C) then in the first regrowth period part of the reason why the low pressure treatment tended to yield more than the high pressure 'grazed' treatment was because of the larger and heavier leaves being produced. The rates of leaf production and the average number of growing points over the regrowth period were similar for the high pressure 'grazed' and low pressure treatments. The larger increase in petiole weight of the low pressure than the high pressure 'grazed' treatment over the first regrowth period was also a reason for the larger production of the former than the latter treatment.

In the second regrowth period the average numbers of growing points over the regrowth period were similar between treatments as also were the sizes of mature leaves and rates of leaf production. The difference in production already discussed, therefore, was possibly a reflection of the greater increase in the area of developing leaf in the high pressure 'grazed' treatment than in the low pressure treatment, and also the trend towards a greater increase in weight of the leaf and petiole fractions of the former compared with the latter treatment.

In the third regrowth period the average number of growing points over the regrowth period was considerably greater in the low pressure than the high pressure 'grazed' treatment although the rates of leaf production and average mature leaf sizes were similar. For this reason it would be expected, as far as the clover production is concerned, that greater production should have come from the low pressure treatment than from the high pressure 'grazed' treatment. This would also have been expected from the greater increase in petiole weight of the low pressure than the high pressure 'grazed' treatment. The trend in production, however, did not follow this pattern.

In general, within a regrowth period, the increases in the weight and length of stolon of the high pressure 'grazed' and low pressure treatments followed the same relative trends as those of dry matter production.

Perhaps the most notable feature of the stolon data was the dramatic increase in the numbers of new stolons of the high pressure 'grazed' treatment in the first two regrowth periods, which appeared to contribute significantly to production. Also notable was the death of new stolons during the second regrowth period of the high pressure 'ungrazed' treatment.

For the high pressure 'ungrazed' treatment in the second regrowth period, despite the death of new stolons, the increase in stolon length associated with increased terminal bud numbers appeared also to be associated with an increased size of leaf. The increase in petiole weight appeared to be a large part of the reason for the greater production of this treatment than the high pressure 'grazed' treatment over the second regrowth period.

Another effect of severe grazing appeared to be the reduction in weight of roots of white clover in the surface layers of soil, but not lower in the soil profile. It might have been expected from this that the low pressure treatment would have responded more quickly to moisture replenishment in the surface layers than the high pressure 'grazed' treatment. In the third regrowth period the information on the clover production from the core samples appeared to support this expectation.

4.5. The 3, 6 and 9 day grazing period treatments

Tables 4.4.2. and 4.4.3. are similar in form to Table 4.4.1. They show some parameters of clover production for the 3, 6 and 9 day grazing periods for the high pressure 'grazed' and low pressure treatments separately. The Tables 4.4.2. and 4.4.3. are not strictly comparable because, unlike the situation for the grazing pressure treatments where adjustment was made in Table 4.4.1. for any underestimation of mature leaf area increases, this has not been estimated and allowed for in Table 4.4.2. and 4.4.3.

The general conclusion from these Tables (4.4.2. and 4.4.3.) is that the rates of leaf production are similar between treatments, although estimates appear more variable in Table 4.4.3.

TABLE 4.4.2.

Some clover production parameters of the 3, 6 and 9 day grazing periods for the high pressure 'grazed' treatment

Regrowth period	Average length of re-growth period (days)	Grazing period	Nos. growing points immediately after grazing (a)	Nos. growing points at end of regrowth period (b)	Average number of growing points over re-growth period (c)	Average area of individual mature leaves at end of re-growth period cm^2 (d)	Increase in mature leaf area over regrowth period cm^2 (e)	Nos. of mature leaves formed per growing point over re-growth period $\frac{e}{bd}$ (f)	$\frac{e}{cd}$ (g)	Nos. leaves formed per growing point per week ($h = \frac{f}{weeks}$)
1	25	3	9.4	29.7	19.6	1.3	77.0	2.0	3.0	0.55
	22	6	8.1	28.1	18.1	1.0	54.0	1.9	3.0	0.61
	19	9	11.3	36.7	24.0	0.8	48.0	1.6	2.5	0.59
2	32	3	12.2	30.0	21.1	1.0	32.0	1.1	1.5	0.24
	29	6	14.0	28.4	21.2	0.5	21.0	1.5	2.0	0.37
	26	9	20.2	24.1	22.1	0.6	21.0	1.4	1.6	0.38
3	35	3	16.1	24.5	15.3	0.9	31.0	1.4	2.3	0.28
	32	6	24.9	25.4	26.1	1.0	33.0	1.3	1.3	0.28
	29	9	17.9	22.2	20.1	0.8	20.0	1.1	1.2	0.27

TABLE 4.4.3.

Some clover production parameters of the 3, 6 and 9 day grazing periods for the low pressure treatment

Regrowth period	Average length of re-growth period (days)	Grazing period	Nos. growing points immediately after grazing (a)	Nos. growing points at end of re-growth period (b)	Average number of growing points over re-growth period (c)	Average area of individual mature leaves at end of re-growth period cm^2 (d)	Increase in mature leaf area over re-growth period cm^2 (e)	Nos. of mature leaves formed per growing point over regrowth period $\frac{e}{bd}$ (f)	$\frac{e}{cd}$ (g)	Nos. leaves formed per growing point per week $\frac{f}{(h=weeks)}$
1	25	3	17.1	21.7	19.4	3.3	128.0	1.8	2.0	0.50
	22	6	16.1	25.5	20.8	2.5	91.0	1.4	1.8	0.45
	19	9	18.5	30.7	24.6	1.6	89.0	1.8	2.3	0.67
2	32	3	16.3	24.2	20.2	1.6	31.0	0.8	1.0	0.27
	29	6	18.3	25.7	22.0	0.9	18.0	0.8	0.9	0.20
	26	9	29.4	30.4	29.9	0.6	4.0	0.2	0.2	0.05
3	35	3	16.9	30.8	23.9	1.1	50.0	1.5	1.9	0.30
	32	6	22.7	33.7	28.2	1.0	58.0	1.7	2.1	0.37
	29	9	32.0	37.9	34.9	1.1	29.0	0.8	0.8	0.20

In the first regrowth period therefore, the longer period of uninterrupted regrowth resulted in greater production from the 3 day than the 9 day treatment because of the larger leaves and greater petiole elongation of the former than the latter treatment. The rates of leaf production and the average number of growing points per treatment were similar (Tables 4.4.2. and 4.4.3.).

In the second regrowth period it appears that the differences between treatments were the result of the larger leaves and longer regrowth period of the 3 day than the 9 day treatment. The result for the 9 day grazing period on the low pressure treatment appears to be anomalous.

In the third regrowth period the fact that there were no significant differences between the 3, 6 and 9 day grazing periods is supported by the similar sizes of leaves, but the average number of growing points/62.2 cm^2 appears to favour the 6 and 9 day treatments. These treatments nevertheless had a shorter period of uninterrupted regrowth than the 3 day treatment.

SUMMARY AND CONCLUSIONS

1. Of the grazing pressure treatments, total production was greatest for the high pressure 'ungrazed' treatment, intermediate for the high pressure 'grazed' treatment and lowest for the low pressure treatment during an experiment over the summer months.

2. In the first regrowth period the low pressure treatment produced more than the high pressure 'grazed' treatment because of the greater petiole production and greater area and weight of leaf produced. The large numbers of newly initiated stolons on the high pressure 'grazed' treatment appeared to contribute significantly to production but resulted in the smaller average leaf size of this treatment than the low pressure treatment. Petiole production was lower for the high pressure 'grazed' than the low pressure treatment because light restriction to developing leaves was less severe for the former than the latter treatment.

3. In the second regrowth period the high pressure 'grazed' treatment produced significantly more than the low pressure treatment. This appeared to be the result of the greater production of developing leaf and petiole of the former than the latter treatment. The dry conditions during this regrowth period resulted in a large reduction in the average size of mature leaves on the low pressure treatment. The rate of leaf production was also reduced in this regrowth period compared with the first regrowth period. Here again new stolons appeared to contribute significantly to production on the high pressure 'grazed' treatment.

4. The high pressure 'ungrazed' treatment produced more than the high pressure 'grazed' treatment in the second regrowth period. A large increase in the average mature leaf size took place probably because of the death of some new stolons but also because of the larger leaves being produced from larger stolons. A large increase also took place in petiole production as a result of restriction of light penetration into the canopy.

5. In the third regrowth period there was no difference in production between the high pressure 'grazed' and the low pressure treatments. This did not appear to be reflected in the production found from the core sample data which favoured the latter treatment.

6. In the fourth regrowth period there were no significant differences in production between the high pressure 'grazed' and low pressure treatments and the high pressure 'grazed' and high pressure 'ungrazed' treatments.

7. Of the 3, 6 and 9 day grazing periods, the total production was greatest for the 3 day treatment, intermediate for the 6 day treatment and least for the 9 day treatment.

8. In all regrowth periods the 3 day treatment had three days longer uninterrupted regrowth than the 6 day treatment and six days longer uninterrupted regrowth than the 9 day treatment. It appears that some of the production occurring during grazing was consumed, especially on the 9 day treatment.

9. In the first regrowth period, the reason for the trend in production 3 days > 6 days > 9 days was that the production of leaf and petiole was greater for the former than the latter treatment. The average mature leaf size was greater on the 3 day treatment than the 9 day treatment, with the 6 day treatment leaves being intermediate in size. This probably resulted because the greater numbers of small leaves arising from the greater numbers of new stolons initiated on the 9 day than the 3 day treatment.

10. In the second regrowth period the greater production of the 3 day than the 9 day treatment was attributed to the larger leaves being produced and longer regrowth period of the 3 day than the 9 day treatment.

11. In the third and fourth regrowth periods there were no differences in production between the 3, 6 and 9 day grazing periods. Although the lengths of the regrowth periods were shorter for the latter two treatments the average numbers of growing points over the third regrowth period appeared to be greater for the 6 and 9 day treatments. This may have partly compensated for the longer regrowth period of the 3 day treatment.

12. Longer stolons generally had larger leaves and were more prehendable by sheep than shorter stolons. New stolons appeared to be initiated as a result of increased light penetration to stolon level and to a further degree by the removal of terminal buds. This refers to new stolon production over and above that which normally occurs in undisturbed clover canopies.

13. Over the experimental period there was a gradual increase in the percentage of weeds in the sward.

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APPENDIX 1

1. RAINFALL

Monthly rainfall figures over the experimental period.

RAINFALL (mm)

Year	Month	Experimental month	30 year Average
1971	June		97.6
	July		89.5
	August		86.0
	September		69.9
	October		89.1
	November	59.8	79.0
	December	52.5	103.0
1972	January	63.5	85.5
	February	50.3	69.2
	March	139.0	69.9
	April	73.9	73.2
	May	97.0	88.6

From November until February the rainfall during the experiment was lower than average. Heavy rain in March 1972, however, resulted in much higher rainfall than average.

Appendix 1 (cont.)

2. TEMPERATURES

Mean monthly maximum, mean monthly minimum and mean monthly temperatures.

TEMPERATURES (°C)

Year	Month	Mean Max.	(30 yr Av.)	Mean Min.	(30 yr Av.)	Mean	(30 yr Av.)
1971	June	15.2	12.8	7.7	4.8	11.5	8.8
	July	12.4	12.1	4.5	4.0	8.5	8.0
	August	14.3	13.2	6.7	4.9	10.5	9.0
	September	14.7	15.0	7.3	6.6	11.0	10.8
	October	16.1	16.5	8.8	8.2	12.5	12.4
	November	19.4	18.6	10.0	9.8	14.7	14.2
	December	21.5	20.6	12.2	11.5	16.9	16.2
1972	January	21.7	21.9	13.0	12.6	17.3	17.2
	February	21.7	22.4	11.6	12.9	16.7	17.5
	March	21.4	21.0	13.5	11.6	17.5	16.4
	April	18.4	18.2	9.7	9.3	14.1	13.6
	May	14.7	15.2	6.3	6.9	10.5	11.0

APPENDIX 2

GRAZING PRESSURE X GRAZING PERIOD INTERACTIONS

R.B. = randomised block and S.P. = split plot. These abbreviations in the table below describe in which comparison the interaction occurs, whether in the comparison of the high pressure 'grazed' and low pressure treatments (R.B.) or in the comparison of the high pressure 'grazed' and high pressure 'ungrazed' treatments (S.P.).

Section	R.B. or S.P.	Observation	Type of Interaction	Comment
1. Herbage dry matter yield	R.B.	Regrowth period 3 2nd cut after grazing	+Q	
		Regrowth period 3 3rd cut after grazing	+Q	
		1st grazing decrease	÷L	*
	S.P.	Regrowth period 3 3rd cut after grazing	+L	
		Regrowth 4	+Q	
2. Botanical Analyses. cl = clover w = weeds g = grass	R.B.	Before 2nd grazing (cl)	+L	
		Before 3rd grazing (w)	++L	*
		Final cut (g)	+L	
	S.P.	Final cut (g)	++L	
3. Weights of leaves, petioles and stolons. l = leaves pet. = petioles st. = stolons	R.B.	Before grazing 2 (pet)	++L	
		After grazing 2 (pet)	++L	
		After grazing 4 (pet)	++Q	
		Regrowth 1 (pet)	++L	
		Total regrowth (pet)	+L	
		1st grazing decrease (l)	+L	*
		2nd grazing decrease (pet)	+L	
	S.P.	After grazing 4 (st)	+Q	
		Regrowth 3 (st)	+L, +Q	
		Total regrowth (st)	+L	

Appendix 2 (cont.)

Section	R.B. or S.P.	Observation	Type of Interaction	Comment
4. Length stolon (l.s.)	R.B.	After grazing 2 (n.s.)	+L	
		After grazing 3 (n.s.)	+L	
Nos. terminal		Before grazing 4 (l.s.)	+Q	*
buds = (t.b.)		Before grazing 4 (t.b.)	++Q	*
and new		Before grazing 4 (n.s.)	++L	*
stolons (n.s.)		Regrowth 2 (l.s.)	+Q	
		Regrowth 3 (l.s.)	+Q	
		Regrowth 3 (t.b.)	+Q	
		Total regrowth (n.s.)	+Q	
		Total decrease (n.s.)	+Q	
	S.P.	Before grazing 4 (n.s.)	++L	
		4th grazing decrease (n.s.)	+L	
		Total decrease (n.s.)	++L	
5. Individual stolon observation.	R.B.	Plants/quadrat 1	+L	
		No. st. with mat. leaf 1	+++L, +Q	*
		No. t.b. remaining 4	+Q	
		No. dev. leaf remaining 4	+L	
	S.P.	No. st. with pet. remaining 3	+L	
6. Leaf Area	R.B.	Before grazing 1 Total M	++Q	
D = developing		Before grazing 4 Total S	+Q	
M = mature		After grazing 4 Total M	+L, ++Q	
S = senescing	S.P.	After grazing 3 Total S	+Q	
		Before grazing 4 total S	+L	
	R.B.	Total regrowth D	+L	
		1st grazing decrease M	+L, ++Q	*
		4th grazing decrease S	+Q	
		Total decrease M	+Q	
	S.P.	Regrowth 3 S	+L	

APPENDIX 3

The table below shows a comparison of the numbers of growing points remaining after each grazing from the core sample data and the individual stolon measurement data.

% of growing points remaining after each grazing

After grazing	Grazing pressure	Core Analysis	Individual stolons
1	HP	48	52
	LP	88	92
2	HP	49	42
	LP	82	77
3	HP	72	61
	LP	89	76
4	HP	114	85
	LP	89	96
3	HP	72	61
	HPU	70	38
4	HP	114	85
	HPU	108	86

The results are in reasonable agreement between the two techniques except for three comparisons, namely; at the fourth grazing for the high pressure 'grazed' treatment and at the third and fourth grazings for the high pressure 'ungrazed' treatment.

APPENDIX 4

STATISTICAL THEORY

(a) Randomised block design

The classification model which describes the yield for an experiment of randomised block design is :-

$$y_{ij} = \mu + b_i + t_j + e_{ij} \qquad \underline{1}$$

for the plot in the ith block receiving the jth treatment where :-

y_{ij} is some yield measurement on the clover for the plot in the ith block and jth treatment.

μ is the general mean effect

b_i is the effect due to the ith block

t_j is the effect of the jth treatment

e_{ij} is the error which includes residual effects not incorporated in the block or treatment effects.

For the experiment here i = 1, 2, 3 are the three blocks
j = 1, 2, 3 = H3, H6 and H9
j = 4, 5, 6 = L3, L6 and L9

It could be noted here that the classification model can be written in the more familiar notation of the generalised regression model :-

$$y_{ij} = \mu x_o + b_1x_1 + b_2x_2 + b_3x_3 + t_1x_4 + t_2x_5 + t_3x_6 + t_4x_7 + t_5x_8 + t_6x_9 + e_{ij}$$

Where x_k is either zero or unity according to the following rules :-

(1) x_o is always 1

(2) x_k for k = 1, 2, 3 is equal to 1 if i = k, equals zero otherwise

(3) x_k for k = 4..9, is equal to 1 if j = k-3, equals zero otherwise

A tableau giving the regression equation for each plot can be set out (Appendix 5). Look, for example, at the model for a particular plot y_{11}, the yield of the plot on the 1st block receiving treatment H3

$$y_{11} = \hat{\mu} + \hat{b}_1 + \hat{t}_1 + \hat{e}_{11}$$

$$\hat{e}_{11} = y_{11} - \hat{\mu} - \hat{b}_1 - \hat{t}_1$$

$$\hat{e}_{11}^{\,2} = (y_{11} - \hat{\mu} - \hat{b}_1 - \hat{t}_1)^2$$

where $\hat{u}$, $\hat{b}_1$ $\hat{t}_1$ are estimates of the true regression coefficients and $\hat{e}_{11}$ is an estimate of the error term.

Appendix 4 (cont.)

Given a model of the response of the dependent variable (of interest) to various effects (equation 1), the aim in regression analysis is to obtain estimates of the regression parameters of the model such that certain desirable properties are met. When estimates of the parameters of the model are such that the amount of variance of the dependent variable (y_{ij}) 'unexplained' by the parameters of the model is minimised, and if we assume that the errors are identically and independently distributed, then the resultant estimates have the property of being the best (minimum variance) unbiased estimates of the parameters of the model (BLUE). Hence we wish to obtain the estimates of the parameters that minimise $\sum e_{ij}^2$. These estimated parameters are called the least squares estimators.

Setting the first differential of a function equal to zero and solving the resultant equation finds the turning points of the function and evaluating the second differential at each turning point indicates the nature (maximum, minimum or inflexion) of these points.

Consider $Q = \sum (y_{ij} - u - b_i - t_j)^2 = \sum e_{ij}^2$

Minimising the sum of squares of residuals from regression involves setting $dQ = 0$ and solving the resultant equation. This involves setting the partial derivatives of Q with respect to each of the estimates equal to zero, and solving the resultant set of normal equations (N.E.)

$$\frac{\partial Q}{\partial \hat{\mu}} = 0$$

$$\frac{\partial Q}{\partial \hat{b}_i} = 0 \text{ for each } \hat{b}_i$$

$$\frac{\partial Q}{\partial \hat{t}_j} = 0 \text{ for each } \hat{t}_j$$

The solution values for $\hat{\mu}$, $\hat{b}_i$, $\hat{t}_j$ from the N.E. are the values at which Q reaches a stationary value. It has been shown (Kempthorne 1962, p55) that Q is a quadratic function of a form such that the solution to the normal equations gives a minimum value for Q.

It is possible to derive a set of rules for obtaining the N.E. by manipulating the columns of numbers, obtained by setting out the observations as a function of the estimated parameters in tableau form (Appendix 5). In the general case, the solution to the N.E. gives a unique value for each estimated regression coefficient. For classification models, however, the resulting normal equations are not linearly independent (Appendix 5 where A = B + C + D = E + F + G + H + I + J) and there is no unique solution to the normal equations.

Appendix 4 (cont.)

In this situation we can make use of the property that non-estimable functions of the parameters can be assigned arbitrary values without affecting the least squares estimates of estimable functions of the parameters. We can therefore constrain selected non-estimable functions of the parameters, taking care, in doing so, that no estimable function of the parameters is constrained, so that the resultant set of equations has a unique solution.

Two appropriate constraints for the solution of the normal equations in our example (Appendix 5) are :-

$$\hat{b}_1 + \hat{b}_2 + \hat{b}_3 = 0$$

$$\hat{t}_1 + \hat{t}_2 + \hat{t}_3 + \hat{t}_4 + \hat{t}_5 + \hat{t}_6 = 0$$

i.e. $$\hat{b}_3 = -(\hat{b}_2 + \hat{b}_1)$$

$$\hat{t}_6 = -(\hat{t}_1 + \hat{t}_2 + \hat{t}_3 + \hat{t}_4 + \hat{t}_5)$$

A new reparameterised tableau (Appendix 6) can now be drawn up and the values of the X variables in the tableau chosen so that the expectations of the estimated regression coefficients are some required linear combination of the parameters of the model and also so that the estimates of interest are orthogonal. Orthogonality means that the estimates of interest are independent of each other and block effects. In addition, this property means that the ratio of the regression mean square for an estimate and the error mean square follows an F distribution under the null hypothesis that the expectation of the estimate equals zero.

It may be worth noting here that this ratio is the square of the t value that is commonly used to test the null hypothesis that the expectation of the regression estimate of interest equals zero. In this case either the F or t distributions can obviously be used for testing hypotheses.

The reparameterised tableau (Appendix 6) was used in the randomised block analysis and the normal equations shown derived from the tableau. The expectations of the estimated regression coefficients described the effects :-

1. Low pressure treatment - High pressure 'grazed' treatment.

2. The linear grazing period effect.

3. The quadratic grazing period effect.

4. The linear grazing period X grazing pressure interaction.

5. The quadratic grazing period X grazing pressure interaction.

The sum of squares associated with each estimated regression coefficient can be

Appendix 4 (cont.)

found by multiplying the value for the estimated regression coefficient by the R.H.S. of the N.E. (Appendix 6; Kempthorne 1962) and the null hypothesis that the regression coefficient equals zero then tested using the ratio $\frac{R.M.S.}{E.M.S.} \sim F(1, d.f.)$. The regression analyses of the results was done on an I.B.M. 1620 computor using a programme called Bar 3.

The split plot analysis (S.pt.)

In the analysis of the randomised block designs (R.B.D.) it can be noted that it is possible to estimate regression coefficients for the treatment x block interaction. The appropriate x_k variables would be obtained by multiplication of each reparameterised x_k for blocks with each reparameterised x_k for treatments. Where treatments are not replicated within blocks the resulting regression will exactly account for all the observed variation in the y_{ij}'s. In this situation we are forced to assume TXB interaction is zero if we wish to obtain an estimate of error variance.

In the split plot analysis we identify blocks for the split plots (these are usually whole plots). In this case we can identify replicates of the split plot treatments as the whole plot blocks. With respect to split plot treatments we have :-

1. Block effects.
2. Split plot treatment effects.
3. Split plot treatment x block interaction.

This can clearly be considered as a R.B.D. as far as the split plot treatments are concerned. We could obtain the reparameterised variables, in the tableau, for each of the split plot treatment x block interaction terms.

With respect to whole plot treatments, the split plot replicates are whole plot blocks and we have :-

1. Rep. effects.
2. Whole plot treatment effects (w.p.t.).
3. Whole plot treatment x rep. interactions.

but the corrected total S.S. in this analysis is the corrected S.S. due to blocks in the split plot treatment analysis, since split plot blocks are whole plots. That is, it is possible to choose the reparameterisation of the block variables so that the new variables estimate rep. effects, whole plot treatment effects, and whole plot treatment x rep. interactions. Having done this we can then easily

Appendix 4 (cont.)

derive the regression variables to estimate :-

1. Split plot treatment x reps.
2. Split plot treatment x whole plot treatments.
3. s.p.t. x w.p.t. x reps.

interactions.

In analysis of split plot experiments we need to test w.p. treatments against w.p.t. x rep. interaction and split plot treatments and s.p.t. x w.p.t. interactions against the remaining s.p. x block interaction.

In using generalised regression analysis to partition the total sum of squares of the dependant variable we can choose to allow either (w.p.t. x rep.) or (s.p.t. x rep. + s.p.t. x w.p.t. x rep.) effects to be calculated as the residual error term.

Clearly it is possible to use generalised regression of the reparameterised variables to obtain the necessary partition of the total S.S. for the split plot analysis of variance.

APPENDIX 5

y_{ij}	u	b_1	b_2	b_3	t_1	t_2	t_3	t_4	t_5	t_6
y_{11}	1	1	0	0	1					
y_{12}	1	1	0	0		1				
y_{13}	1	1	0	0			1			
y_{14}	1	1	0	0				1		
y_{15}	1	1	0	0					1	
y_{16}	1	1	0	0						1
y_{21}	1	0	1	0	1					
y_{22}	1	0	1	0		1				
y_{23}	1	0	1	0			1			
y_{24}	1	0	1	0				1		
y_{25}	1	0	1	0					1	
y_{26}	1	0	1	0						1
y_{31}	1	0	0	1	1					
y_{32}	1	0	0	1		1				
y_{33}	1	0	0	1			1			
y_{34}	1	0	0	1				1		
y_{35}	1	0	0	1					1	
y_{36}	1	0	0	1						1

NORMAL EQUATIONS

$$y_{..} = 18\hat{\mu} + 6\hat{b}_1 + 6\hat{b}_2 + 6\hat{b}_3 + 3\hat{t}_1 + 3\hat{t}_2 + 3\hat{t}_3 + 3\hat{t}_4 + 3\hat{t}_5 + 3\hat{t}_6 \qquad A$$

$$y_{1.} = 6\hat{\mu} + 6\hat{b}_1 + \hat{t}_1 + \hat{t}_2 + \hat{t}_3 + \hat{t}_4 + \hat{t}_5 + \hat{t}_6 \qquad B$$

$$y_{2.} = 6\hat{\mu} + 6\hat{b}_2 + \hat{t}_1 + \hat{t}_2 + \hat{t}_3 + \hat{t}_4 + \hat{t}_5 + \hat{t}_6 \qquad C$$

$$y_{3.} = 6\hat{\mu} + 6\hat{b}_3 + \hat{t}_1 + \hat{t}_2 + \hat{t}_3 + \hat{t}_4 + \hat{t}_5 + \hat{t}_6 \qquad D$$

$$y_{.1} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_1 \qquad E$$

$$y_{.2} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_2 \qquad F$$

$$y_{.3} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_3 \qquad G$$

$$y_{.4} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_4 \qquad H$$

$$y_{.5} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_5 \qquad I$$

$$y_{.6} = 3\hat{\mu} + \hat{b}_1 + \hat{b}_2 + \hat{b}_3 + 3\hat{t}_6 \qquad J$$

Appendix 5 (cont.)

Where $y_{..} = \sum_{ij} y_{ij}$ grand total of observations

$y_{.j} = \sum_{i} y_{ij}$ total of jth treatment from all blocks

$y_{i.} = \sum_{j} y_{ij}$ total of all treatments from ith block

Rules for the tableau

There is one equation for each estimated regression coefficient

i.e. $\frac{\partial Q}{\partial \hat{b}_i} = 0$ gives us the normal equation for b_i

These N.E. are derived from a tableau in which there is a column for each regression coefficient. Rules for obtaining the N.E. for b_i are to take the column of the tableau for b_i and use it as a 'pivot column'. Multiply each column of this tableau by this 'pivot column' and associate the regression coefficient of the non-pivot column with the resultant multiplication. The right hand side of the normal equation for b_i is obtained by multiplication of the y_{ij} column with the 'pivot column'.

APPENDIX 6

Rules for reparameterisation

When changing the tableau to ensure linear independence between all columns, two rules have to be obeyed :-

1. The reparameterised tableau must be of the same rank as the original tableau.
2. Each column of X variables must be some linear combination of the columns of the original tableau.

Appendix 6 (cont.)

y_{ij}	$\tilde{u}$	$\tilde{b}_1$	$\tilde{b}_2$	$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{t}_3$	$\tilde{t}_4$	$\tilde{t}_5$
y_{11}	1	1	0	-1	1	-1	-1	1
y_{12}	1	1	0	-1	0	2	0	-2
y_{13}	1	1	0	-1	-1	-1	1	1
y_{14}	1	1	0	1	1	-1	1	-1
y_{15}	1	1	0	1	0	2	0	2
y_{16}	1	1	0	1	-1	-1	-1	-1
y_{21}	1	0	1	-1	1	-1	-1	1
y_{22}	1	0	1	-1	0	2	0	-2
y_{23}	1	0	1	-1	-1	-1	1	1
y_{24}	1	0	1	1	1	-1	1	-1
y_{25}	1	0	1	1	0	2	0	2
y_{26}	1	0	1	1	-1	-1	-1	-1
y_{31}	1	-1	-1	-1	1	-1	-1	1
y_{32}	1	-1	-1	-1	0	2	0	-2
y_{33}	1	-1	-1	-1	-1	-1	1	1
y_{34}	1	-1	-1	1	1	-1	1	-1
y_{35}	1	-1	-1	1	0	2	0	2
y_{36}	1	-1	-1	1	-1	-1	-1	-1

NORMAL EQUATIONS

$$18\tilde{\mu} = y_{..}$$
$$12\tilde{b}_1 + 6\tilde{b}_2 = y_{1.} - y_{3.}$$
$$6\tilde{b}_1 + 12\tilde{b}_2 = y_{2.} - y_{3.}$$
$$18\tilde{t}_1 = -y_{.1} - y_{.2} - y_{.3} + y_{.4} + y_{.5} + y_{.6}$$
$$12\tilde{t}_2 = y_{.1} - y_{.3} + y_{.4} - y_{.6}$$
$$36\tilde{t}_3 = -y_{.1} + 2y_{.2} - y_{.3} - y_{.4} + 2y_{.5} - y_{.6}$$
$$12\tilde{t}_4 = -y_{.1} + y_{.3} + y_{.4} - y_{.6}$$
$$36\tilde{t}_5 = y_{.1} - 2y_{.2} + y_{.3} - y_{.4} + 2y_{.5} - y_{.6}$$

L.H.S. = R.H.S.

where

$y_{..} = \sum_{ij} y_{ij}$ grand Total

$y_{.j} = \sum_{i} y_{ij}$ jth Trt. Tot

$y_{i.} = \sum_{j} y_{ij}$ ith block To