Grass.............

"Grass is the forgiveness of nature - her constant benediction. Fields trampled with battle, saturated with blood, torn with the ruts of cannon, grow green again with grass, and carnage is forgotten. Streets abandoned by traffic become grass grown like rural lanes and are obliterated; forests decay, harvests perish, flowers vanish, but grass is immortal. Beleaguered by the sullen hosts of winter, it withdraws into the impregnable fortress of its subterranean vitality and emerges upon solicitation of spring. Sown by the winds, by wandering birds, propagated by the subtle horticulture of the elements, which are its ministers and servants, it softens the rude outline of the world. It invades the solitude of deserts, climbs the inaccessible slopes and forbidding pinnacles of mountains, modifies climates and determines the history, character and destiny of nations."

John J. Ingalls.

A STUDY OF THE REACTION OF SEVERAL VARIABLES OF TOP GROWTH OF A PERENNIAL RYEGRASS/WHITE CLOVER PASTURE, TO DIFFERENT DEFOLIATION TREATMENTS; AND MEASUREMENTS ON SOIL MOISTURE STATUS.

A Thesis presented at Massey Agricultural College
in part fulfilment of the requirements for
the Degree of Master of Agricultural
Science in the University of New
Zealand.

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by

J. P. Kerr

- 1959 -

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CHAPTER I

Introduction.

The agricultural research worker must on occasion adopt a broad view of farming purely as the management of plants and animals to produce human food. He has the task of outlining many of the principles to be used in farming practice, to increase world food production, in order to meet the challenge of a growing world population. He needs to consider the biological efficiency of the living processes and systems involved in food production; in much the same way as a businessman or farmer must consider the business efficiency of his factory or farm operations.

Food production may be increased either by bringing more land under cultivation or by intensifying agriculture on the existing areas of cultivation, thereby increasing production per acre. Watson (1958) described the problem as fundamentally one of increasing the total annual photosynthesis per unit area of crop, for it is the net product of photosynthesis which the farmer harvests. Photosynthesis requires light, moisture and nutrients, and as light is the only one of these factors which can not be readily supplied artificially, Donald and Black (1958) have suggested that the ultimate measure of agricultural efficiency could well be expressed in terms of the proportion of light energy utilised by the crops or pastures. The size and activity of the photosynthetic system then becomes one of the determinants of crop yield. The potential rate of photosynthetic activity is controlled by the genetic make-up of the plant. The same is true to a certain degree of the size of the photosynthetic system, but the farmer too, through various cultural and management methods, exerts considerable control over the size of the system. Particularly is this the case in grassland farming when periodic harvesting of the herbage whether by machine or the grazing animal is responsible for sudden changes in the size of the photosynthetic system - the pasture canopy. Knowledge of the optimum canopy for maximum pasture growth on different types of pastures is necessary. Also information regarding potential yield losses suffered under various frequencies and intensities of defoliation, and on the influence of the type and method of grazing on plant growth form is needed.

Past studies on the influence of various frequencies and intensities of defoliation on the yield of pastures have generally shown that lengthened spells between grazings result in increased yield. (Stapledton 1924; Richardson et al. 1932; Hudson et al. 1933; Sears 1949; Wagner 1952).

These studies have largely measured seasonal or annual herbage yields and botanical changes.

On the other hand controlled environment studies on individual plants, together with other single plant studies, have presented information on plant behaviour and growth.

Within recent years investigations to bridge the gap between field trials on the one hand, and controlled environment and individual plant studies, on the other, have been undertaken by several workers. (Brougham 1955, Black 1958). Plant growth has been studied in swards where competition for the individual factors which determine growth is present. The presence of competition between plants for water and nutrients, is probably of lesser significance than it is for light, for information on plant requirements can be obtained from individual plant studies. These studies of Brougham and Black have helped to explain the effects of different frequencies and intensities of grazing on pasture yields as well as to aid the application of results from individual plant studies to field conditions.

The work undertaken for this thesis has been an investigation into the reaction of pasture yield and composition, as well as pasture canopy and tiller population to two different grazing treatments. Measurements have also been taken during part of the experimental period on soil moisture status at predetermined depths under the two treatments. The experiment was carried out under conditions similar to those prevailing on a normal establishing perennial ryegrass/white clover sheep pasture. The investigation tends to be broad in nature rather than tackling a specific problem and consequently many further questions have been posed.

C H A P T E R II

Review of Literature .

This review will be presented in four parts as follows:

I. Light and pasture growth.

II. Pasture composition and tiller population studies.

III. Soil moisture and plant growth.

IV. Pasture root growth - root distribution.

P A R T I

Light and Pasture Growth.

A. Definition of terms used in the text. The term plant growth covers both stem elongation and the accumulation of plant dry matter (Stoughton, 1955). In pasture production the latter is of primary importance, but the need to consider growth habit and the partitioning of material between "roots" and "shoots" must not be overlooked.

Plant growth (dry weight increase) may be measured in terms of relative growth rate which is defined as the "increase in plant weight in gms. (lb.), per gm. (lb.) total weight, per day (week)", Blackman, (1919). This may be divided into two components:

a. net assimilation rate, defined as the increase in plant weight per unit leaf area, and

b. leaf area ratio, which is the ratio of leaf area to total plant weight.

The following abbreviations have been used in the text:

R.G.R. - relative growth rate.

N.A.R. - net assimilation rate.

L.A.R. - leaf area ratio.

L.A.I. - leaf area index.

B. Size and Activity of the Photosynthetic System.

Watson (1958) stated that although total dry matter production by a crop may vary either through a change in size of the photosynthetic system or in its activity, the photosynthetic capacity of crops expressed in terms of leaf area is much more variable in agricultural environments than the photosynthetic efficiency as measured by the N.A.R. It cannot be assumed that leaf area is a perfect measure of the size of the photosynthetic system (Watson, 1956) as other parts of the plant are capable of photosynthesis. With pot experiments using several barley varieties, Watson *et al.*(1958), discovered that up to 26% of the dry matter of grain at harvest originated from photosynthesis in the ears and 15% from photosynthesis in parts of the sheath below the flag leaf.

The N.A.R. concept, introduced by Gregory (1917) has considerable use in "growth analysis" studies, despite limitations which have been outlined by Williams (1946), Watson (1952), and Mitchell (1954). Brougham (1956), preferred the term "leaf efficiency index". (i.e. average daily herbage dry matter increment per unit area of leaf.)

Differences in N.A.R. within the ryegrasses (*Lolium perenne* and *Lolium multiflorum* x *L. perenne*) have been demonstrated. (Mitchell, 1954). Gregory (1956) considered that there appears to be little opportunity of improving the efficiency of the photosynthetic process by selection or breeding. However, the introduction to agriculture of new species with higher N.A.R. than those at present in use, should be borne in mind. Watson (1958) considered that within the limits set by natural climates to the length of the growing season, increasing L.A.I. is the best means of improving yields in existing cropping systems.

It appears, therefore, that more immediate advances in the achievement of increased utilisation of solar energy by agricultural crops can be obtained by increasing the size of the photosynthetic system per unit area of land, rather than by concentrating on improving the photosynthetic efficiency of crop plants by selection and breeding.

Studies have been made of the relationship between the area of photosynthetic tissue of a crop plant and its production (Watson et al.), and more recently several groups of research workers have become interested in the relationship between leaf area of a sward, light interception by the leaf canopy, and pasture production.

C. Influence of Light on Plant Growth.

(i) Plant processes: Stoughton (1955) lists the following plant processes which are in some way affected by light: photosynthesis, seed germination, leaf expansion, the growth of stem and shoot, flowering and fruiting, dormancy and bud break. These plant processes may be indirectly influenced by the effect of light on hormone production. Stem elongation is reduced approximately in proportion to the intensity of light (Stoughton loc.cit.), whereas the accumulation of dry matter is primarily determined by the quantity of light energy which the plant receives. Black (1956) Milthorpe and Newton (1958).

(ii) Grass and clover species: The early interest in light intensity in relation to pasture ecology, arose from the study by Blackman (1938) of the grass/clover balance in a sward of white clover and two *Agrostis* species. He sought to explain the changes in botanical composition brought about by various management techniques and fertiliser applications. He noted that grass became dominant in a rank sward and concluded that the reduced light intensity within the sward had a direct effect on clover by suppressing its growth. Application of nitrogenous fertilisers encouraged grass growth, which resulted in greater shading of the clovers and consequently reduced clover growth. Similar results have been reported by Brougham (1953-54) in a study in which he varied both the seeding rates and defoliation heights of a short-rotation ryegrass, red clover and white clover pasture.

In a series of papers, Blackman and other workers have reported studies which have sought to establish more accurately the response of plants to different light intensities, and much of this work, has formed a foundation upon which has been based subsequent and continuing investigations.

Blackman and his co-workers at Oxford found that the pattern of response of a large number of agricultural and other plants, subjected to a range of shading treatments, is similar, and takes the generalised form shown in figure 1.

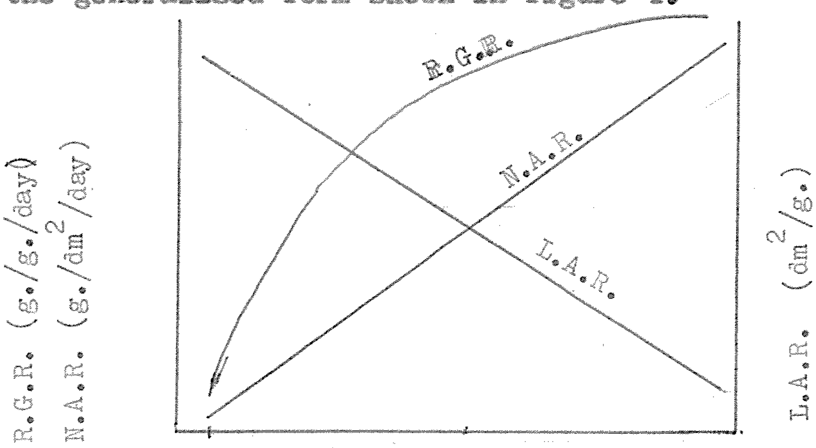


Fig. 1. The effect of varying light intensity on the growth of a wide range of plant species.

(After Black, 1957.)

The work of Black (1952) at Oxford indicated that the R.G.R. of certain leguminous pasture species; white, red and alsike clovers, and lucerne; is at a maximum at a light intensity above full daylight. Investigations with nine varieties of grasses showed that these grew most rapidly at light intensities at or above full daylight. Blackman and Wilson (1951 a & b) placed the theoretical optimum light intensity for subterranean clover at 1.81 daylight (full daylight was based on Oxford summer conditions), although when these conditions were attained under natural sunlight at Adelaide, South Australia, Black (1955) found that the R.G.R. of subterranean clover was still rising, suggesting that the earlier estimates of optimum light intensity were too low. These results suggested that the legumes examined are intolerant of even slight shade, whereas the grasses make most rapid growth at or about full daylight.

Various workers, using a range of pasture species, have reported a decrease in dry matter of plants, and an increase in stem elongation under different intensities of full daylight and varying shading treatments. Reid (1933), Watkins (1940), Benedict (1941), Pritchard and Nelson (1951), Ludwig _et al._ (1953).

Mitchell (1954) in examining the rate of tissue formation of short-rotation and perennial ryegrasses, at temperature levels of 55°F. and 70°F. and light intensities of 0.65 and 0.20 daylight, found that the rate was reduced by shading. He also obseved that at the lower temperatures and the higher light intensities, the R.G.R. of short-rotation ryegrass (_L. multiflorum_ x _L. perenne_) exceeded that of perennial ryegrass (_L. perenne_). Later work with perennial and short-rotation ryegrass, cocksfoot, paspalum, white and subterranean clovers, and _Lotus major_ (_L. uliginosus_) revealed that shading (0.20 daylight) reduced the rate of tissue formation to about one third of that under 0.65 daylight. Mitchell (1955 a& b) (1956).

<u>(iii) Effect of temperature</u>: Light cannot be regarded as the sole determinant of the dominant species in a grass/clover sward. Other factors are important also. Environmental temperature will be considered in this section. In controlled environment studies Mitchell (1956) has shown that the maximum growth rate for clover species occurs about 75°F. whereas the optimum temperature for growth of the European grass strains which he studied was 65°F. The favourable temperature range for grass growth lay between 55°F. and 85°F. whereas the range for clover growth was 65°F. - 85°F.

In field studies of a short-rotation ryegrass/white clover sward, Brougham (1959) found that weekly fluctuations in growth rate of total herbage and of the ryegrass component over the winter and spring months was associated with variations in weekly mean radiation and temperature levels. However in summer and early autumn when clover was the dominant species, weekly fluctuations in growth rate were mainly correlated with temperature changes. The absence of a significant correlation between weekly fluctuations in growth rate and the amount of incoming radiation over this period was attributed by Brougham to the relative stability of the quantity of light received each week.

D. Light Penetration into the Pasture.

Weaver and Flory (1934) showed that at half the height of an upland prairie pasture in Nebraska, light intensity was only 25% of that above the sward, and at ground level, was only 5%. Mitchell and Calder (1958) investigated the penetration of light into a dominant perennial ryegrass pasture and found a steady decline in light intensity with increasing depth below the top of the pasture, much of the light penetrated to a considerable depth. However, when there was a canopy of clover leaves present, or where the tops of grass leaves lay over to form a canopy, 85% or more of the incident light was intercepted by this canopy. Black (1958) noted that in a subterranean clover pasture the leaf area was concentrated in a relatively shallow band at the top of the sward.

Mitchell and Calder (1958) suggested that the efficiency of utilisation of light by an area of pasture, as judged by quantity of tissue formed per unit of light energy, is probably highest where a large proportion of the photosynthetic tissue is in moderate shade.

Studies of the influence of light intensity on the photosynthesis of individual leaves or parts of leaves indicate that maximum photosynthesis is effectively attained at intensities of 2-3000 foot-candles, which must be compared with bright sunlight at 10-15000 f.c., Davidson and Philips (1956). Davidson and Philips considered that as the leaf area of a pasture approached that of the individual leaf then a lower light intensity was required for maximum photosynthesis. Consequently in pastures of a high leaf area with a considerable area of tissue shaded from full light, the efficiency of utilisation of sunlight tends to be greater than that of pastures with a lower leaf area.

E. Leaf Area Index and Pasture Growth.

(i) Concept of Leaf Area Index.

Boysen-Jensen (1943), emphasised the important relationship between the total leaf area of a plant community and the light supply. Later, Watson (1947) stressed the relationship of leaf surface to soil surface and placed it on a quantitative basis. He formulated the measure of leaf area per unit area of land. This is a measure of the whole crop, not of individual plants, and because it is independent of plant spacing, is more suited for comparitive studies. Watson termed this measure the leaf area index (L.A.I.) of a pasture or crop.

(ii) Comparison of L.A.I. of crops and pastures.

Table 1 gives a comparison of pasture and crop leaf area indices. The greater L.A.I. of the pasture plants may be due to the degree of selection for leafy types of plants which has been undertaken. Cereals, on the other hand, have been selected more on the basis of grain yield than foliage production and are relatively sparsely tillered and of upright habit. Pastures are more dense than crops, which also affect the resultant L.A.I., Donald and Black (1958).

TABLE 1. Comparitive L.A.I. values of Pastures and Crops.

Pastures	L.A.I.		Crops	L.A.I.	
Subterranean clover	8.9	Davidson (1954)	Wheat	4.3	Watson (1947
	6.2	Black (1957)	Barley	2.4	" "
	8.7	Davidson & Donald (1958)	Potatoes	2.5	" "
Short-rotation ryegrass and white clover	7.3	Brougham (1958)	Mangolds	3.0	" "
Short-rotation ryegrass	9.5	" "	Kale	5.0	" (1956
Perennial ryegrass	8.8	" "	Sugar beet	4.6	" "
Timothy	10.8	" "	Barley (est.)	4.5	"
White clover	5.6	" "	Sugar beet (est.)	9.0	"

(iii) Significance of L.A.I. in pastures:

Considerable attention has been given in the past to the study of the leaf area of crops, but recent literature has confirmed an increasing interest in the leaf area of pastures. Donald and Black (1958) have enumerated reasons why the inter-relationship of light, leaf area, and production is likely to be of greater significance in pastures than in crops. These are:-

1. In pasture leaf production directly governs the value of the sward for livestock (i.e. yield) whereas crops commonly provide their yield in non-leafy parts.

2. Almost all field crops make steady growth to a peak yield, to be harvested at a certain time of the year : pastures ideally give a sustained high level of leaf production throughout the year.

3. The leaves of pasture lie within a narrow vertical span and the mutual shading of leaves may be expected to be far greater when they are crowded into a small height than when light can diffuse and reflect through a sparse deep canopy.

4. Crop density is usually less than plant density in a pasture.

5. Light relationships within the sward undergo frequent and often sudden change as a result of defoliation.

6. Pastures are almost invariably composed of species differing in stature and foliage distribution so that shading may become a prime factor in competition.

7. Competition for light is operative at all times in perennial pastures contrasting with annual crops, and pastures where light is not a limiting factor during the establishment stage.

(iv) Relation between growth, light interception and L.A.I.

Brougham (1955) examined the nature of the growth curve for a ryegrass-clover pasture (short-rotation ryegrass, red and white clovers,) following defoliation to a height of 1 in. A sigmoid growth curve showing three growth phases was obtained. For approximately three weeks following defoliation the growth rate increased, for a further five weeks it remained constant at a maximum rate, and thereafter it declined. The duration of the first growth phase was apparently related to leaf area and light interception, and continued until there was sufficient leaf area to intercept all the incident light after which growth proceeded at the maximum rate for a period. Brougham (1956) tested this assumption by determining the effect of various defoliation heights on subsequent growth rate and light intercepting ability of the sward. The sward was defoliated to 1 in., 3 in., and 5 in. height and the recovery growth and leaf area observed until light interception was virtually complete (>95%). Under these conditions complete light interception by the pasture canopy occurred at L.A.I. 5, after which maximum growth rate was maintained. The time taken to reach this L.A.I. increased with the severity of the cutting.

Subsequently in this text the L.A.I. at which light interception was complete will be referred to as the optimum L.A.I.

It appears that a pasture does not attain its maximum growth rate until the leaf development is sufficient to intercept all the incident solar light, this rate being maintained for a period, after which it declines at a higher L.A.I.

(v) Dependence of recovery growth on existing leaf area.

The results of the experiment conducted by Brougham (1956) indicated that recovery growth following defoliation is greatest when L.A.I. remaining after defoliation approaches the optimum L.A.I. Edmond (1949) who conducted experiments on the effect of severity of cutting on cocksfoot and perennial ryegrass plants, and Langer (1959) from a study of the growth of timothy and meadow fescue swards, concluded that growth rate following cutting was greatest when the amount of leaf remaining after defoliation was greatest.

(vi) Pasture establishment.

Black (1957) studied seed size as a factor in the growth of subterranean clover (Bacchus marsh strain) under spaced plant and sward conditions. Prior to the attainment of L.A.I. 4, plant dry-weight was proportional to seed weight. In a later experiment, Black (1958) using various seed sizes found that in a "mixed" sward of different seed sizes, only plants from small seeds died and the number of large-seeded plants remained unchanged. Lawson and Rossiter (1958) designed an experiment to determine whether large and small seeds, when sown at equal seeding rates on a weight per unit-area basis, gave rise to swards with identical growth patterns. They concluded that seed size has no effect on the growth rate of a subterranean clover sward, provided that sowing rate is held constant.

In field experiments conducted by Heddle and Herriot (1954) with four grass varieties and a common seeding rate of white clover, the results obtained confirmed earlier findings of Davies (1927) and other workers, that generally better establishment may be expected from large-seeded than from small-seeded grass species and varieties.

No attempt has been made by these workers to explain these differences in establishment in terms of differences in the initial area of assimilating tissue at the time of seedling emergence.

Observations by Black (1955, 1956) suggest that, sowing depth did not affect the initial cotyledon area of assimilating tissue of subterranean clover plants, but the delay in emergence due to increased sowing depth (2 in. c.f. ½") could exaggerate the ensuing inter-specific competition in the developing sward.

Numerous investigations into the placement of grass seeds in relation to optimum moisture and nutriment levels in the soil have been reportedin the literature (Herriot, 1958), and the importance of shallow sowings in pasture establishment has long been recognised (Yarranton, 1663). However, there does not appear to have been any work on grass species similar to the studies of clover made by Black on the effect of sowing depth on the area of emerging assimilating tissue.

Satisfactory pasture establishment involves the securing of an optimum leaf canopy (L.A.I.) as quickly as possible in order to achieve conditions for maximum rate of growth and discourage growth of undesirable species. Therefore, seed size and sowing rate, together with sowing depth, are important factors to consider in pasture establishment. Brougham (1954) qualified the general aim of a rapid development of leaf canopy to attain the optimum L.A.I. It is often necessary to encourage the clover establishing species (e.g. clover) in a mixed sward and thereby reduce inter-specific competition. This may have to be accomplished at the expense of pasture production during the establishment period.

(vii) L.A.I. values associated with maximum growth rate.

Brougham has measured various swards and obtained a series of optimum L.A.I. values for different species. In a short-rotation ryegrass-white clover pasture, the optimum L.A.I. was constant at 4.3 and was unaffected by a change in the grass/clover ratio from 75:25 in the spring (1956) to 50:50 in January (1957). Marked differences were obtained in optimum L.A.I. values when these species were grown in pure stands. Values obtained in pure stands were: short-rotation ryegrass - 7.1, white-clover - 3.5, perennial ryegrass - 7.1, timothy - 6.5. The differences in light intercepting capacity may be explained in terms of the growth form, orientation and shape of leaves. Brougham (loc. cit.)

Black (1957) took successive measurements of the optimum L.A.I. of a subterranean clover sward and found that the value increased with sward height over a two month period which commenced approximately eight weeks after sowing.

Brougham (loc. cit.) found that maximum pasture growth rate was associated with optimum L.A.I. Davidson and Donald (1959) reported that maximum growth rate was attained in a subterranean clover sward with a L.A.I. of 4 - 5. Niciporovic and Strogonova (1959) regarded 30 - 40,000 sq. m. per ha. (i.e. L.A.I. 3 - 4) as an optimal leaf development of annual plants for maximum rate of growth.

(viii) Ceiling L.A.I. values.

Eventually an equilibrium value must be reached with leaf development, as the L.A.I. continues to increase above the optimum value. At this point the death of leaves is equal to leaf initiation and expansion giving rise to a maximum or ceiling L.A.I.

value for current environmental conditions. Davidson and Donald (1958) found this value to be 8.7 for subterranean clover in November (late spring). Brougham (1958) found the following maximum L.A.I. values for various spedies: short-rotation ryegrass-9.5; perennial ryegrass-8.8; timothy-10.8; white clover-5.5; mixed stand-7.3.

Brougham (1957) has shown that the rate of growth of pastures over the winter months reached a ceiling yield at which there was only sufficient growth to offset herbage losses due to decomposition. Later investigations by Brougham (1959) at Grasslands Division, have shown a distinct seasonal trend in yield ceilings of a short-rotation ryegrass/white clover pasture in that locality. The lowest ceiling yields were obtained in the winter and the highest in the spring. They yield ceilings and the time interval required to reach this ceiling decreased over the summer and autumn months.

Donald (1956) has quoted the example on the southern tablelands of N.S.W. where the maximum attainable yield of an ungrazed sward of the Mt. Barker strain of subterranean clover is about 70 cwt. D.M. per acre.

P A R T II

Pasture composition and tiller population Studies.

A. Introduction.

Examination of the pasture unit has in the past been undertaken primarily as a means of characterising the pasture by its botanical composition. However, present research makes use of the pasture unit in pasture growth analysis, as well as in botanical composition studies.

Methods of assessing the botanical composition of pastures and changes induced by man, per medium of animals, fertilisers or irrigation, have been widely discussed in the literature. Particular attention has been paid to the unit of measurement, and the criteria to be adopted, which will characterise the pasture under consideration. Donald (1946) has classified methods in use according to which of the following criteria is adapted namely: density (number of plants or units present in a given area), foliage cover or basal area (area of plants), and yield (weight of plants). Mitchell and Glenday (1958) have pointed out that the pasture assessment can be directly influenced by such factors as sampling height and amount and frequency of grazing. Consequently, methods based on yield, foliage cover, and basal area, may be biased by these factors. The use of plant density methods, preferred by the above workers, reduces these sources of error but introduces another problem: that of defining a pasture unit.

B. Pasture Unit - the Tiller.

Recent studies of the growth rate and morphology of individual plants, together with observations made in the field, have suggested that in closely grazed pastures the tiller can be considered as the fundamental unit in a grass sward. The growth of each tiller is governed by the quantity of light which it receives, the availability of mineral nutrients and water, the physical crowding by other tillers, the position of the tiller base at or above the soil surface, the position and vigour of its roots and by the temperature of its microenvironment. Mitchell (1953) studied the vegetative growth of ryegrass plants and found that shading treatments, exposure to high temperature and partial defoliation of the plant, reduced lateral tiller formation. A reduction in general tillering of short-rotation ryegrass has been reported by Mitchell and Coles (1955) as a result of applying treatments involving the repeated defoliation, base and generalshading, of the plants.

A pasture may be regarded as a population of tillers and hence subject to the constant changes of any normal population, (Mitchell and Glenday, 1958, Langer 1958). The consideration of a pasture as a dynamic population of individual tillers has directed recent research work to a study of this population; in order to collect information on pasture growth, rather than solely as a means of describing the proportion of various species present in the pasture.

Langer (1956) working with timothy plants in pots observed a continual replacement of old tillers by new ones throughout the season, and also noted seasonal fluctuations in the death rate and rate of initiation of new tillers. He found that any one generation of tillers did not survive more than one year - the longest survival period being that of the main stem tillers with a mean life of 324 days.

In the field the length of life of the tillers is dependent on climatic factors and management practices.

C. Seasonal Trends in Tiller Populations.

Schwass (1955), in New Zealand, found that with plants of perennial ryegrass maximum tiller numbers per plant were recorded over the autumn-spring period, and subsequently dropped to minimum values in the summer. Langer (1956), at Hurley, used timothy plants to study the seasonal variation in the rate of tiller formation and observed that the rate was slowest during winter, increased to a peak in spring, declined immediately and then rose to a summer peak, after which it fell away during winter.

Later observations by Langer (1958) on S 215 meadow fescue and S 48 timothy swards indicated that grass tiller numbers reached a maximum in early spring and declined in the late summer and autumn.

Counts taken by Mitchell and Glenday (1958) on a short-rotation ryegrass/white clover dairy pasture indicated the presence of an overall seasonal trend in the grass tiller component as well as an alteration in the balance of pasture species. The maximum number of white clover nodes was recorded in autumn (March, 1956), ten months after sowing, but the number fell during winter and increased over the spring-summer period to reach a second autumn peak (March, 1957). Grass tillers reached a peak in spring five months after sowing. Minimum values attained in the two successive autumns coincided with the maximum number of clover nodes. During the intervening twelve months maximum grass tiller counts were recorded in early summer.

D. Influence of Defoliation on Tiller Numbers.

Several workers have demonstrated that frequency of defoliation does alter the size of a tiller population.

Langer (1958) found that both timothy and meadow fescue maintained a greater population of tillers in response to frequent cutting than under a hay and aftermath system involving a longer period of uninterrupted growth. Baker and Garwood (1959) found that tiller numbers in a perennial ryegrass/white clover sward which had not been cut for 4½ months were significantly lower than those in the same pasture which had five cuts during that period. Mitchell and Glenday (1958) examined four high producing pastures. The estimated tiller populations of each are shown in table 2.

TABLE 2.

Tiller Population of Four Pastures.

Pasture Type.	Species Present	Tillers/ft.^{2}
1. Sheep	Ryegrass/white clover.	1814
2. Sheep	Ryegrass/browntop/Yorkshire fog/*Poa* spp. white clover.	3203
3. New dairy	Ryegrasses/little white clover.	831
4. Old dairy	Ryegrasses. *Poa* spp. white clover	857

The greater tiller density in the sheep pasture was attributed to the closer and more continuous (i.e. more frequent) grazing normally experienced in a sheep pasture. Mitchell (1958).

E. Relationships of Tiller and Root Population, and Herbage Production.

There are three components of the grass plant which show distinct seasonal fluctuations viz. herbage production, tiller and root numbers. The seasonality of grass production has been outlined by various workers. The general trend for N.Z. conditions is towards a spring-summer maximum followed by poorer late summer, autumn and winter growth. The length of the winter growing period is largely dependent on soil and air temperatures of the area under consideration, Mitchell (1956). Seasonal trends in tiller population size have been discussed above. High tiller numbers were recorded over the autumn-spring period falling away towards the summer. The population of roots also showed a pattern of seasonal growth with a spring maximum after which numbers fell off in the summer, and increased again in late autumn and through the winter. Stuckey (1941), Jacques and Edmond (1952).

The integration of the information obtained from these seasonality studies is difficult. Jacques and Edmond (loc. cit.) suggested that maximum herbage production coincided with periods of poor root initiation. A negative correlation, based on observations over 14 months, between mean tiller numbers and dry weight of leaf, per plant, was found by Schwass (195~~6~~5) in studies on perennial ryegrass and other species. Therefore leaf yield per tiller increased to a summer maximum as the tiller population decreased. Schwass and Jacques (1956) found that root numbers per tiller were high in April during autumn growth and again when spring growth commenced in September. They attributed the high numbers in April to tiller mortality rather than a spectacular production of new roots and those in September, to excess of root production over root decay.

P A R T III

Soil Moisture and Plant Growth.

Water may influence plant growth directly through the plants' nutrition, or indirectly through regulation of the soil temperature. Changes in soil temperature will in turn affect the soil organisms and the rate of the soil processes. Soil moisture may also affect growth by determining the physical condition of the soil in which the plant is growing.

A. Definition of Terms.

There are various methods in use to define the quantity of moisture in the soil. The unit of pF is used in this review. The pF concept was introduced by Schofield (1935). The pF value is defined as the logarithm of the tension (as expressed in cm. of water) under which water is held in the soil. Schofield has shown that this tension is equal to the decrease in the free energy of the water in the soil, referred to a free water surface at the same temperature. It is therefore equal to the work that must be done to remove one gram of water from the soil.

B. Soil Moisture Regime within a Pasture. (After Mitchell and Butler,1956)

(i) At or above field capacity: Field capacity is the amount of water retained in soil which has drained for about two days while covered to prevent transpiration and evaporation losses, Wadleigh, (1955). This point is constant between soil types if measured in terms of moisture tension (approx. pF 2.7); but varies between soils if measured in terms of moisture percentage (e.g. moisture percentage of clay soils exceeds that of sandy soils at field capacity, Marshall 1959). Edmond (1958a) found that herbage yields of a perennial ryegrass/white clover pasture were reduced by stock treading. Later investigation (1958 b) showed that ryegrass growth was reduced on puddled soils. Edmond considers that this could be important in practice when wet pastures (pF $\leqslant$ 2.7) are trodden. The reduction in growth has been explained in terms of reduced soil oxygen tension and increased CO_2 - tension. This reduces metabolism of root tissue, thereby reducing root growth and nutrient uptake. Shaw (1952) Mitchell and Butler (loc. cit.), Gingrich and Russel (1956) studying the growth of corn roots, found that under conditions of low soil moisture tension the oxygen concentration of the root atmosphere needed to exceed 10.5% (by volume) for maximum growth.

<u>(ii) At or below wilting point:</u> The permanent wilting point has been defined as the water content of the soil at which the plant wilts, but fails to recover turgidity when placed in a humid atmosphere overnight, Marshall (1959). Earlier workers considered that wilting point was a soil constant (pF. 4.2). However, Slatyer (1957) has suggested that the point at which wilting occurs is controlled, not by the soil, but by the osmotic characteristic of the plant concerned. This is in direct contrast to the early views of Briggs and Shantz (1912) and others, who held that the permanent wilting point was independent of the type of plant used to measure it. Mitchell and Butler (1956) point out that the stress imposed on plants by low water availability is accompanied by decreased availability of nutrients.

<u>(iii) Between wilting point and field capacity:</u> Contrary to the early belief that the availability of water to the plant does not alter between field capacity and wilting point (Veihmeyer and Hendrickson, 1955), it now appears that plant growth responds to changes in soil moisture status over this range, and that the

greatest yield is generally associated with the wettest soil, Stanhill, (1957), Milthorpe, (1959).

Marshall (1959) advanced two reasons supporting the thesis that the availability of water to the plant alters between field capacity and wilting point. They are:-

(1) As the soil dries and the suction increases, an increasing amount of work has to be done in removing a given amount of water from it. (Soil moisture tension increases from 0.1 to 15 atmospheres).

(2) The drier the soil the less permeable it is to water, and movement towards the root hairs will be more restricted.

In a field experiment in which plots were irrigated when a pF of 3.3 and 4.0 was reached, Low and Armitage (1959) found that heavier yields on grass-clover plots were obtained when the soil moisture deficit was small. This result also tends to refute the theory of "equal availability of water."

<u>(iv) Availability of water for transpiration, photosynthesis and respiration.</u>

Upchurch *et al.* (1955) found no reduction in the rate of photosynthesis of Ladino clover until the plants were distinctly wilted. There was a slight increase in the respiration of plant shoots as wilting appeared.

Closs (1956) reported that actual transpiration equals potential transpiration until soil dries out to a value corresponding to approx. pF 3.4. The actual transpiration then decreased linearly with increasing pF. Observations on kidney beans (*Phaseolus vulgaris*) by Bierhuizin (1958) are in agreement. Slatyer's (1956) observations on sorghum and peanuts in Northern Australia, and Makkink and van Humst's (1956) work on grassland, indicated a decline in transpiration rates as soil moisture tension increased.

C. Vegetative Cover and Soil Moisture Status.

At the present time there is only limited information available on the effect that pasture cover can have on the moisture status of the soil.

Geiger (1950) quoted Bartels who made comparative measurements of evaporation from a sod surface and a sandy surface and found that the average yearly evaporation was greater from the turf. This refutes the general observation that the water content beneath soil covered with vegetation is above that of bare ground.

Goods (1956) found that close and frequent mowing of a S23 perennial ryegrass-white clover stand, could conserve from 1.0 - 1.5 in. of water under his particular experimental conditions.

On the other hand, Mitchell and Closs (1958) found that moisture was lost at a greater rate and from greater depths from the soil under short pasture during the summer. In spring the position was reversed when soil moisture under short pasture was depleted from 2.3 in. to 1.55 in (in top 8 in. of soil), but under long pasture decreased from 2.3 in to 0.78 in.

D. The Effect of Defoliation on the Availability of Water to Plants.

Previous workers have made the assumption that defoliation reduces pasture yields by reducing the area of photosynthetic tissue of the plant, and therefore the amount of photosynthesis. Consequently frequent defoliation might be expected to deplete the carbohydrate reserves of the plant (Weinmann, 1948). However, Jantti and Kramer (1956) have suggested that this may be only a partial explanation of the reduced pasture production as a result of frequent defoliation.

The plant absorbs water only when a gradient of diffusion pressure deficit exists from the soil to the roots. The magnitude of the gradient depends on the soil moisture tension and the diffusion pressure deficit existing in the plant. Jantti and Kramer have shown that defoliated root systems cannot absorb water held in the soil at tensions above 1 - 2 atmos., whereas intact plants can absorb water held at tensions of 15 atmos. or more, (i.e. approx. the permanent wilting point of many soils). They have stated that a diffusion pressure deficit of 10-20 atmos. develops in the leaves of a transpiring plant which enables the plant to absorb soil water held at tensions up to 15 atmos. The active absorption mechanism of the roots alone seldom exceeds a pull of 1 - 2 atmospheres. Therefore the defoliated plant has much less water available for its use than has the undefoliated one.

Jantti and Heinonen (1957) have reported field experiments which support this theory. Preliminary investigations by Pohjakallio and Antila (1955) have shown that the removal of shoots reduced the drought resistance of red clover and timothy. Jantti and Heinonen have found that defoliation alone reduced pasture yields, independent of the soil moisture status. However, with pastures growing in soil at or near permanent wilting point they noted a yield reduction due to the interaction between defoliation and moisture level. On moist soils they found that the reduced yields were primarily due to defoliation alone, since the defoliated plant was able to withdraw water from the soil. This result confirmed earlier observations by Jantti (1953) that frequent severe defoliation gives greater reduction of pasture growth in semi-arid than in humid regions.

P A R T IV

Pasture Root Growth - Root Distribution.

The arbitrary division of a grass plant into roots and shoots is permissible provided that either component is not considered as a separate entity. The work done for this thesis was primarily concerned with shoot growth, but it was considered desirable at the conclusion of the experiment to evaluate the treatment effect, if any, on root growth, more particularly on the root distribution throughout the 12 in. profile. The literature concerning grass roots has been extensively reviewed by Troughton (1957).

A. Root Distribution.

The concentration of roots within the top few inches of the soil has been reported by various workers. Troughton (1951) who examined a mixed pasture (L. perenne, T. repens, Poa trivialis, Phleum pratense, Agrostis spp., Holcus lanatus), found that 95.7% by weight of the underground material was distributed in the upper 12 in. of the soil profile, with 79.3% in the 0-3 in. horizon, and 10.6% in the 3-6 in. horizon. Similar distributions have been reported by Low and Armitage (1959) and Baker and Garwood (1959).

Barley (1953) demonstrated the use of this knowledge in irrigation work where he found that on sandy loam soils in Australia there was little poi n t in wetting soils to field capacity, to a greater depth than 2 ft., for clover-rye or clover-cocksfoot pastures; and 2.5 ft. for clover paspalum or clover-phalaris swards, as very few roots of the pastures examined penetrated beyond these depths - therefore further water added would be lost by percolation.

Edmond (1949) found that soil moisture played an important part in root initiation.

B. The Effect of Defoliation on Root Distribution.

The literature presents conflicting reports regarding the effect of defoliation on root distribution in the soil. Torstensson (1938) following observations on *Festuca pratensis*, *Poa pratensis*, and *Phleum pratense*; and Sprague (1933) with *P. pratensis* and *Agrostis alba*; both reported root weight increase at lower depths under lenient or no defoliation. On the other hand Klapp (1943) found that defoliation tended to concentrate roots in the upper soil layers. This observation is supported by Baker (1955) who found that *L. perenne* plants subjected to his most severe defoliation treatment tended to have a greater proportion of their root weight in the surface horizon than did undefoliated plants. Subsequently, Baker and Garwood (1959) found no significant effect of cutting treatment on the vertical distribution of roots under a ryegrass/white clover pasture. These latter results are in agreement with the findings of Weaver (1950) who could not determine any changes in the percentage root distribution in the upper soil layers (0-6 in. and 6-12 in.) associated with grazing intensity of the prairie grass pastures examined.

CHAPTER III

MATERIALS AND METHODS.

This section will be presented in three parts:

I. The Experiment.

II. A description of the area used, layout and establishment of plots, and the application of treatments.

III. A description of the methods of sampling and experimental techniques used.

P A R T I

A. The Experiment.

The object of this experiment was to study the influence of two grazing treatments on yield, L.A.I., and tiller numbers of a newly sown perennial ryegrass/white clover sward. The treatments chosen involved defoliating the pasture at 3 in. and 6 in. heights respectively, leaving a stubble height of 1 in. Subsequently in this text the two treatments will be referred to as the 3" treatment and the 6" treatment.

In terms of the sigmoid pasture growth curve obtained by Brougham (1955) it was considered that under the 6" treatment the pasture would experience a longer period of phase 2 growth than would the 3" treatment. It could not be judged whether either treatment would experience growth under phase 3 conditions.

Translated into farming practice these treatments would approximate to a comparison of two frequencies of rotational grazing using pasture height, in contrast to an arbitrary time interval between grazings, as the determinant of grazing time. In this experiment the frequency of defoliation was altered, but the intensity of defoliation remained unchanged except in so far as the treatments themselves may have changed the growth form of the plant during the course of the experiment. It could be that the more frequent defoliation encouraged a more prostrate growth form and therefore after defoliation a greater area of photosynthetic tissue remained than when defoliation was less frequent.

The experiment may be divided into three periods:

1. Establishment (May-Aug.).
2. Intermediate (Sept.-Dec.) Treatments applied using sheep to defoliate the pastures.
3. Final (Jan.-March). Treatments applied using a Hayter

rotoscythe to defoliate the pasture. More detailed analysis of pasture growth was made during this period.

Reasons for the change from grazing to cutting the pastures are discussed below.

Three variables of top growth were measured:

1. Yield - in terms of dry matter.
2. Leaf area.
3. Tiller numbers.

Daily measurements of soil moisture at four depths were recorded during the final period. At the end of the experiment the root weights under the two grazing treatments were measured and the root distribution over the 0-12 in. soil profile determined.

PART II

Experimental area, Layout and Establishment of Plots, and Application of Treatments.

A. The Experimental Area.

The experiment was laid down on part of the Crop Demonstration Area, Massey Agricultural College. This particular area had previously been in pasture in 1955-56. It had been used for Chou Moellier spacing and weed control trials in 1956-57, and then sown in drills of cereals, legumes and forage crops in 1957-58.

The soil type is similar to that described in the Soil Bureau bulletin No. 5 (1954) as an Ohakea Loam. It is formed on an intermediate terrace carved by the Tiritea Stream out of an old Terrace - the soil of which is a yellow grey earth (Tokomaru silt loam). The soil profile on the intermediate terrace comprises a fairly heavy silt loam (0.8 in.) overlying a pale grey mottled rusty brown silty clay loam to clay loam subsoil, with some ironstone nodules present, and extending to a depth of 20-30 in. This is underlain by a pale grey and rusty brown claying gravel becoming straight gravel with depth. (Pollock, 1959).

The plots are bounded by an open drain, parallel to, and approximately nine feet from the northern edge of the experimental area. The Crop Demonstration Area was tile-drained in 1948 at intervals of approximately 30 ft., using the above open drain as the outlet.

Uneven growth of the previous crop indicated that the presence of a row of trees along the eastern end of the experimental area, could reduce the growth of crops or pastures for a distance of 40 ft. from the base of the tree.

B. Experimental Layout.

A simple randomised block layout was used in this experiment. The experimental design had to consider any effect on growth which might be introduced through the proximity of the open drain or the row of trees, as well as possible fertility gradients introduced as a result of the previous crops.

Initially it was planned to apply treatments per medium of the grazing animal. Therefore the plots were made large enough to allow several sheep to graze freely over the plot area. $\frac{1}{2}$ acre was chosen as a suitable plot size. The limited area available for the experiment placed an upper limit on the number of replications possible.

Figures available at Grasslands Division, Palmerston North, suggest that the best estimate of coefficient of variation for total production of a ryegrass-white clover pasture would be 10-15%. Therefore with a coefficient of variation of 10-15% and using four replications, an experimentally found difference of 20-26% would be significant. (Glenday 1958). If the number of replicates was reduced to three, then larger treatment differences would be required to obtain significance. Brougham's (1954) work on the influence of grazing height over the establishment period on pasture yield, indicates that four replications would probably produce differences of the required significance.

Hence considering the need for replications demanded by the statistical analysis of the results, the expected order of treatment differences, and the area of land available, four replicates were chosen for this experiment.

The experimental blocks (I, II, III, IV) each comprising a 3 in. and a 6 in. treatment were placed parallel to the drills of the previous crops. (see fig. 2). The plot treatments are shown in figure 2.

Figure 3b shows the experimental area in March, 1959, when all plots were approximately at their respective treatment cutting heights. The position of the switchboards used in the soil moisture measurements is shown on the boundary fences.

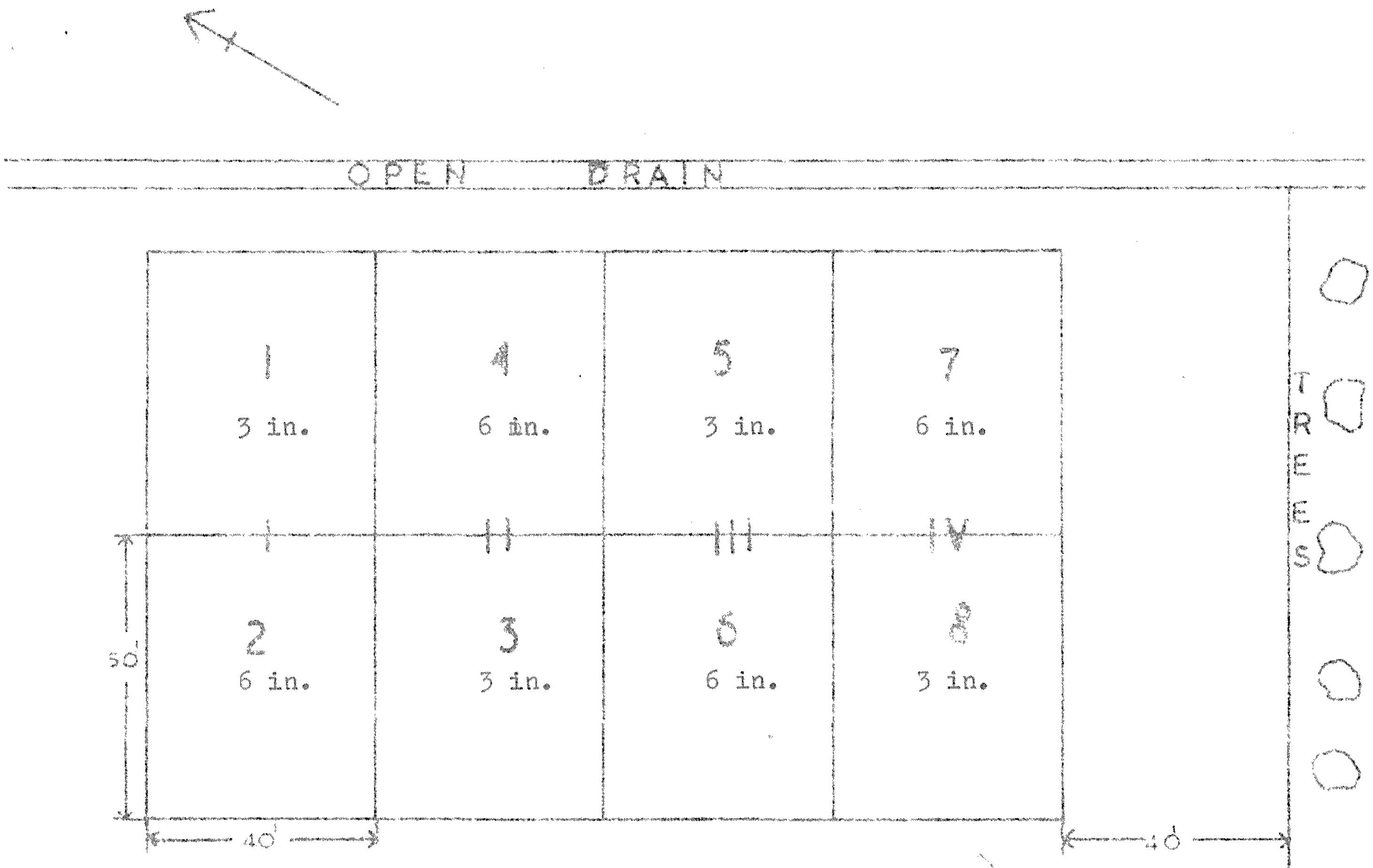


FIG. 2 Plan of Experimental Area.

C. Establishment of the Sward.

The field was rotary-hoed after the removal of previous crop residues in March, 1958. Normal cultivation followed with the peparation of a firm seed-bed. The area was sown with a roller-drill on April 11th, 1958, at a sowing rate of 30 lb. seed per acre, (measure contained 30 lb. N.Z. Cert., another perennial ryegrass and 3 lb. N.Z. Cert. mother white clover) with a fertiliser application of 3 cwt. superphosphate per acre. This seeding rate is widely used in the Manawatu district.

The use of the roller drill in pasture establishment work, is reported by Sears et al. (1955), with particular reference to the pumice country. The implement (see fig. 3a.) was designed to sow seed at a depth of about $\frac{3}{4}$ in. in compacted drills 3 in apart, at the same time giving even distribution of seed, and placement of most of the fertiliser close to the seed. Seed distribution depends on the release of seed from the seed-box mounted on the back of the roller, on to a scatter board which sprays it out over the ground. The seed falls mainly to the bottom of the compacted drills and is covered with soil by light trailing harrows. Fig. 3a illustrates the method of pasture sowing used.

The first seedlings emerged 10 days after sowing, but within a week it was apparent that a large quantity of the seed had been distributed into the rows immediately under the drills in the seed-box, and only small quantities had been directed into the intermediate rows by the scatter board. This was attributed to the incorrect positioning of the scatter board on the machine used. It was decided therefore, to resow the plots.

On May 2nd, the plots were rotary-hoed to a depth

FIGURE 3a.

Sowing the plots using the roller-drill.

FIGURE 3b.

Experimental plots; March, 1959.

of 2 in. and then harrowed to produce a firm seed-bed. The pasture was resown with a proven roller-drill on May 3rd and 4th using the same seed mixture and sowing rate as previously but with a further superphosphate application of 2 cwt. per acre. The second sowing was successful in giving an even seedling distribution as judged by visual observation.

To help establishment, the pasture was grazed by wethers while the ground was reasonably dry on July 3rd, for approximately two hours. The area was fenced into plots during August in readiness for the first main grazing on 2nd Sept.

D. Application of Treatments.

The habit of plant growth produced under cutting differs from that of a grazed sward. As the treatmentswere chosen to simulate grazing conditions, the experiment was commenced using the grazing animal as the defoliating agent.

Two-tooth Romney wethers were used to graze the plots. Grazing was based on a twenty-four hour cycle and the sheep were grazed on a pasture of similar growth and botanical composition, if possible, before placing on the plots. This cycle was adopted in an attempt to minimise the transfer of dung and urine between the experimental area and the outside grazing areas due to variations in the sheep's diurnal rhythms of dung and urine excretion. Sheep numbers per plot were adjusted according to the estimated growth on the plots, and normally the plots were grazed within 48 hours. A light trimming cut with the mower slightly above the average grazing height, immediately following grazing, helped to maintain the sward uniformity. The quantity of clippings was small and therefore were left on the pasture to decompose. The clippings did not interfere with subsequent sampling.

Plots were grazed when soil conditions were reasonably dry in order to avoid puddling and excessive treading damage of the area.

During December it was noted that the dung and urine patches had resulted in considerable loss of uniformity. It was therefore decided to cut the plots using a Hayter-rotoscythe and remove the clippings. This method of defoliation was adopted in January. Rust incidence, which reduced the palatability of the grass, also made grazing difficult.

P A R T III

Sampling Methods and Experimental Techniques.

A. Method of sampling each plot.

The plots were sampled according to a 40 ft. x 50 ft. grid design based on two foot squares. The two foot border of each plot remained unsampled as the excessive treading and greater stock return of dung and urine produced different pasture growth on this strip from that on the remainder of the plot.

The tiller plug samples were taken at the intersections of the grid, whereas the leaf area, yield and root weight samples were taken from within randomly sited squares. The method eliminated the possibility of obtaining a biassed tiller count due to selecting plug samples from sites previously sampled for yield or leaf area, and consequently not supporting a typical tiller population. Two methods of marking sampling areas to avoid double-sampling were used:

1. position of each sample was marked with a peg.
2. a record was taken of each sampling site in relation to the closest plug sample.

D. Yield Measurement.

Methods of measuring grassland production in New Zealand have been discussed by Lynch (1947 (1951). The method adopted in this work had to take into account the presence of the grazing animal. Suitable methods discussed by Lynch and applicable to plot trial work have employed the use of frames or enclosures to protect the herbage while the stock grazed the pasture. Cowlishaw (1951) has criticised the use of cages in pasture evaluation work and Williams (1951) has shown that the microenvironment existing within the cage differs from that outside. It was decided not to use frames but a modified Australian difference method (Lynch) instead.

The plots were sampled before and after defoliation. Any growth which may have occurred during defoliation was ignored. Herbage yields were obtained from the difference between the yield measured after one grazing and that measured prior to the following grazing. On the other hand, herbage consumed by the grazing animal could be determined by taking the differences between samples, before and after defoliation. Donald (1946) explains that in these instances when the yield is based on differences, apart from the statistical error due to the sampling of a variable sward, there is another error due to the initial difference between the site cut immediately after the one grazing and those cut prior to the following grazing. He substantially reduced the initial difference of "matching" the two sites with regard to yield and botanical composition. In this experiment, however, it was hoped to obtain a uniform sward and hence eliminate this initial difference; therefore the sites were not "matched".

Eighteen inch square sample quadrats were cut with a pair of sheep shears to leave a stubble height of ½ in. This height insured that the sample was cut below the average grazing height, yet sufficiently high to avoid inclusion of dirt in the sample. The material was placed in a plastic bag and taken to the laboratory where the green weight was obtained, using an E.T.A. triple beam balance, (weighed to 0.1 gms.) The herbage was dried in a Wilee Electric oven for 24 hours at 105°C. and then removed to a desiccator. Subsequently, dry weights of the samples were obtained and the dry matter percentages calculated. The advantages of using dry weight of herbage in preference to wet weight as a measure of pasture yield have been discussed by Greenhill (1936).

C. Leaf Area Measurements.

Different methods of measuring the area of plant leaves have been employed by various workers. Black (1958) in measuring the leaf area of subterranean clover leaves used the relationship between the midrib-length of the leaf and its area. Langer (1956) used a method of determining the area of grass leaves based on linear measurements of the individual leaves. In investigations with timothy leaves he measured the length of the leaf and the breadth at points $\frac{1}{4}$ and $\frac{3}{4}$ along the length of the leaf. He was able to compute the area of a population of leaves from the mean linear measurements of a sample population.

The method used for leaf area measurementsin this work was similar to that used by Brougham (1956) in his investigations. Samples were taken from randomly sited square foot quadrats. The herbage in each quadrat was cut to leave a $\frac{1}{2}$ in. stubble. The material was placed in plastic bags and brought into the laboratory and separated into ryegrass and clover, and then into leaf and stem. Only the laminae were classed as leaf. Petioles and leaf sheath were classed as stem.

Twenty-five ryegrass leaves were taken at random from each sample and a 50 m.m. section cut from the central portion of each leaf. The width at the middle of the section was determined using a microscope equipped with graticule. These sections were then oven dried and the weight per unit area calculated. The remainder of the ryegrass leaf obtained from the quadrat was also oven dried and weighed, and the area of ryegrass leaf per square foot of ground was calculated. The area of clover leaf was similarly determined using discs of known diameter taken from the leaves by means of a leather punch. Leaf area measurements were made for one surface only and were expressed as leaf area per square foot of ground. The dry weight of the stems and petioles were also obtained. The dry material was weighed to the nearest milligram on an air-damped Sartorious balance.

The accuracy with which the leaf area of the quadrat could be estimated from a portion of the sample was determined, with a view to reducing the time required for analysis.

A sq. ft. sample was taken from a ryegrass/white clover pasture 4 in. high. This was mixed to ensure a random distribution of grass and clover leaves throughout the sample. It was then divided into eight equal portions on a green weight bases, and the area of grass and clover leaf present in each eighth was determined. The coefficients of variation calculated were 11.77% for grass and 11.05% for the clover component. A sq. ft. sample could therefore be divided into four on a green weight basis and an estimate of the leaf area of the whole sample obtained from any one quarter with an accuracy of $\pm$ 1.7% for 2/3 of all samples measured. Estimates of the coefficient of variations made subsequently agreed fairly closely with these initial estimates. As an approximate guide, samples under 15 gm. gram weight were completely analysed, 15-30 gm. were divided into two sub-samples, 30-40 gms. into three sub-samples and over 40 gms. into four sub-samples.

D. Tiller Counts.

The value of the tiller as a unit of measurement in pasture studies has been discussed above and this section will discuss the choice and application of the technique used in this study to obtain information on tiller populations.

The method of Mitchell and Glenday (1958) was used in estimating the tiller populations, as it was relatively simple and easy to operate, and being essentially an objective method overcame many of the errors associated with alternative subjective techniques.

The pasture units measured are defined as follows:

a. Grass tiller - a live shoot.

b. Clover node (tiller) - any node possessing several leaves and functional roots.

c. Rosette plants (e.g. catsear, mouse-eared chickweed) - a single rosette was taken as the unit irrespective of the number of roots.

On each occasion the pasture was sampled prior to grazing using the sampler described by Mitchell and Glenday.

The author sampled each plot by walking up and down the plot on the grid lines which were marked out by lengths of string x units * apart across the field. Samples were taken y units apart along each line, thereby avoiding unconscious selection of sampling sites. The distances x and y were varied according to the number of samples taken from each plot. Therefore, if n samples were to be taken, no area of 1/n of the total remained unsampled,

(* unit = 2 feet.)

thus avoiding bias due to uneven sampling of the field.

The plugs were placed in boxes and removed to the laboratory for analysis. It was found that plugs could be stored several days after collection in a cool shaded room without appreciable breaking and crumbling, or death of plants. Normally plugs were analysed within two days of lifting.

Counts were made of the grass and clover tillers and of weed species present. The invasion of the perennial ryegrass/white clover sward by other grass species was negligible and therefore no division of the grass tillers into species was undertaken.

E. Soil Moisture Measurement.

(i) General.

Methods used to determine the moisture in the soil vary considerably in the information which they present. Closs (1956) points out that the determination of moisture content of soil by drying and weighing is merely a physical measurement of the amount of water which can be removed from the soil by a standard technique. It bears no simple relation to either the physical properties of the soil or to plants growing in the soil. Consequently a method providing information on the availability of water to plants, was sought. To eliminate tedious sampling, which would involve disturbing the soil structure of the plots, and to avoid excessive trampling of the plots while the samples were being taken, an in situ method of determination where readings could be recorded from outside the plot area was preferred.

Noble (1956) has outlined various direct and indirect methods of soil moisture measurement and from these a method had to be chosen which provided the information required and could be operated with the equipment available.

The gypsum resistance block method of Bouyoucos and Mick (1939) fulfilled these requirements.

Aitchison and Butler (1951) have shown that the gypsum blocks have a reproducible characteristic resistance-tension relationship with a sensitive range from pF 2.4 to 4.2 or higher. Resistance changes in blocks may be expressed directly as a change in soil moisture tension. This relationship between log resistance and pF is not significantly affected by variability from soil to soil, and therefore the gypsum blocks can be used as an accurate indicator of the change of energy status of any fixed point in the soil under any desired treatment.

It would have been necessary to use an alternative method for soils wetter than pF 2.4 but it was considered that the resistance blocks would be adequate for the pF range likely to be experienced in this work.

(ii) Installation of the gypsum blocks.

(a) Construction:

The blocks were manufactured according to the method reported by Closs and Jones (1955-56).

(b) Resistance characteristics of the gypsum blocks to be used.

The method adopted to test the resistance characteristics of the gypsum blocks, was a modification of the one reported by Aitchison et al. (1951), and which is at present in use by the microclimate group at Grassland's Division.

The gypsum blocks were evacuated in a closed chamber and water was then admitted. The blocks were allowed to remain in the water at atmospheric pressure until judged to be completely saturated. The blocks were removed from the water and the block resistance measured with a Philip's Universal Resistance Bridge. The blocks were then divided into four resistance groups (16 blocks each) with a tolerance of ±5% permitted for each group.

The groups were as follows:

1. 255 - 274 ohms.
2. 275 - 294 "
3. 295 - 314 "
4. 315 - 334 "

Each had a characteristic log R. - pF curve. Data were available at Grasslands from which to plot the characteristic curve for each group.

(c) Field installation of the gypsum blocks:

The resistance blocks were located at the same depths as are used by the Microclimate group at Grasslands Division, in their soil moisture measurements viz. 2", 4", 8", 16" below the soil surface. In this experiment the 1" depth, which is also used at Grasslands, was excluded, primarily because it was intended that stock graze the plots. Stock treading could alter the depth of soil covering these blocks, therefore in practice the depth of the 1" block would vary. Consequently 1" measurements were excluded from the experiment.

Two blocks were sited at each depth within each plot. The blocks were randomly placed inside an area of 6 ft. x 4 ft. within each plot. It was therefore possible to maintain a uniform sward above the blocks and to avoid taking top growth samples from the area. Four switchboards were erected on the outside fence (see Fig. 3b) at the boundary between plots 1 - 4, 2 - 3, 6 - 7 and 5 - 8. The group of blocks was positioned 15 ft. from the switchboard diagonally towards the centre of each plot. Each switchboard was attached to sixteen blocks of the one resistance group.

The soil was firm and dry at the time of installation. The blocks were installed in the field by careful placement in $2\frac{1}{2}$" diameter augur holes. During sinking of these holes, the excavated material from each horizon was collected separately. The blocks were placed on the floor of the holes at the required depth below ground level, and the excavated soil returned to the hole and tamped in approximately 4 in. layers so that the material from each horizon occupied its original volume at its proper location. Aitchison et al. (1951) reports that no evidence has been found of excessive water penetration down the augur hole.

The wires from each block were relayed beneath the surface to an underground junction box where they were joined to wires from the switchboard. The junctions were taped and placed in a wooden mould into which "araldite" was poured. This effectively insulated the joins in the wire. The switchboard is shown in fig. 4 together with the D.P.L. Portable Resistance Bridge used for field measurement of the resistances, and record sheet.

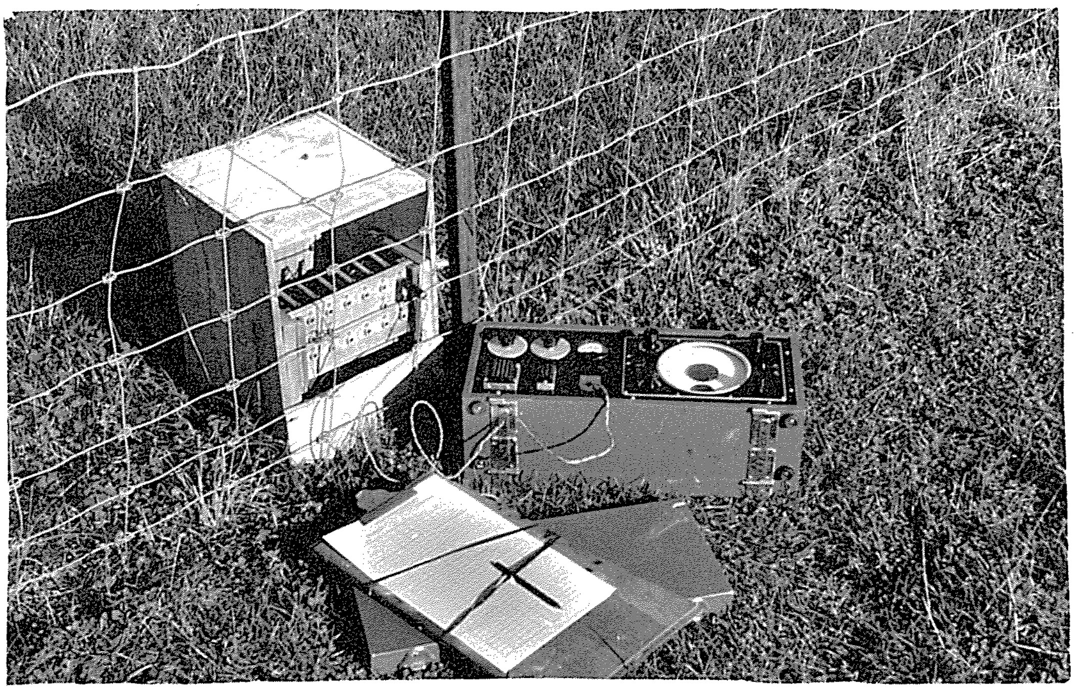
The blocks were installed on Oct. 9th, 1958. During installation the existing sward in the immediate vicinity of the blocks was disturbed. Consequently the sward covering the blocks was not representative of the remainder of the plot. In order to take measurements under the actual treatment conditions it was necessary to wait until the development and composition of the pasture above the blocks was the same as that on the remainder of the plot. This was not achieved until December.

(d) Measurement recordings.

Preliminary measurements were made during November and December to test the installation. Daily measurements were taken between 8.00 a.m. and 9.00 a.m. from Jan. 6th to March 24th. Three blocks failed during the experiment and all recordings from them have been excluded from the results. Investigations at the conclusion of the work indicated that the underground wires connecting these blocks to the switchboard had been inadvertently cut.

FIGURE 4.

Switchboard, D.P.L. Resistance Meter, and Record Sheet.



F. Estimates of Number of Samples Required.

In order to obtain an estimate of the number of yield and leaf area samples per plot, required to give a reasonable detectable difference between treatments, the two samples per plot for each measurement were taken at random on the first sampling date. The samples consisted of an 18 in. square for yield measurements and a 12 in. square for leaf area. The coefficients of variation were calculated in both instances and are shown in Table 3.

TABLE 3. Expected detectable differences at the 5% level using various numbers of samples per plot.

	Coefft. of Variation \ No. Samples/Plot	1	2	3	4
Yield (Dry Matter)	21.4%	30.3%	21.4%	17.3%	15.2%
Leaf Area	16.8%	23.8%	16.8%	13.6%	11.9%

The significant treatment differences at the 5% level were calculated for 1, 2, 3, and 4 samples per plot. Since two samples per plot gave a detectable difference of 21.4% for yield, and 16.8% for leaf area measurements; the gain, in both instances, to be achieved by increasing the number of samples was insufficient to warrant further sampling. Therefore two samples per plot were taken.

An estimate of the number of tiller plugs per plot necessary to give a detectable treatment effect at the 5% level was made on the first and second sampling dates. On these dates 80 plugs per plot were collected and analysed and the coefficients of variation calculated.

It was realised that the data obtained in these estimations may not have been normally distributed. However, Mitchell and Glenday (1958) tested the accuracy with which the number of plugs necessary could be determined from the coefficient of variation calculated on the assumption that the data was normally distributed. They found that this assumption did not lead to large errors. Therefore subsequent calculations are based on this assumption.

Table 4.

Expected detectable differences at the 5% level using various numbers of plugs per treatment.

Coefficient of Variation	Number of plugs per Treatment.			
	320	160	100	4.0
60% (25. 8.58)	6.6%	13.2 %	16.8 %	27.0 %
70% (19.11.58)	7.7%	15.4 %	19.6 %	31.5 %

Table 4 shows the difference which could be detected using various numbers of plugs. The approx. coefficients of variation determined at both the Aug. and Nov. samplings are given. The coefficients are based on ryegrass tiller counts as there were very few clover tillers present at the first sampling date. 100 plugs per treatment were sufficient to detect a difference of 16.8 -19.6% which was significant at the 5% level. Therefore 100 plugs were taken per treatment at subsequent sampling dates and further plugs were collected when it seemed likely that a treatment effect could be determined if more information was collected.

G. Root Measurements.

Recent studies by Troughton, Baker and others, confirm that most of the root tissue of pastures is in the top four inches of soil. Troughton (1951) sampled Brookfield at Aberystwith and found that 95.7% of root tissue, by weight, occurred in the top 12 ins. of the soil. Therefore only the upper 12 in. of the soil profile was sampled in this work. The method employed involved the use of the tubular soil sampler (area 20.15 cm^2) designed by Robinson (1955), two randomly sited samples being taken per plot. The two 6 in. cores from each site were taken into the laboratory where the upper core was divided in half i.e. root weights were determined for 0-3 in., 3-6 in. and 6-12 in. horizons.

The method of separation of roots and soil, used in the laboratory, was that of Jacques (1945). The samples were soaked in loosely tied plastic bags and then washed in a nylon sieve of plain-weave mesh with 21 holes to the inch. By carefully breaking up the soil in the sieve while the latter was resting in a pan of water and following this with agitation of the sieve in the water, the sample was considerably reduced without the loss of root material. Decantation on to a rubber baffle and a certain amount of cleaning of the sample with forceps completed the separation.

The cleaned root samples were placed on blotting paper and oven dried for 24 hours at 105°C. After drying they were placed in a desiccator until cool when they were weighed on a Sartorius balance, the weights being recorded to the nearest milligram.

CHAPTER IV

Results.

The results of this experiment will be presented in seven sections:

I. An analysis of herbage production based on dry matter yields.

II. An examination of the leaf area measurements recorded.

III. The relationship between herbage yield and leaf area.

IV. An analysis of the effects of treatment and season on the size and type of grass and clover tiller populations.

V. An analysis of the soil pF measurements made under each sward over the period 6th Jan.-24th March.

VI. A description of the distribution of roots within the 12 in. soil profile.

VII. Estimation of soil moisture deficit from climatological records.

The following recordings and observations are also presented:

VIII. Weekly weather data prepared from records of the Grasslands Division meteorological station.

IX. Comments on pasture pests and diseases, notably Crown rust on perennial ryegrass, and the Lucerne flea on white clover.

(For abbreviations used in text, see appendix 1.)

P A R T I

Herbage Production Based on Dry Matter Yields.

A. Dry Matter Yields.

The yield data is presented in summarised form in table 5, together with the results of the analyses of variance for each experimental period. Further detail, together with the analyses of variance, is given in appendices 2, 3 and 5. The recorded yield measures the herbage produced by the pasture between defoliations, as opposed to the herbage consumed by the act of cutting and removing clippings, or grazing by stock. The production figures have been calculated by subtracting the yield recorded after one grazing from that measured immediately before the following grazing. The reasons for subdivision of the experimental period have been presented in an earlier section.

Table 5. Dry Matter Yields. (lb. per acre.)

Period / Treatment	Establishment 18 weeks	Intermediate 17 weeks	Final 10 weeks	Total 45 weeks
3 in.	1337	5420	1952	8709
6 in.	1341	5762	2760	9863
Results of Analysis of variance	N.S.	N.S.	**	
		N.S.		

Since the treatments were not imposed until the establishment period was completed, the yield data for this pre-treatment period were excluded from an analysis of variance on total yields. No significant treatment effect could be detected on the total yield recorded over the remainder of the experimental period.

(Appendix 3.1.)

(i) Establishment period. This period embraces the time from sowing on 3rd May until the pasture was first grazed at a height of 3-4 in. on 2nd Sept. Measured yields from each treatment group of plots in Sept. were similar. (Appendix 3.2.) No account has been taken of the herbage removed during the light grazing given the area in July. This procedure would only slightly under-estimate the total dry-matter production of the plots.

(ii) Intermediate period. (Sept.-Jan.) The treatments were applied at the commencement of this period following the initial grazing of the swards at a height of 3-4 ins. During this period there were eight grazings of the 3 in. treatment plots and four of the 6 in. treatment. An analysis of variance of the yield data collected showed that there was no significant treatment effect. (Appendix 3.3.) It is estimated from the figures in table 5 that the average weekly production exceeded 300 lb. D.M. per acre.

(iii) Final period. (Jan.-March.) The same defoliating heights were employed over this period as previously, but the plots were cut with a rotoscythe and the clippings removed, instead of being grazed by sheep. It was considered that the removal of herbage from the plots, without the addition of fertilisers to replace the loss of nutrients would, over a short period, have only a limited effect on subsequent pasture growth. This view was strengthened by the fact that there were no visual symptoms of nitrogen deficiency observed. The 3 in. treatment was cut three times and the 6 in. treatment twice during this period. An analysis of variance of the yield data showed a significant difference ($p = 0.01$) between treatments in favour of the 6 in. cutting height. (Appendix 3.3.) Average weekly production as calculated from the figures in table 5 was 195 lb. D.M. per acre under the 3 in. treatment and 276 lb. D.M. per acre under the 6 in. treatment.

Measurements were taken at 7-day intervals after each cutting, to determine the weekly dry matter increment within each production period, and the relationship between dry matter yield and the time since cutting. The growth curves obtained for each production period are shown in figure 5. For convenience of reference the curves of the 3 in. treatment will be referred to as I, II and III, and those of the 6 in. treatment as Ia. and IIa. The standard error for each weekly mean has been plotted on the curves. Significant dry matter increases between sampling dates may be determined by using the following simplified "t" test:

$$d_{0.05} > 3 \text{ S.E.}$$

The trend towards a linear relationship between dry matter and time under both treatments is illustrated in fig. 5. The use of the simple "t" test procedure outlined above, on the data obtained, suggested that there would be no consistent departure from this linear relationship at any point on a hypothetical curve embracing all measurements under one particular treatment. Therefore statistical tests of the departure of this relationship from linearity were not applied. Four isolated weekly periods were noted on individual curves when no significant increase in growth was recorded.

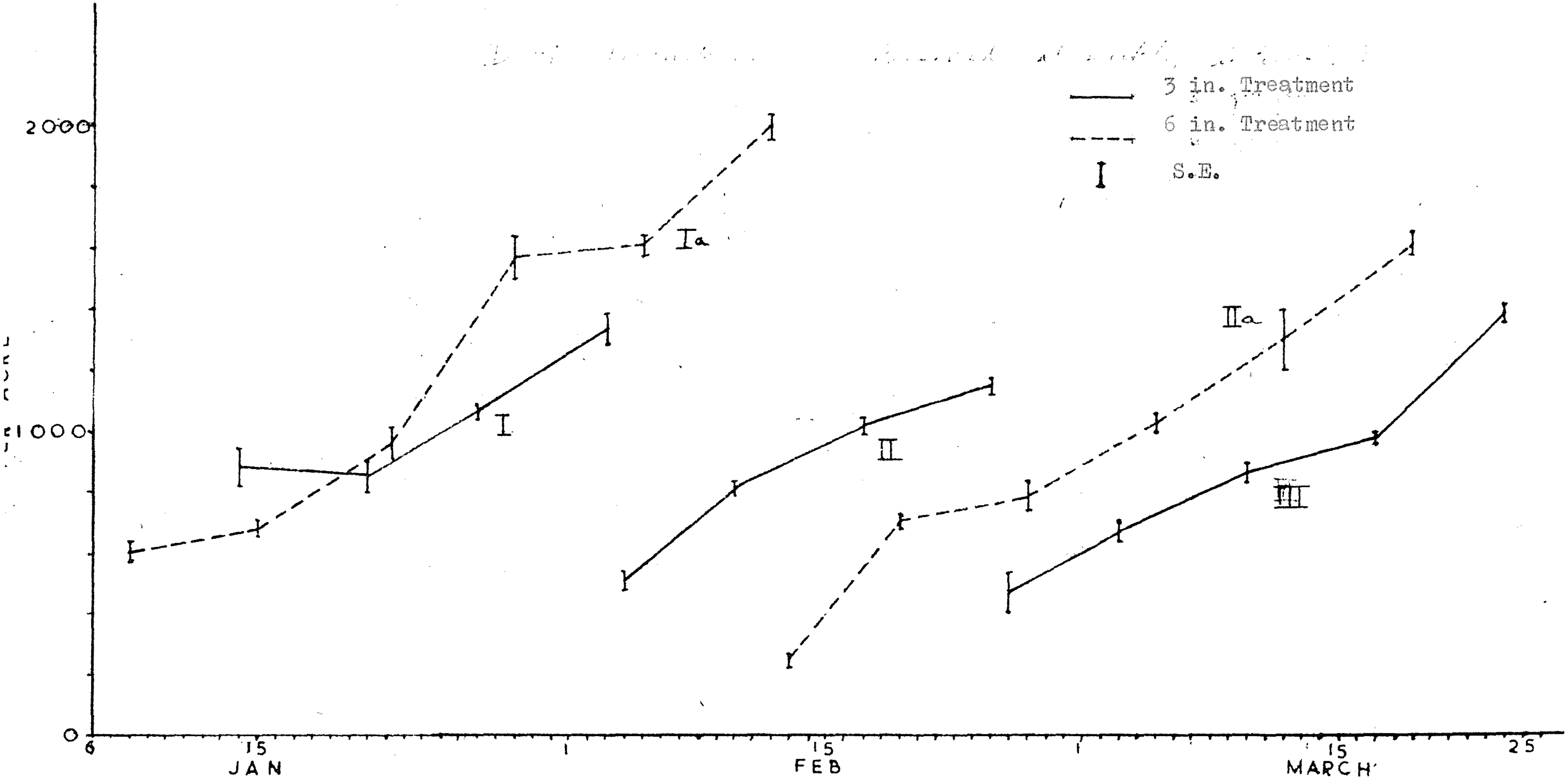


FIG. 5 Dry Matter Production Curves.

B. Growth Rates.

Changes in dry weight between adjacent grazings or cuttings, and possible differences between treatments in the rate of these changes, can be described in terms of growth rates. Estimates of the R.G.R. under each treatment have been made for each between-grazing (cutting) period and are shown in table 6.

R.G.R. values were calculated using the formula

$$\frac{\log e\, W_1 - \log e\, W_o}{t_1 - t_o} \qquad \text{where } W_1$$

and W_o and are dry weights recorded at times t_1 and t_o. The actual data from which the values were calculated are given in Appendix 4. It should be noted that the estimates made assume that the rate of pasture growth follows the Exponential(or Logarithmic) law, i.e. that the rate of growth is proportional to the weight at any given instant. This agrees with the findings of Brougham (1955), although it appears to contradict the results of this experiment which indicated a linear relationship between yield and time (days after defoliation). However, it is suggested that with greater precision a curvilinear (logarithmic) relationship between dry matter yield and time would havebeen found. Therefore the assumption that pasture growth after defoliation did follow the Exponential law, would appear to be valid.

Inspection of the R.G.R. values in table 6 shows that the range is greater under the 3 in. treatment (o.13 - 0.43 lb./lb./week) than under the 6 in. treatment (0.19 - 0.37 lb./lb./week). It is not possible from the data available to determine any seasonal trends in growth rates between grazings. The estimates show that the growth rate seldom dropped below 20% increase per unit of dry matter per week, and on several occasions this rate was almost doubled.

TABLE 6.

Estimates of Relative Growth Rates. (lb./lb./week.)

Spelling period	Treatments 3 in.	Treatments 6 in.	Spelling Period
2nd. Sept. - 16th Sept.	0.38	0.21	2nd Sept. - 4 th Oct.
16th Sept. - 4th Oct.	0.37		
4th Oct. - 17th Oct.	0.43	0.33	4th Oct. - 24th Oct.
17th Oct. - 24th Oct.	0.13		
24th Oct. - 7th Nov.	0.16	0.19	24th Oct. - 24th Nov.
7th Nov. - 24th Nov.	0.33		
24th Nov. - 25th Dec.	0.32	0.21	24th Nov. - 7th Jan.
25th Dec. - 13th Jan.	0.24		
13th Jan. - 3rd Feb.	0.14	0.24	7th Jan. - 12th Feb.
3rd Feb. - 24th Feb.	0.27		
24th Feb. - 24th Mar.	0.27	0.37	12th Feb. - 19th Mar.

Table 6 shows that the average of the estimates of R.G.R. obtained during the intermediate period was greater under the 3 in. treatment than under the 6 in. treatment. As similar yields were recorded under both treatments, it is suggested that the higher R.G.R. estimates of the 3 in. treatment were offset by the longer period of uninterrupted growth obtained under the 6 in. treatment. However, during the final period the order of R.G.R. values was reversed and it is probable that the combination of a higher growth rate and longer period of uninterrupted growth accounted for the significant yield increas under the 6 in. treatment.

C. Dry Matter Percentages.

Dry matter percentage estimates were made on the herbage samples cut for yield determinations. The data obtained are presented in fig. 6. Two sampling dates have been excluded from the results because of surface moisture on the leaves at the time of sampling.

Fig. 6 illustrates that herbage samples cut prior to grazing contained a higher moisture content than those taken of the stubble remaining after grazing. This can be attributed to the higher proportion of stem and petioles in the latter samples. The dry matter percentage of the stem and petioles is higher than that of the leaves.

Both treatments showed an overall decline in the dry matter percentage of the pre-grazing samples during the course of the experiment. This can be best be explained by the increase in the clover component of the sward, since Sears (1953) found that the dry matter percentage of a grass-clover association was below that of cloverless plots.

The intermediate dry-matter determinations made at 7-day intervals following cutting are shown in fig. 6. These determinations illustrate the decline in dry matter percentage which occurs as leaf development of the sward proceeds.

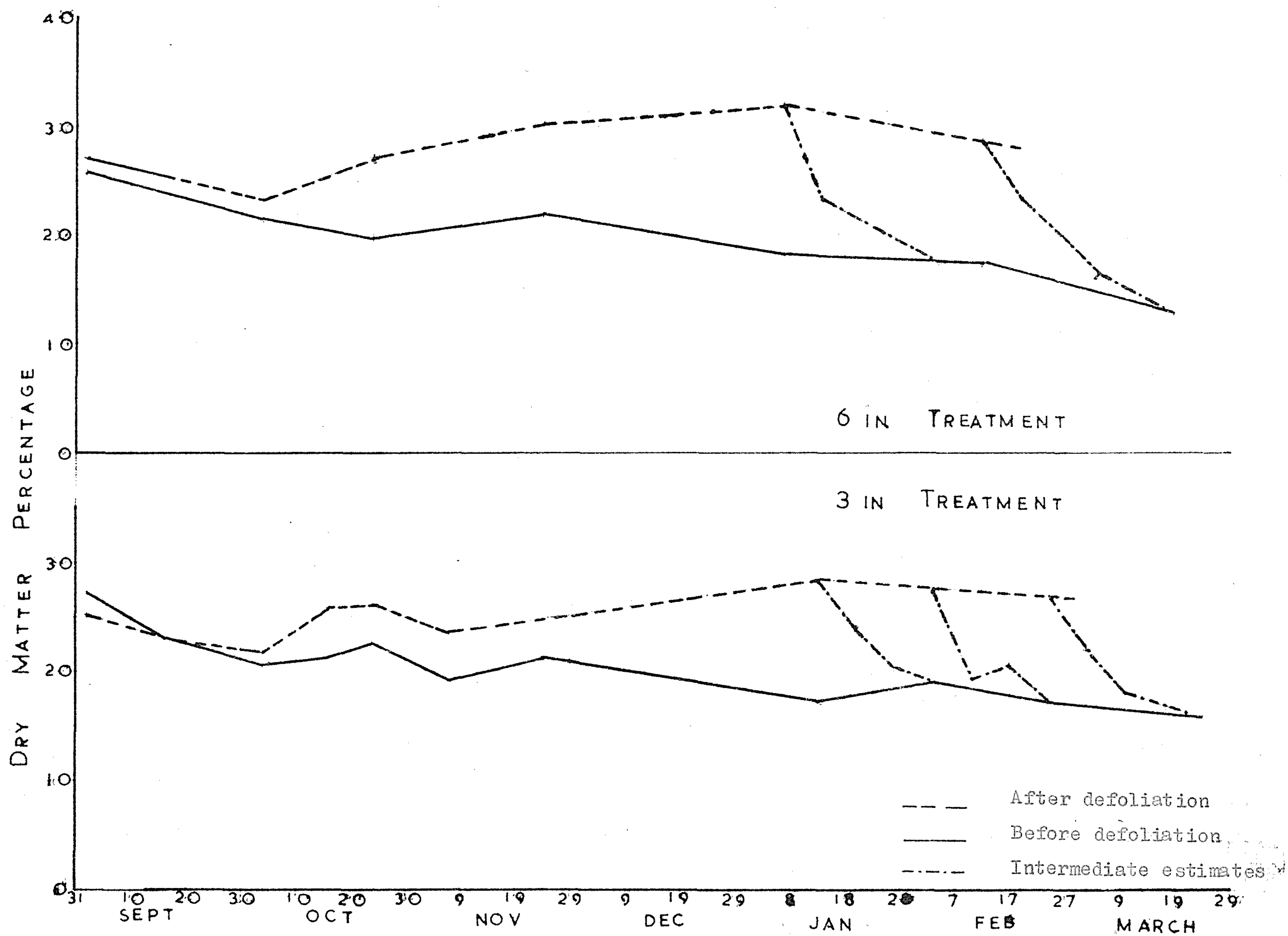


FIG. 6 Dry Matter Percentages.

PART II

Leaf Area Measurements.

A. L.A.I. Values Obtained.

Initial L.A.I. measurements were made on 2nd Sept. when the pasture height of all plots was 3-4 ins. A L.A.I. of 2.56 was recorded with a grass/clover leaf area ratio of 88:12. The plots were grazed to a height of 1 in. immediately after sampling.

The plots were sampled a second time (4th Oct.) at the respective treatment grazing heights. This was after 32 days' regrowth during which time the 3 in. treatment had been grazed once. L.A.I. values of 2.02 $\pm$ 0.079 and 3.95 $\pm$ 0.303 were recorded under the 3 in. and 6 in. treatments respectively. The difference between treatments is significant at the 5% level. ($d_{0.05} > 3$ S.E.). The average grass/clover ratio was 84:16, indicating only a slight increase in percentage clover leaf, following the Sept. sampling. Differences between treatment means of the grass and clover components of the total L.A.I. were significant according to the simplified "t" test. (see Table 7). The leaf area of each component under the 6 in. treatment was approximately double that of the 3 in. treatment.

Leaf area measurements were not taken over the next 12 weeks. During this time the pasture was subjected to the two grazing treatments.

During the final 10 weeks, intermediate weekly L.A.I. measurements were taken as well as pre- and post-cutting estimates. The data obtained are tabulated in Appendices 6.1 and 6.2.

B. Regression of L.A.I. on Time.

During the final 10 weeks the 3 in. treatment plots completed three growing periods (growing period = interval between one grazing and the next) each of three weeks' duration. The third cycle, however, was continued for a fourth week. The leaf area growth curves obtained under the 3 in. treatment are shown in fig. 7 and the 6 in. treatment curves in fig. 8

Significant linear regressions of L.A.I. on time (days after cutting) were obtained for both sets of data. The regression coefficients obtained were 0.158 $\pm$ 0.0123 and 0.142 $\pm$ 0.0105 for the 3 in. and 6 in. treatments respectively. These values are interpreted as meaning an average weekly increase of 1.11 L.A.I. units under the 3 in. cutting and 1.00 L.A.I. units under the 6 in. cutting.(Appendices 7.1 and 7.2).

Inspection of the individual leaf area curves under the 6 in. treatment (fig. 7) indicates that there were no significant changes in L.A.I. over the 4th and 5th week of curve Ia, and 5th week of curve IIa. Although the data were not significantly curvilinear the trend suggests that the maximum rate of total leaf area increase may have been reached about L.A.I. 3.75 in curve Ia and L.A.I. 4.60 in curve IIa. Once these values had been reached there was no significant change in the L.A.I. of either grass or clover components, with the exception of an increase in the L.A.I. of the grass component in the final week of curve IIa.

There was no evidence of a corresponding decline in the rate of total leaf area development under the 3 in. treatment.

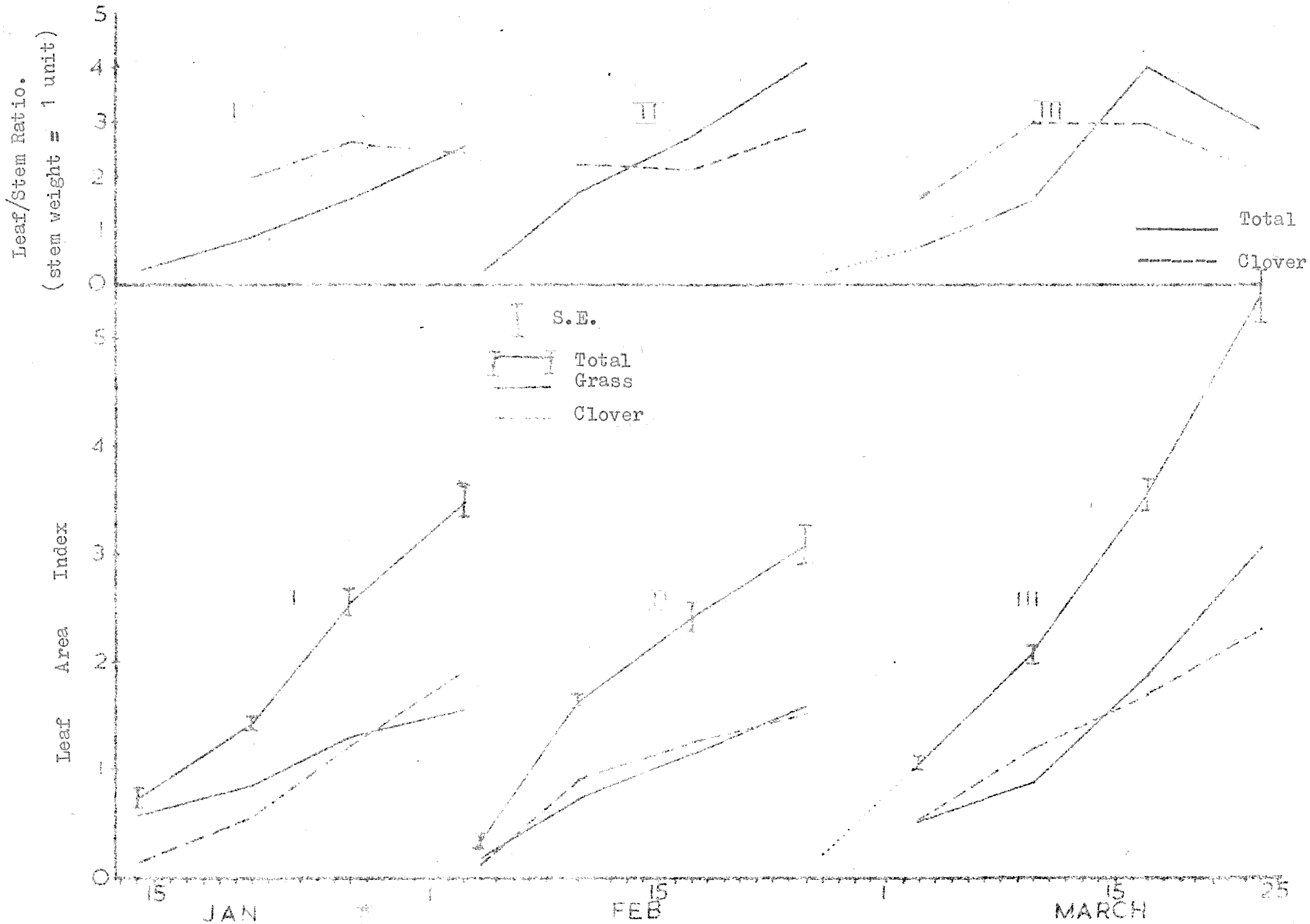


FIG. 7 L.A.I. - Curves for 3 in. Treatment and Leaf/stem Ratio curves for Total Herbage and Clover Component.

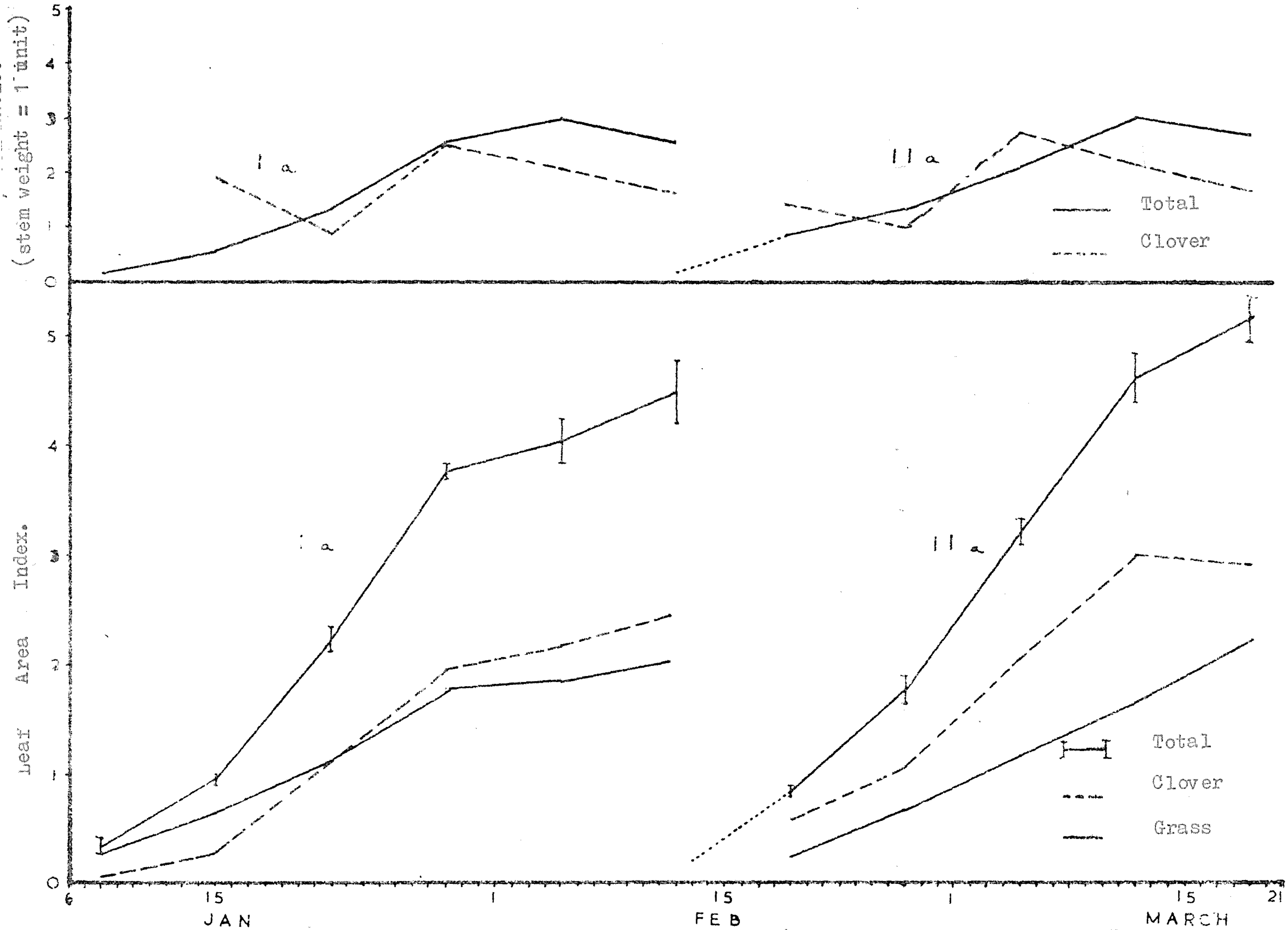


FIG. 8 L.A.I. - curves for 6 in. Treatment and Leaf/stem ratio Curves for Total Herbage and Clover Component.

C. Spatial Density of the Sward.

The spatial density of a sward refers to the quantity of plant material within a given height covering a definite area. In this case the leaf area of the plant is the quantity considered, and spatial density can be measured by the L.A.I. within a given height.

Table 7 shows the maximum L.A.I. values at the respective treatment cutting heights on 4th Oct., and at the completion of each of the five growing periods recorded during the final ten weeks. To enable between treatment observations to be made, the figures recorded after three weeks'growth, (pasture was then approximately 3 in. tall) under the 6 in. treatment are also given. The leaf area indices of the grass and clover components have been tabled.

TABLE 7.

Maximum L.A.I. values attained under each treatment.

Treatment		4th Oct.	I 3rd Feb.	II 24th Feb.	III 17th March
3 in.	Grass	1.71 ± 0.099	1.57 ± 0.154	1.56 ± 0.142	1.88 ± 0.082
	Clover	0.31 ± 0.046	1.93 ± 0.101	1.54 ± 0.203	1.70 ± 0.094
	Total	2.02 ± 0.074	3.50 ± 0.153	3.10 ± 0.187	3.58 ± 0.133
			Ia. 29th Jan.		IIa. 5th Mar
6 in. after 3 weeks' growth	Grass		1.79 ± 0.059		1.16 ± 0.113
	Clover		1.96 ± 0.065		2.06 ± 0.178
	Total		3.75 ± 0.035		3.22 ± 0.109
		4th Oct.	Ia. 12th Feb.		IIa. 19th March
6 in. after 5 weeks' growth	Grass	3.30 ± 0.316	2.04 ± 0.314		2.24 ± 0.257
	Clover	0.65 ± 0.071	2.46 ± 0.147		2.93 ± 0.120
	Total	3.95 ± 0.303	4.50 ± 0.290		5.16 ± 0.214

An analysis of variance of the L.A.I. values recorded on Oct. 4th and March 17th, under the 3 in. treatment, showed that the March value was significantly ($p = 0.05$) greater than the October value. (see Appendix 8.1). This can be attributed to a significant increase in clover leaf over this period, whereas the area of grass leaf recorded was virtually the same at each sampling. (Table 7.)

An analysis of variance of L.A.I. values recorded under the 6 in. treatment on 4th Oct. and 19th March, failed to detect any significant change between these dates. (Appendix 8.2). Analyses of the grass and clover components showed a significant between-date difference in clover leaf area ($p = 0.01$) but no difference was detected in the area of grass leaf. (Appendices 8.3 and 8.4). The data indicate that there is a trend towards a decrease in the area of grass leaf within the leaf area sample, between these two dates. However, this trend could only be detected at the 17% level of significance.

An increase in the sward spatial density was detected under the 3 in. cutting treatment between 4th Oct. and 17th March. On the other hand, a similar increase could not be detected at the 5% significance level under the 6 in. treatment.

Comparative figures between the two treatments taken at a height of 3 in. are given in Table 7. It is not possible to make a statistical comparison between treatments but observation suggests that at this stage the total and component leaf area indices of the two swards were similar.

D. Grass/clover Ratio.

The grass/clover leaf area ratios have been calculated and tabulated in Appendix 6. Dominance of either grass or clover species was determined by the species percentage contribution to the total leaf area of the sward. Sept. and October leaf area samples showed a marked grass dominance. Observations showed that this was maintained into November when clover growth increased.

In most instances, over the final period, a grass/clover ratio ranging between 45:55 and 55:45 was achieved within 7 days of defoliation. From January to March there were only two periods when either species showed a marked dominance in the sward, viz.:-

1. During cycle IIa, the clover became dominant and a 35:65 ratio was achieved. A return to a balanced ratio was evident after 13th March.
2. During cycle III, grass dominance developed after 17th March, when plots were allowed to grow beyond the 3 in. cutting height.

E. Leaf/stem Ratio.

The leaf/stem ratio for the total sward and clover component are shown in Figs. 7 and 8 for each sampling date. The ratios were estimated from the leaf area data. Leaf area growth is more rapid than stem growth in the total sward. Figs. 7 and 8 indicate that there are only small variations in the clover leaf/stem ratio whereas the grass ratio varied from 0.5:1 following defoliation to 11.0:1 prior to grazing under the 6 in. treatment and 0.5:1 to 6.0:1 under the 3 in. treatment

P A R T III

Relationship Between Herbage Yields and Leaf Area Index.

The regression lines for herbage yield on leaf area are shown in Fig. 9 for the two treatments. The data used are those obtained over the months of January, February, and March. The regression analyses are shown in Appendices 9.1 and 9.2. The regression lines have been fitted to the data for each treatment separately, but neither lines are significantly curvilinear nor of differing slopes.

The regression coefficients and their standard errors were 184 ± 34 for the 3 in. treatment and 199 ± 49 for the 6 in. treatment, i.e. an increase in 1 sq. ft. of leaf area was accompanied by an increase in herbage yield of 184 lb. D.M. per acre under the 3 in. treatment and 199 lb. D.M. per acre under the 6 in. treatment.

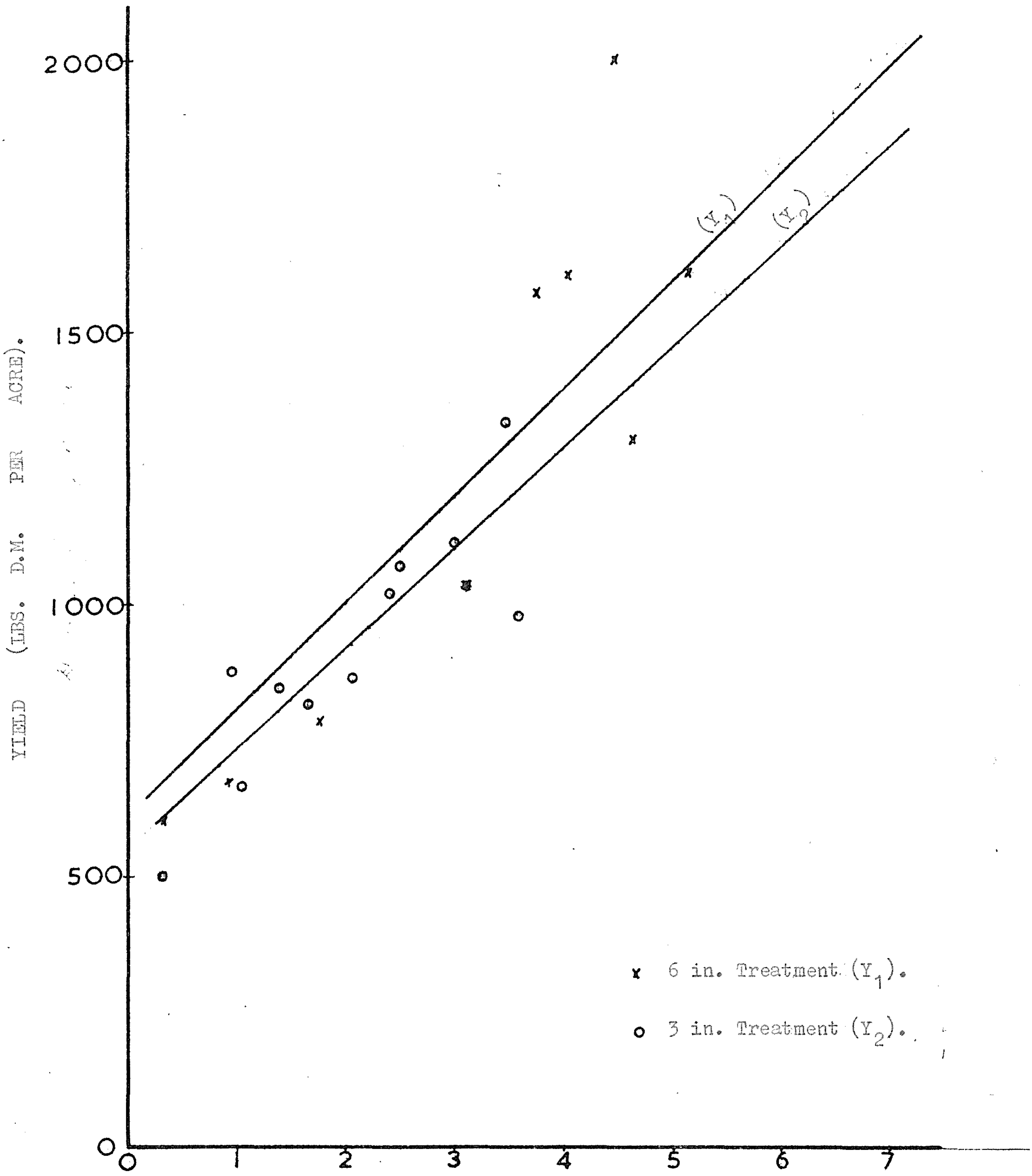


FIG. 9 The Relationship between Herbage Yield and Leaf Area Index.

P A R T IV

Tiller Populations.

A. Introduction.

Estimates of the tiller population size of the two treatment swards were made on four dates during the experiment. A fifth estimate was made approximately two months after the termination of the experiment to determine the presence of residual treatment effects. Plot data obtained, based on tiller numbers per square foot, are presented in Appendix 10.

The sampling dates were: 25th Aug. 1958.
19th Nov. "
6th Jan. 1959.
31st Mar. "
9th June "

The mean tiller numbers per plot for each treatment, recorded on the above sampling dates are presented in Table 8. The total tiller population has been divided into three components, viz. grass, clover, and weeds. In the statistical analysis and general discussion the weed population will not be considered since after the Aug. sampling only "trace" numbers of weed plants were recorded.

B. Examination of Treatment Effect on Tiller Population.

The first tiller count following sowing on 3rd May, 1958, was taken on 25th August, 1958. A total tiller population of 250-259 tillers per square foot was recorded at this sampling. Grass tillers dominated the sward to the extent that only 12-13 clover plants were found per square foot of pasture. At this stage tillering had commenced in the grasses and each plant comprised a group of tillers. On the other hand, there had been no appreciable elongation of clover stem internodes and generally each clover node was in effect a small plant.

TABLE 8.

Results of "t" tests on tiller numbers within sampling dates, and percentage of plugs containing various species.

Species	Treatment	Date	25 Aug. No.	%	19 Nov. No.	%	6 Jan. No.	%	31 Mar. No.	%	9 June. No.	%
Grass	3 in.		247	97	212	97	183	92	109	89	133	91
	6 in.		242	98	169	96	140	86	71	86	93	76
		$d_{0.05}$			± 50		± 64		32		51	
		p				0.12		0.16		0.03		0.10
Clover	3 in.		12	58	72	82	61	91	84	99	69	99
	6 in.		13	67	51	80	48	93	79	99	79	98
		$d_{0.05}$			26		18		23			
		p				0.09		0.19				
Weeds	3 in.		6	38	1	7	1	1	0	0	1	11
	6 in.		5	35	1	6	0	0	1	4	1	2
Total	3 in.		259		284		244		193		202	
	6 in.		255		220		188		150		172	
		$d_{0.05}$			60		63		52		35	
		p				0.05		0.10		0.09		0.08

The experimental treatments were started in mid-Sept. so that prior to the November sampling the 3 in. treatment plots had been grazed six times, compared with three grazings of the 6 in. plots. Total tiller numbers at the November sampling date were significantly greater (5% level) on the more frequently grazed plots. Analysis of the grass and clover components revealed that differences between treatment means were significant at the 12% and 9% levels, respectively. This suggests that the overall treatment effect on tiller numbers could not be attributed to one species rather than the other.

The January counts followed two further grazings of the 3 in. plots and one grazing of the 6 in. plots. In this case the difference in total tiller numbers between treatments was significant at the 10% level. A greater density of tillers occurred under the

3 in. grazing. The probability values obtained from the analysis of treatment effects on component species (see Table 8) are similar. It was therefore concluded, that treatment effects on total tiller numbers could not be attributed solely to either species.

The March sampling was preceded by three cuttings of the 3 in. plots and two cuttings of the 6 in. plots. The difference between treatment means of total tiller numbers was significant at the 9% level. The presence of this difference is largely due to the effect of the treatment on the grass tiller populations, as the difference between grass tiller means was significant at the 3% level, (Table 8). There was no significant treatment effect on the number of clover nodes.

Visual observation of the plots 6-8 weeks after the experiment concluded, suggested that the grass tiller population of the 3 in. plots was greater than that of the 6 in. plots. A tiller count was made on June 9th to test this observation. Analysis of the results from this count are shown in Table 8. Since a significant difference between grass tiller numbers was detected at the 10% level, but no significant difference in clover node numbers was found, the larger tiller population of the 3 in. plots was attributed mainly to the between treatment difference in size of the grass tiller populations. This confirmed the visual observations.

C. <u>Seasonal Trends of Tiller Populations.</u>

Results of the paired "t" tests determining the significance levels of the differences between adjacent sampling dates, under the two treatments are given in Tables 3 and 4. The seasonal trends of the total tiller populations and of its grass and clover component populations, are illustrated in Fig. 10.

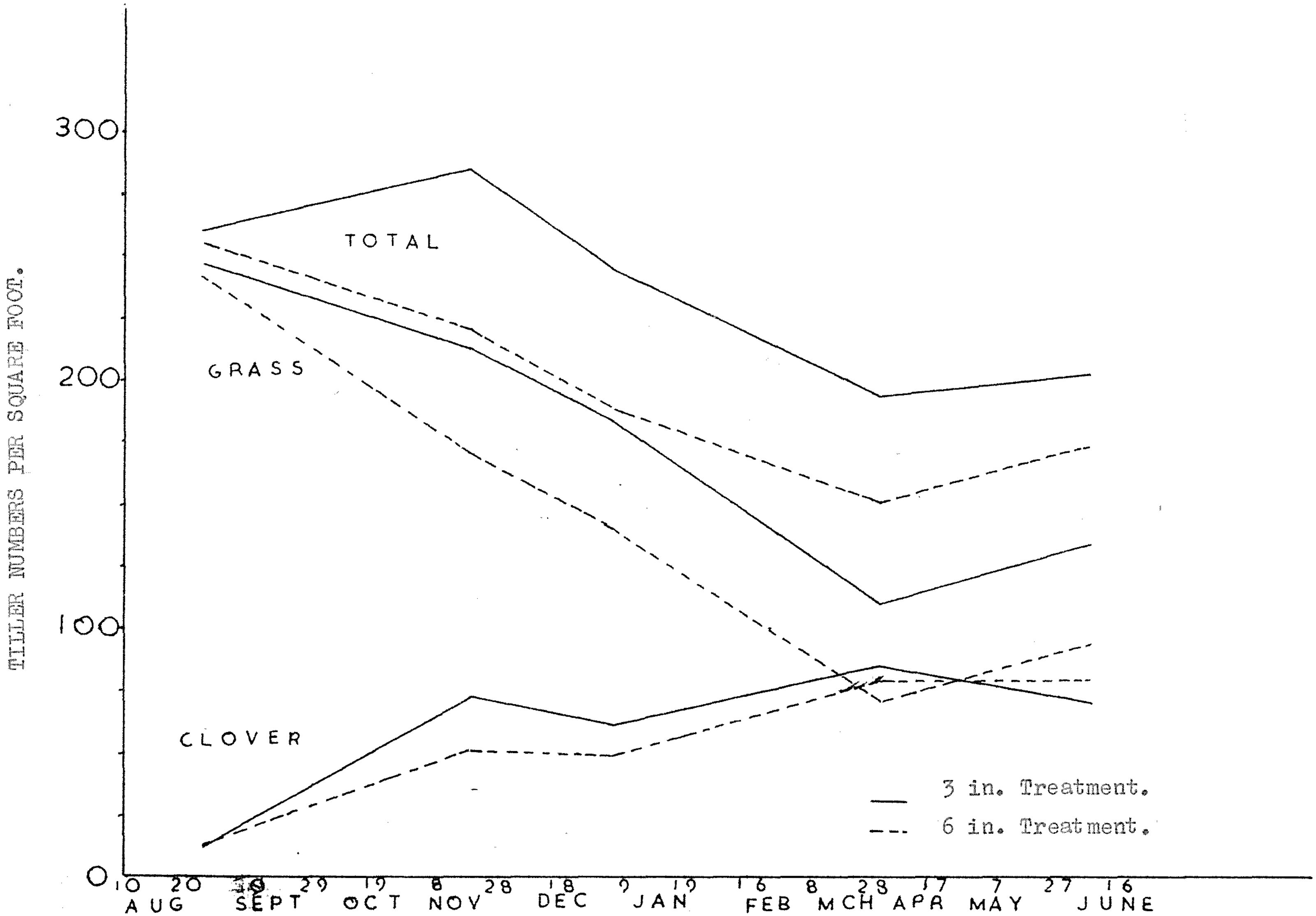


FIG. 10. Seasonal Trends in Tiller Populations.

TABLE 9.

Results of "t" tests on differences in tiller populations between sampling dates.

Species		25th Aug-19 Nov.		19 Nov-6 Jan.		6 Jan - 31 Mar.		31 Mar-9 J	
		3 in.	6 in.	3 in.	6 in.	3 in.	6 in.	3 in.	6 i
Grass	Actual diff.	- 35	- 73	- 29	- 29	- 74	-69	+ 24	+ 22
	Required diff.	± 79	± 45	± 66	± 46	± 49	± 52	± 38	± 47
	p	N.S.	0.01	N.S.	0.12	0.01	0.02	0.18	N.S.
Clover	Actual diff.	+ 60	+ 38	- 11	- 3	+ 23	+ 31	- 15	0
	Required diff.	± 23	± 9	± 26	± 17	± 22	± 20	± 24	± 28
	p	0.001	0.001	N.S.	N.S.	0.04	0.01	0.17	N.S.
Total	Actual diff.	+ 25	- 35	- 40	- 32	- 51	- 38	+ 33	- 2
	Required diff.	103	56	71	39	54	56	44	
	p	N.S.	0.19	N.S.	0.09	0.07	0.15	N.S.	N.S.

The total tiller population decreased until late March after which there was a slight though non-significant increase. Fig. 10 indicates that the rate of decline of tiller population size under the 6 in. treatment was approximately constant from August until March. On the other hand the tiller population under the 3 in. treatment showed a tendency to increase during the spring before it decreased to a minimum in March.

The grass tiller populations decreased over the period of the experiment until the March sampling, after which there was a tendency for tiller numbers to increase. Fig. 10 shows that the decrease in grass tiller numbers was accelerated under the 6 in. treatment. Under the 6 in. treatment a significant decline (1% level) in tiller numbers occurred between the August and November sampling dates, and a difference between January and March samplings was detected at the 2% level. By contrast, no significant changes in tiller numbers, between adjacent sampling dates, was detected under the 3 in. treatment, until the Jan. - March period.

Fig.10 shows, that the grass tiller population curve of the 3 in. treatment followed that of the 6 in. treatment and that the order of the treatment difference, which had developed by November, remained practically unchanged throughout the remainder of the experiment.

The seasonal change in the number of clover nodes was inversely related to the change in grass tiller numbers over the same period. Between the August and November samplings the clover node population increased. This change was primarily due to an increase in stem elongation and node development of existing plants rather than the establishment of new clover plants. The increase in node population was accelerated under the 3 in. treatment during the spring, but after November the rate of change of node numbers was similar under both treatments.

The clover node populations were relatively constant between November and January sampling dates but increased to the March sampling after which there was no change recorded.

D. Tiller Distributions.

It is possible from the data available to obtain information on the distribution of tillers within each sward and changes which occurred during the course of the experiment.

The distribution of the grass and clover tiller numbers per plug for each treatment, and all sampling dates are presented in Fig. 11. The method of presentation is that of Mitchell and Glenday (1958) which has the effect of removing the skewness of the distributions and allows data which were originally log-normally distributed to appear normal. The method used was to condense counts into the following classes:

0, 1-2, 3-6, 7-14, 15-30, 31-62, 63+.

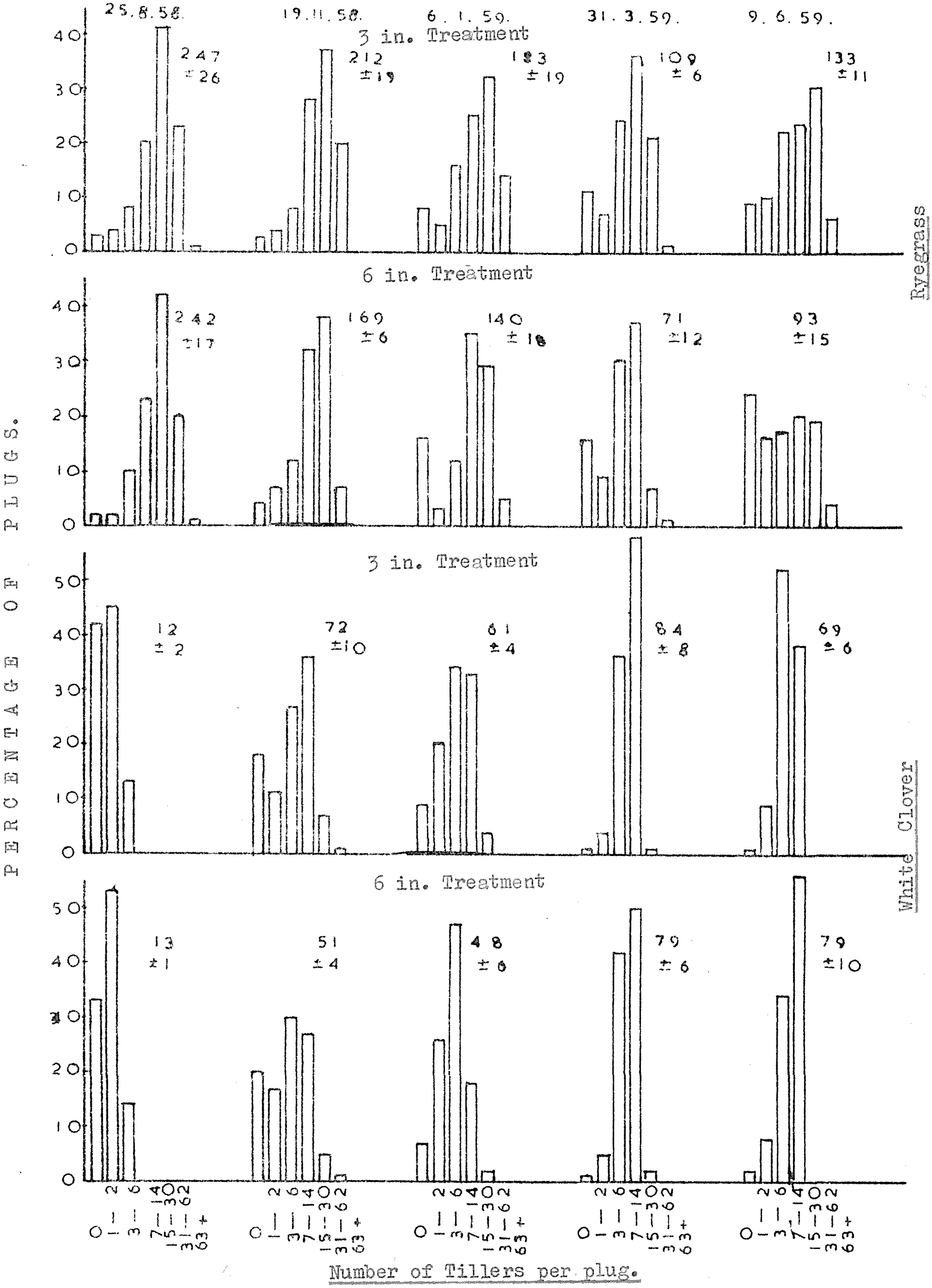


FIG. 11 Tiller distribution diagrams.

(i) Grass tillers.

Examination of the distribution diagrams obtained at the first and last sampling dates (Fig. 11), suggested that during the course of the experiment there was a departure from the log-normal model of the first sampling. At the first sampling the mean tiller count per plug was high with few small or very large counts, indicating that tillers were spread relatively evenly throughout the pasture with no pronounced aggregation.

The distributions shown for the June sampling date (Fig. 11), particularly that of the 6 in. treatment, covered a wide range of classes in relation to the mean, with a considerable number of small counts.

The presence of a real change in distribution of tillers between sampling dates was examined by using a Chi - square test.

Results of the Chi square test between Aug. and June samplings showed that significant changes ($p = 0.001$) had taken place in the distribution of the grass tiller populations under both the 3 in. and 6 in. treatments, between the initial and final samplings (Appendices 11.1, 11.2). Inspection of the grass tiller distribution diagrams in Fig. 11 indicates the mature of this change. There was an increase in the percentage of plugs in the 0 and 1-2 classes with fewer plugs recorded in the 15-30 and 31-62 classes at the June sampling. The wide distribution of plugs at the June sampling (c.f. August sampling) indicates an increase in the degree of tiller clumping. The series of tiller distribution diagrams in Fig. 11 illustrates the progressive departure from the log-normal distribution of the August sampling which took place during the experimental period.

Treatment effect on the degree of clumping which had taken place at the January, March, and June samplings was examined using Chi-square tests. The results are presented in Appendices 12.1, 12.2, 12.3. No treatment effect was detected at the January sampling. Significant treatment effects were obtained at the March ($p = 0.01$) and June ($p = 0.05$) samplings. The greatest degree of clumping as determined by the deviation from the log-normal distribution existed under the 6 in. treatment.

(ii) Clover tillers.

Inspection of the clover node distribution diagrams indicates that the mean count per plug increased during the course of the experiment to a March maximum and thereafter was relatively constant. The distribution diagrams for the initial and final sampling dates were significantly different for both treatments. (Appendices 13.2 and 13.3). However, the narrow range of counts in relation to the mean, at both sampling dates, under each treatment, indicates that the clover nodes were randomly distributed throughout the sward. On the other hand, the wider range of counts with a relatively high number of plugs recorded in both the 0 and 7-14 classes, showed a departure from this random distribution at the November and January samplings.

Between treatment differences in distribution curves within each sampling date were examined using Chi-square tests and the results are presented in Appendices 13.1, 13.4, 13.5, 13.6, 13.7. Significant differences between treatment distribution curves were obtained at the November ($p = 0.05$), January ($p = 0.001$) and June ($p = 0.05$) samplings.

At the November sampling date a larger percentage of plugs were recorded in the 0 and 1-2 classes under the 6 in. treatment than under the 3 in. treatment. This agrees with the results above indicating a more rapid colonisation by the clover of the 3 in. treatment sward. The difference between the distribution diagrams may be interpreted as a less random distribution of nodes under the 6 in. treatment.

The difference between distributions observed at the January sampling can be attributed mainly to the greater number of plugs recorded in the 3-6 class and fewer in the 7-14 class under the 6 in. treatment. Fig.11 shows a tendency for the range of counts to narrow as compared with the November distribution, without any significant change in the size of mean between the two dates.

The presence of a large percentage of plugs within two classes at the March and June sampling, suggests that the clover nodes were randomly distributed within each sward. The trend towards a decline in clover node population between March and June under the 3 in. treatment is revealed by the increased percentage of plugs recorded in the 3-6 class (c.f. 7-14 class) thereby producing a significant Chi-square tests between treatments.

E. <u>Clumping Indices.</u>

Some measure of the degree of clumping would be convenient for comparison between seasons and treatments. Mitchell and Glenday (1958) state "that the usual indices use the Poisson distribution (postulating random occurrence of individual tillers or nodes) as a criterion and test departures from this." However, the use of an index (I) based on a Poisson distribution suggested by David and Moore (1954)

$$\left[\quad I = \frac{s^2}{\bar{x}} - 1 \quad \right]$$

on the grass tiller data in this experiment proved unsatisfactory, thus confirming the finding of Mitchell and Glenday (1958) that the Poisson distribution was inadequate as a test criterion. Consequently the Chi-square test has been used to examine changes in the distribution of tiller numbers between dates or treatments.

However, the use of David and Moore's index on the clover node data proved satisfactory and the results are presented in Table 10.

TABLE 10.

Indices of clumping for clover nodes.

Treatment \ Date	25 August	19 Nov.	6 Jan.	31 March	9 June
3 in.	0.22	3.76	2.15	0.22	0.26
6 in.	0.06	2.71	1.73	0.53	0.37

When $I > 0$ the presence of clumping is indicated. The indices show the negligible clumping recorded at the Aug., March, and June samplings, and the definite existence of clumping in November and January. These results confirm the information already obtained from the distribution diagrams in Fig. 11.

F. Weeds.

Throughout the experiment very few weeds were present, except at the first sampling date when approximately one-third of the plugs analysed contained weeds. After that date the weed-plant densities never exceeded 1 per square foot and the % presence remained below 11%. (Table 8).

P A R T V

Soil Moisture.

A. General.

The soil moisture data collected between 6th Jan. and 24th March, are presented in Appendices 15.1, 15.2 and 15.3. The treatment pF means for each sampling date and depth are given. The same data are also shown in Figs. 12 and 13, together with the daily rainfall figures from the Grassland's Division records.

An indication of the presence of significant differences between treatment means, both between and within sampling dates, was obtained by the use of the following simple "t" test: $d_{0.05} > 3$ S.E. The average S.E. of the pF treatment means was $\pm$ 0.03. This value was determined from a sample of 56 means. (Appendix 15.2). If the value of $\pm$ 0.03 is substituted in the simplified "t" test above then $d_{0.05} > 0.09$.

In some instances where an examination of the results suggested that a significant difference between treatment means, depth means, or date means, was likely to exist, a more complete analysis was used.

B. Field Capacity.

Field capacity, under these experimental conditions was judged from Figs. 12 and 13 to lie between pF 2.70 - 2.80.

An approximate field determination of field capacity was made at the end of the experiment. Two inches of water was applied to the soil immediately above a group of gypsum blocks, at a time when the soil was judged to be near field capacity. Therefore the soil had to lose moisture to regain field capacity. If the sward was covered,

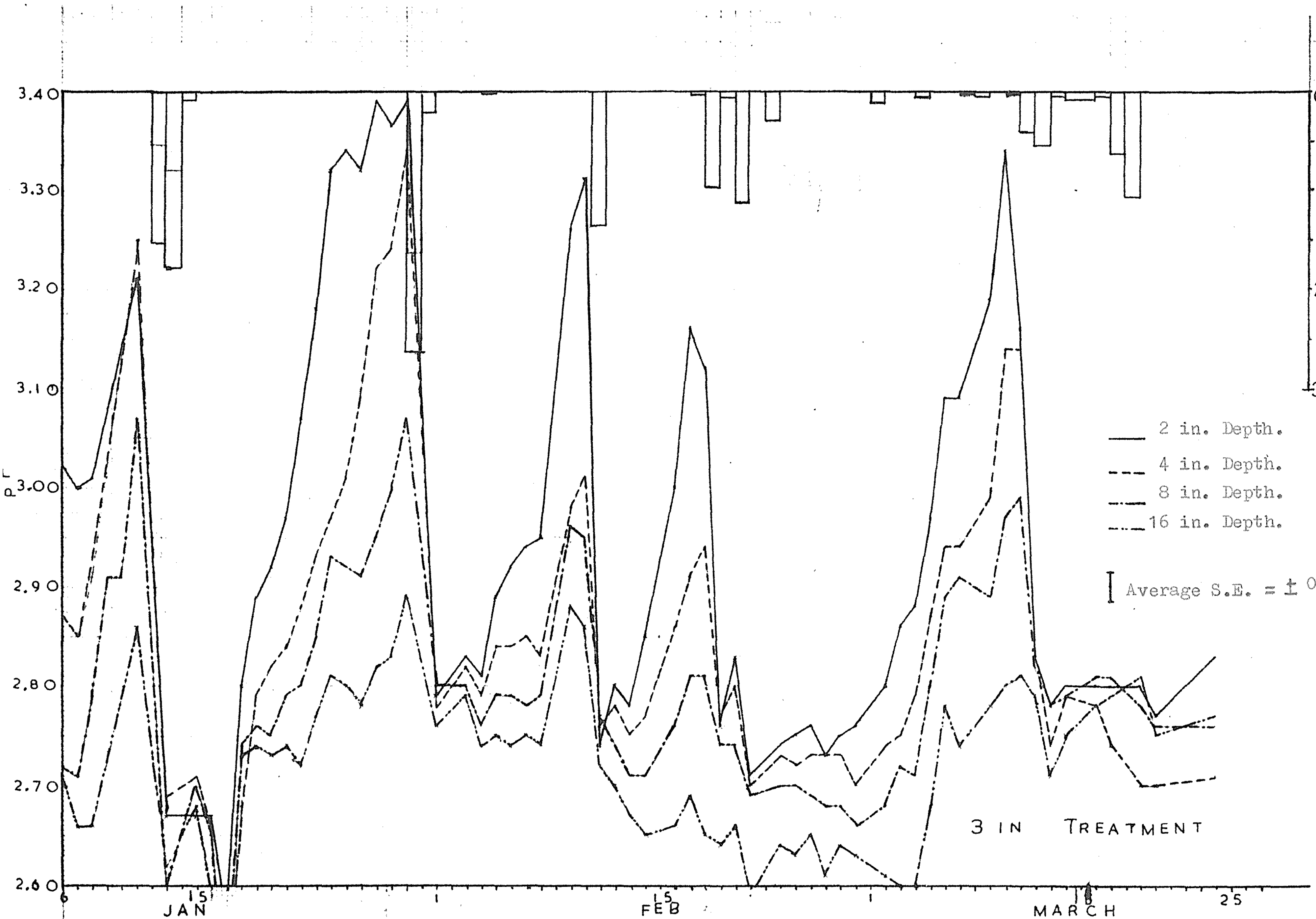


FIG. 12. pF - curves for 3-in. Treatment and daily rainfall figures.

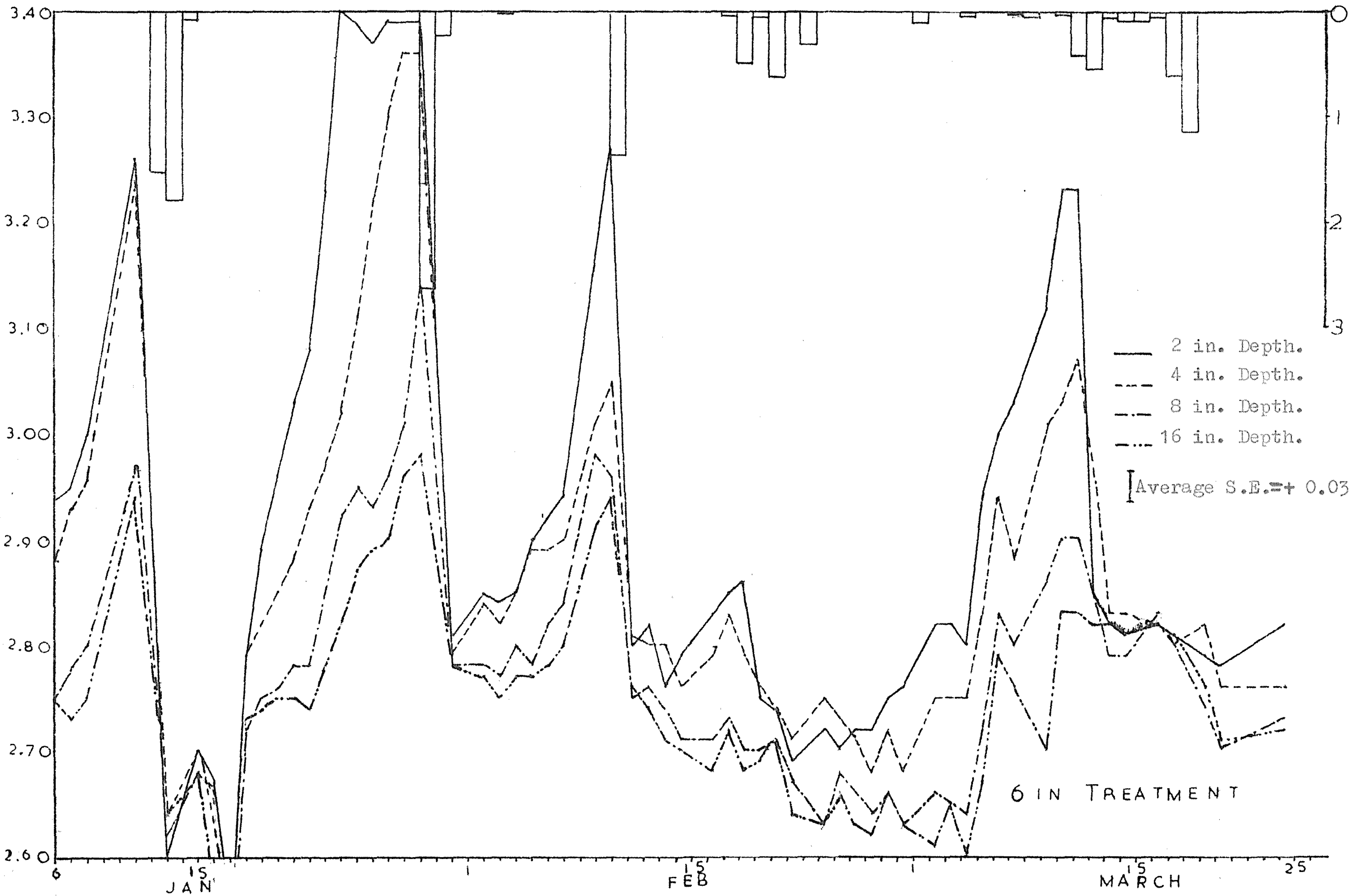


FIG. 13. pF - curves for 6 in. Treatment and daily rainfall figures.

water loss through transpiration or evaporation would largely be prevented and therefore moisture loss from the soil would primarily be achieved through gravitational movement of the water downwards. Once the gravitational movement ceased, the soil would have reached field capacity. The sward was covered with a tarpaulin immediately after applying the water. Moisture readings were taken four days later, by which time the soil should have attained field capacity. (Wadleigh, 1955). An average pF value of 2.75 was recorded. The average was based on two readings from each of four depths. This confirmed the previous estimate of field capacity.

The recorded soil moisture tension remained below pF 3.30 (Fig. 12), except for several measurements at the 2 in. depth. Apart from possibly five days in January (24th - 29th), soil moisture would be unlikely to limit plant growth during the ten weeks over which recordings were taken.

Five drying-cycles were observed during the ten weeks. Each was terminated by an inch or more of rain.

C. Influence of Depth on Soil Moisture Status.

(i) 2 in. depth. Recorded pF values at this depth showed wide fluctuations, ranging from pF 2.60 to pF 3.40. (Fig. 12).

(ii) 4 in. depth. As with the 2 in. depth, the recorded pF values at the 4 in. level were subject to wide fluctuations, but it was observed that there was a delay of 2-4 days in the removal of moisture from the soil, as compared with the lesser depth. The recorded range was pF 2.64 - 3.34.

(iii) 8 in. depth. The pF trends at this depth were intermediate between the 4 in. and 16 in. depths. The upward trend of the pF curve at this depth, which commenced about pF 2.75, lagged 2-4 days behind the 4 in. depth. The length of the drying period determined the maximum pF achieved at the 8 in. depth, whereas other factors appeared to be involved at the 2 in. depth.

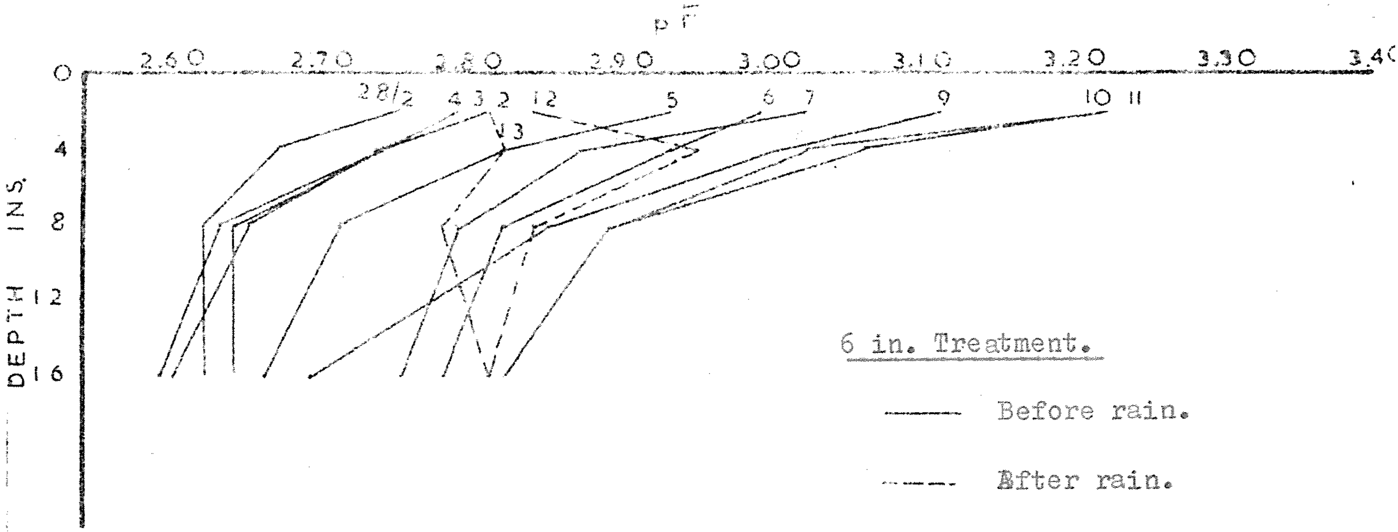
(iv) 16 in. depth. The pF values at this depth remained relatively constant within the range pF 2.60 - 2.90.

The differential rate of decline in available soil moisture with soil depth is illustrated in Fig. 14 for the period 28th Feb. - 13th March. Within 24-48 hours of an inch or more of rain falling, all depths returned to approximately equivalent soil moisture status, around field capacity.

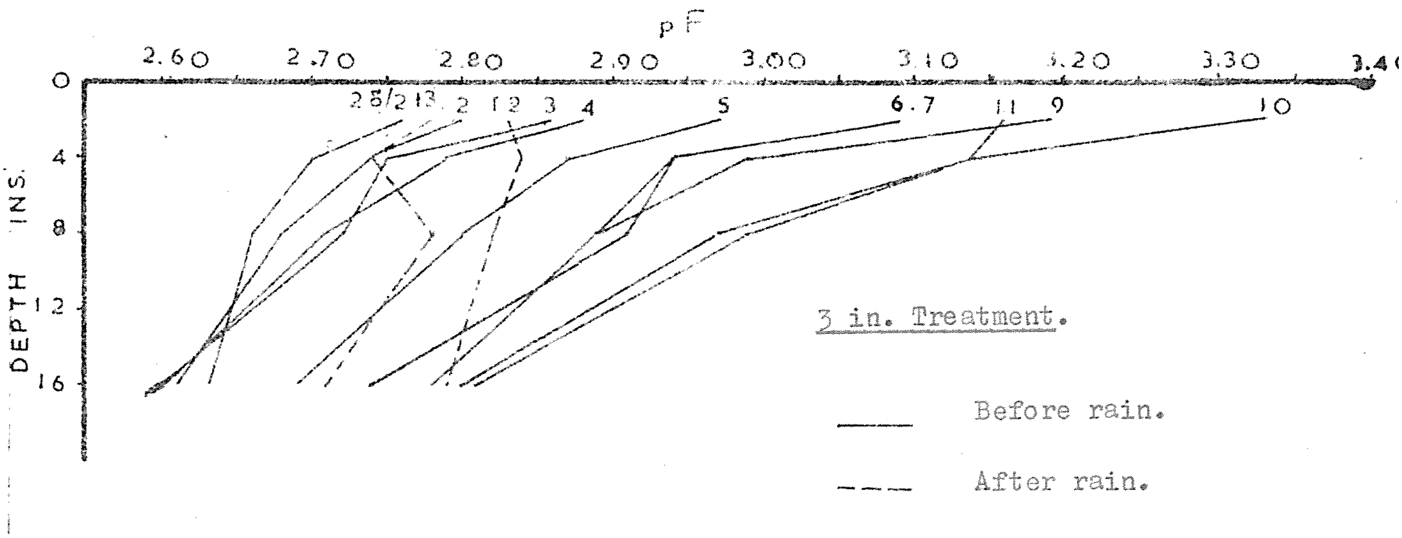
D. Moisture loss from the Soil.

(i) Examination of the 2 in. - pF curve in Fig. 13 shows a steady reduction in available soil water above field capacity until pF 3.30 - 3.40 was reached. On Jan. 24th, this pF was achieved after 10 rain-free days, during which time there had been a steady and significant loss of moisture from the soil. However, over the subsequent five days there was no significant change in soil moisture status. This observation is discussed below in terms of the plants' ability to remove water retained in the soil at greater tensions.

(ii) It was possible, because considerable differences in L.A.I. between the two treatments coincided with periods of soil moisture loss, to observe the effect of pasture cover on the rate of moisture loss from the soil. The widest fluctuations in pF occurred at the 2 in. depth. Therefore it was likely that this depth would be most sensitive to any treatment effects. The initial and final pF values at the 2 in. depth, of the four periods examined, are given in Table 11. The initial and final estimates for these periods, obtained by interpolation or extrapolation of the L.A.I. curves in Figs. 7 and 8 are also given in Table 11.



Approx. Range of L.A.I. of sward
(2.00 - 4.75).



Approx. Range of L.A.I. of sward
(0.75 - 2.75).

FIG. 14. pF - curves for Soil Profile for period 28 Feb. - 13 March.

TABLE 11.

pF and L.A.I. values for the first and last days of four periods of increasing pF values.

DATE	3 in.		6 in.	
	pF	L.A.I.	pF	L.A.I.
18-29 Jan.	2.80 - 3.37	1.2 - 2.8	2.78 - 3.39	1.5 - 3.8
3-10 Feb.	2.81 - 3.31	0.3 - 1.7	2.84 - 3.27	4.0 - 4.4
13-18 Feb.	2.78 - 3.12	2.0 - 2.5	2.76 - 2.86	0.2 - 0.8
Feb. 26-11 Mar.	2.73 - 3.16	0.4 - 2.3	2.72 - 3.23	1.8 - 4.4

Comparisons of the average treatment L.A.I. $\left(\frac{\text{initial L.A.I.} + \text{final L.A.I.}}{2}\right)$ can be obtained by inspecting Table 11. The treatment L.A.I. were similar for the period 18-29th Jan. but for the remaining three periods a difference of the order of 2 L.A.I. units existed.

The simple "t" test showed that there was no significant difference between treatments in daily pF values for three out of four periods.

A fuller analysis was undertaken for the remaining period 13-18th Feb. The analysis of variance on the pF data recorded on 18th Feb. is presented in Table 12.

TABLE 12. Analysis of variance of pF data for 18th Feb.

Source	SS.	d.f.	M.S.	F value	F required	Result
Blocks	0.0980	3	0.0327	1.73	10.10	N.S.
Treatment	0.2563	1	0.2563	13.56	10.10 (34.10)	*
$Error_1$ (B x Tr)	0.0566	3	0.0189			
Depths	0.9746	3	0.3249	49.23	3.16 (5.09)	**
Depth x Tr. (B x D)	0.1862	3	0.0621	9.41	3.16 (5.09)	**
$Error_2$ (B x D x Tr)	0.1189	18	0.0066			
Blocks within depths within plots.	0.1646	29	0.0057			
Total.	1.8552	60				

S.E. = $\pm$ 0.03.

The results of the analysis of variance shows that there are significant differences between treatments within depths and within treatments between depths. Further, the highly significant depth x treatment interaction indicates that the differences between treatments altered with depth.

The detectable difference between treatments at any depth (or between depths for any treatment) is given below:

$$d_{0.05} = 2.101 \sqrt{\frac{2(0.0066)}{8}} \qquad d_{0.05} = 0.08$$
$$d_{0.01} = 0.12$$
$$d_{0.001} = 0.16$$

Table 13 shows the level of significance between depths and treatments.

TABLE 13.

Significance levels of pF differences. (18th Feb.)

Treatment \ Depth	2 in.		4 in.		8 in.		16 in.
3 in.	3.12	***	2.94	**	2.81	***	2.65
			**		*		N.S.
6 in.	2.86	N.S.	2.79	*	2.70	N.S.	2.68

Figs. 12 and 13 illustrates the development of these differences over a period of approximately seven days as a result of differential rates of soil moisture loss under the two different pasture covers. 0.48 ins. rain fell after these measurements were recorded on 18th Feb. Table 14 shows that these differences had disappeared by 19th Feb

TABLE 14.

pF values recorded on 19th Feb., 1959.

Treatment \ Depth	2 in.	4 in.	8 in.	16 in.
3 in.	2.76	2.77	2.74	2.64
6 in.	2.75	2.76	2.70	2.69

E. Examination of the Number of Gypsum Blocks Required Per Site.

In this experiment two gypsum blocks were sited at each depth within each plot. It was decided to test the increase in efficiency which could be obtained by increasing the number of blocks per depth. Data used were obtained from the analysis of variance for pF values recorded on 18th Feb. (Table 12).

In this analysis M_B is an estimate of the variance of blocks within depths within plots (S_b^2), and, M_E is an estimate of the variance of ($S_b^2 + 2S_p^2$) where S_p^2 is the variance between plots at any depth.

Thus: $S_b^2 = M_B = 0.0057.$

$S_p^2 = M_E - M_B = 0.0066 - 0.0057 = 0.0005.$

as $S_b^2 > S_p^2$ greater advantage would be gained by increasing the number of gypsum-blocks per plot rather than the number of plots (replicates).

$$S.E. = \pm\sqrt{\frac{M_E}{r \times b}}$$

where r = number of replications of treatment

and, b = number of blocks per site.

$$S.E. = \pm\sqrt{\frac{S_b^2 + bS_p^2}{r.b.}}$$

If 2 blocks used,

$$S.E. = \pm\sqrt{\frac{0.0057 + 0.0010}{4 \times 2}} = \pm 0.03$$

If 4 blocks used,

$$S.E. = \pm\sqrt{\frac{0.0057 + 0.0020}{4 \times 4}} = \pm 0.02$$

If 1 block used,

$$S.E. = \pm\sqrt{\frac{0.0057 + 0.0005}{4 \times 1}} = \pm 0.04$$

The marginal increase in efficiency to be gained from increasing the number of gypsum blocks per site, would have been insufficient under these exprimental conditions, to justify the extra expense of installation and time spent recording and analysing results.

One block per site would have provided the necessary information but there would then have been no safeguard against failure of a block to operate during the course of the experiment.

P A R T VI

Root Yields.

At the conclusion of the experimental period it was decided to determine the distribution of roots in the soil. An examination of the root weights present in three soil horizons was made on the 27th March. The horizons measured were the 0-3 in., 3-6 in., and 6-12 in. It was anticipated that this information would be of value in explaining the differential removal of soil moisture with depth, by the growing plant.

The plot figures for dry weight of roots measured in gm./cm.^{3} soil for the three horizons are presented in Appendix 16.

The root distribution within the top 12 in. of the soil profile is shown in Table 15.

TABLE 15.

Percentage distribution of root yield based on dry weight.

Treatment \ Depth	0 - 3 in.	3 - 6 in.	6 - 12 in.	0 - 12 in.
3 in.	68.3%	16.6%	15.1%	100.0%
6 in.	66.5%	14.5%	19.0%	100.0%

Analyses of variance on the root weight data within each horizon are presented in the Appendices 17.1, 17.2, 17.3. The analyses failed to show any significant treatment effect within any horizon.

Further calculations estimated the root yield for the 0 - 12 in. profile to be 3732 lb. D.M. per acre under the 3 in. treatment and 4009 lb. D.M. per acre under the 6 in. treatment.

P A R T VII

Estimation of Soil Moisture Deficit.

Certain interest has developed, following the work of Penman and Thornthwaite, in estimating soil moisture deficits and subsequently irrigation needs from meteorological data. Calculated daily soil moisture deficit figures derived from Thornthwaite's formula for potential evapotranspiration, based on the meteorological records from Grasslands, were available for the period 6th Jan. to 24th March. These figures together with the daily potential evapotranspiration figures are presented in Appendix 19.

The method of obtaining these figures is described by Schwass (1959): ** "The soil moisture deficit curve is derived from.........
.........................when the moisture supply is restricted."
The relationship between the calculated soil moisture deficit and the measured pF values for each day was examined. Two periods each of twelve days were chosen for the analysis, viz. 17-28th Jan. and 25th Feb. - 10th March. The daily pF values used were obtained by averaging the two treatment means for the 2 in. and 4 in. depths. This would define the available soil moisture in the 0 - 6 in. profile where concentration of pasture roots is greatest.

Significant linear regressions were obtained for measured pF on calculated soil moisture deficit. The regression lines are shown in Fig. 15 and the results of the analyses in Appendices 20.1 and 20.2. Other points, obtained over the period 6th Jan. - 24th March, but not included in the regression analysis, have also been plotted on Fig. 15.

There is a close relationship between measure pF and calculated soil moisture deficit. Under these conditions the calculated soil moisture deficit appears to have overestimated the actual deficit

**

"The soil moisture deficit curve is derived from the reduction to a daily basis of the formulae for potential evapotranspiration (Thornthwaite, 1948), modified to New Zealand conditions by Gabites (1956). A similar method applied to irrigation problems in mid-Canterbury has been reported by Rickard,(1957).

The method involves the use of maximum and minimum air temperatures and the day-length to compute the daily "water need" of plants; the successive daily values are summed as an increasing deficit which is reduced by rainfall as this is recorded. The deficit is assumed to be zero when the soil is at field capacity and 2.5 inches when wilting point has been reached. The daily deficit is reduced as the cumulative total exceeds one inch to make a purely arbitrary allowance for the effect of higher soil moisture tensions on plant growth (for example, see Closs, 1956). No allowance is made for the soil becoming wetter than field capacity through heavy rain.

Many assumptions are made in the computations. The air temperatures measured in the standard Stevenson screen are not those at ground level, while the 24-hourly temperature march between maximum and minimum will rarely be symmetrical. Other meteorological elements such as wind and dew must affect evapotranspiration (Rickard,1957) but are ignored. No account is taken of soil type, the nature or condition of the vegetative cover (Mitchell and Closs, 1958), or possible plant physiological mechanisms for regulating water loss when the moisture supply is restricted."

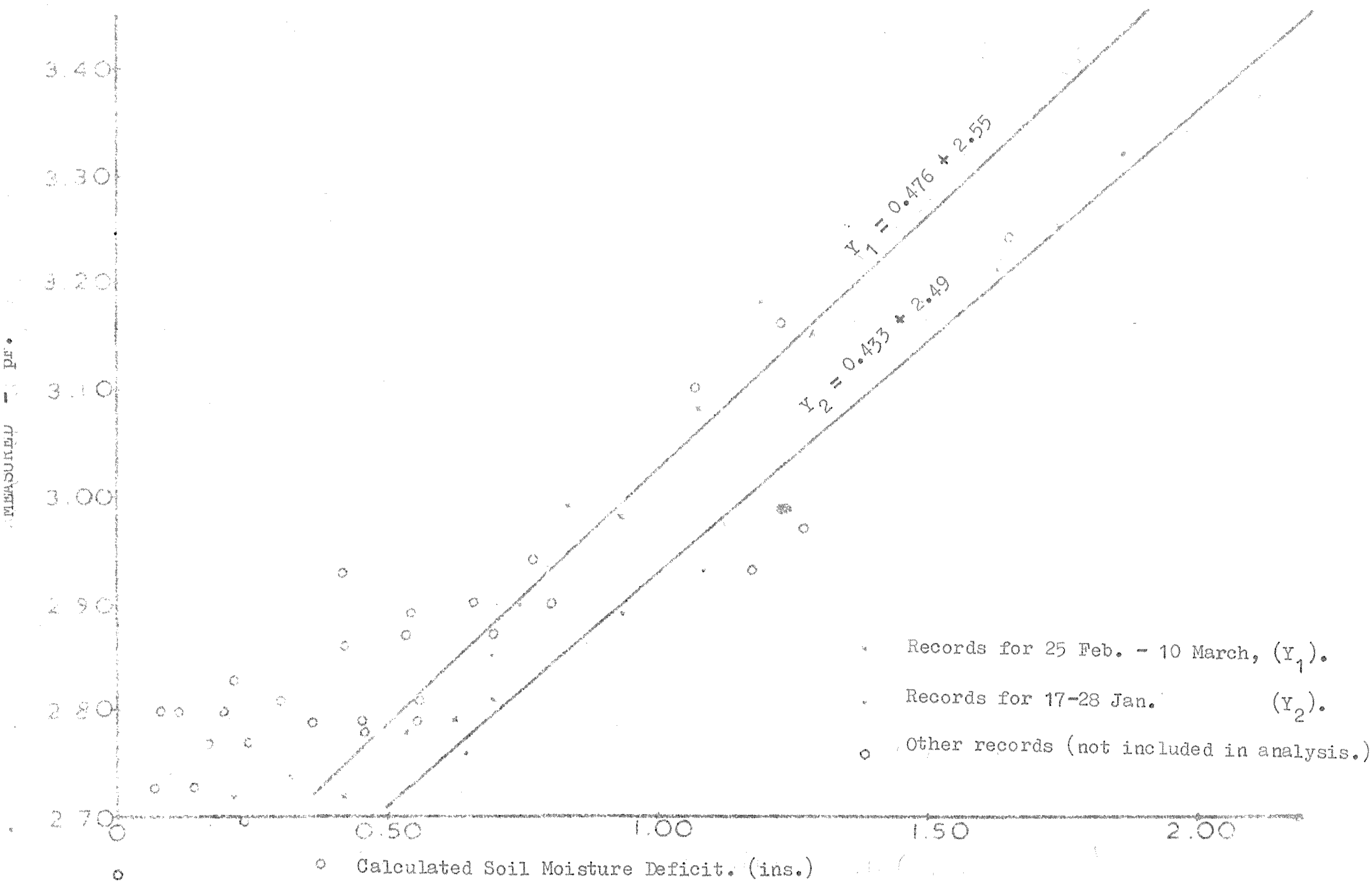


FIG. 15. Relationship between measured pF and calculated soil moisture deficit.

present. This error is due in part to the assumption that the soil returns to field capacity following sufficient rain to replenish the accumulated moisture deficit, whereas in practice, the soil may become wetter than field capacity. An overall regression based on all points recorded during the experiment would have emphasised this source of error, and therefore, it was decided to obtain an indication of the relationship over two drying periods only.

P A R T VIII

Meteorological Data.

The meteorological data have been prepared, from the records of the Grasslands Division Meteorological Station, for weekly intervals over the experimental period. The station is situated approximately half a mile from the site of this experiment.

An analysis of the minimum grass temperature, maximum and minimum air temperature and soil temperature measured at 4 in. depth has been made and is presented in Fig. 16. Weekly totals for sunshine hours, rainfall, evaporation from a free water surface are presented in Fig. 17. These results have also been presented in Appendix 18.

The monthly rainfall data for the period of the experiment, together with the average figures taken from Grasslands' Division records over the period March, 1928 - May, 1955, have been tabulated in Table 16.

TABLE 16.

Monthly rainfall for 1958-59 and 1928-55. (ins.)

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
1958-59	5.85	2.57	2.91	5.84	0.50	2.34	1.31	6.68	6.36	2.89	3.59	40.84
1928-55	3.29	4.31	3.09	3.55	2.81	3.68	3.18	3.46	3.25	2.96	2.39	35.97

These figures show that the months of May, August, Dec., Jan. and March were much wetter than the 27 year average. Of the remaining months June, Sept., Oct. and Nov. were considerably drier.

The monthly sunshine hours for the period Sept. - March (inclusive) for the years 1955-56 and 1958-59 are given in Table 17. Approximate daily averages of solar radiation for each month interpolated from data published by Brougham (1959) have also been presented.

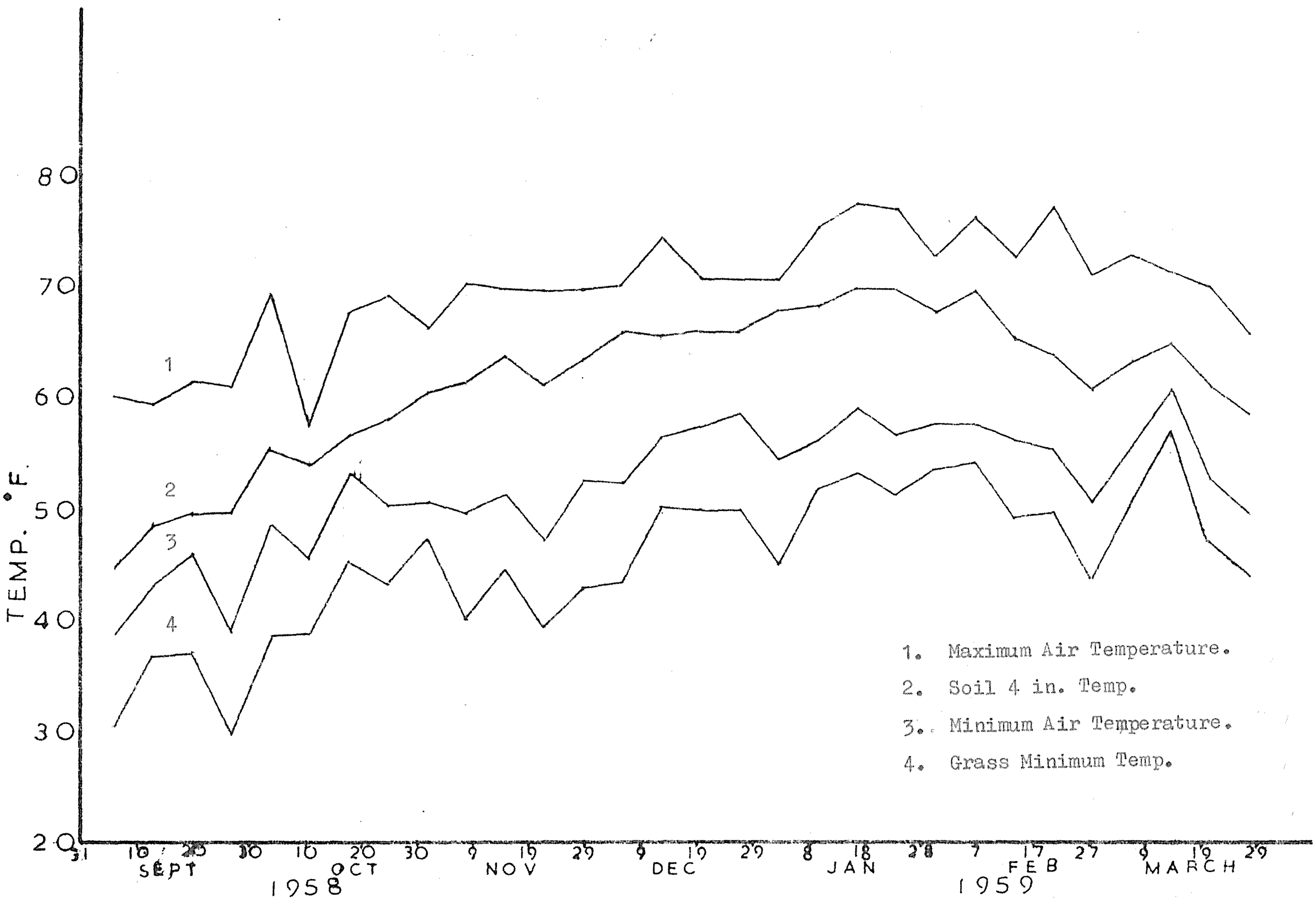


FIG. 16. Temperature data based on weekly means for experimental period.

(From Grasslands Divisions Records.)

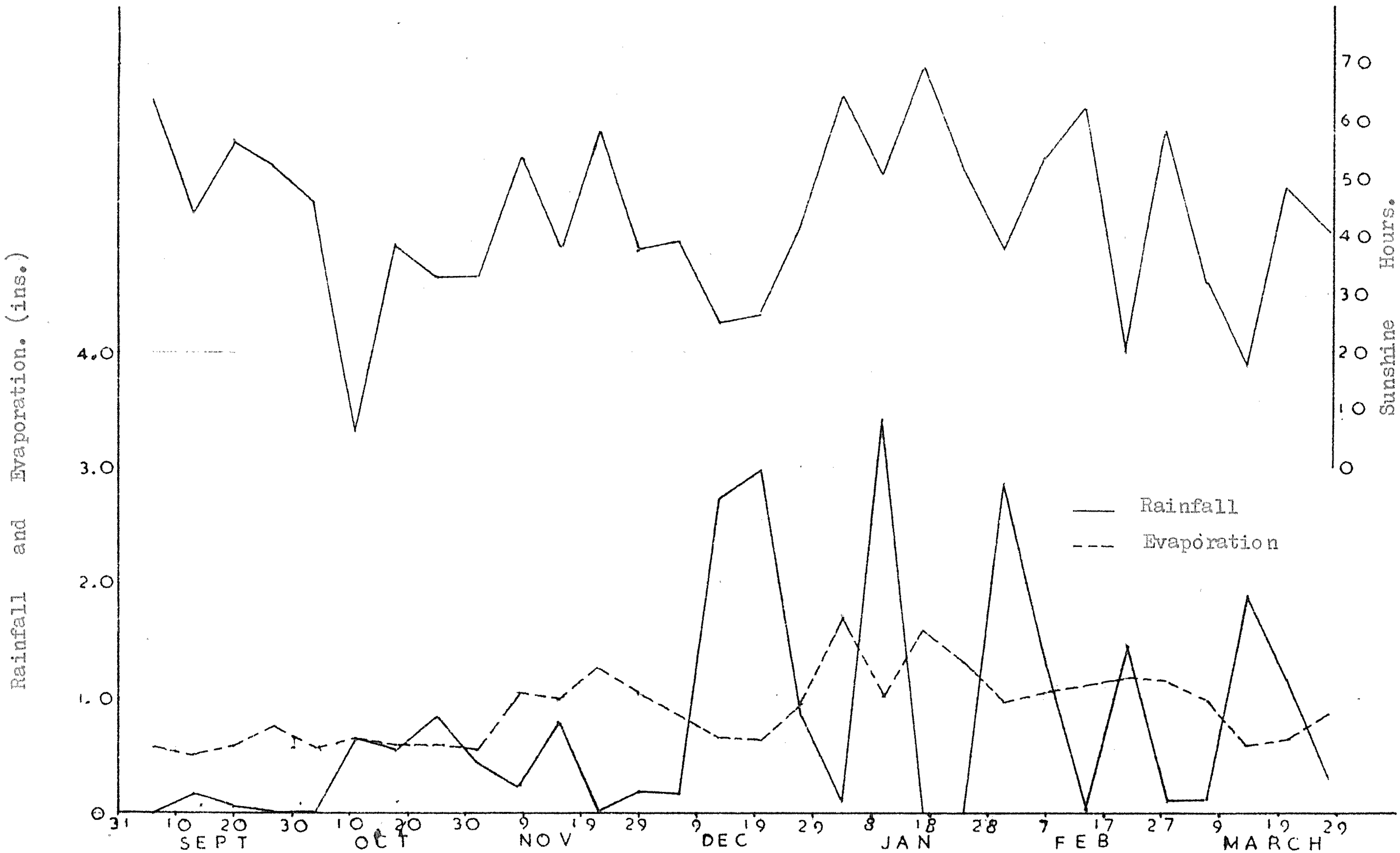


Fig. 17. Weekly figures for rainfall, evaporation and sunshine hours for the experimental period.

(From Grasslands' Divisions Records.)

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TABLE 17.

Monthly sunshine-hours and daily solar radiation figures.

a. Sunshine hours.								
Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
1955-56	109	185	166	243	154	157	185	1199
1958-59	229	143	199	156	233	196	164	1320
b. Average daily solar radiation estimates for each month.								
1955-56	250	400	450	500	475	400	350	cal./cm.^{2}/day.

The data collected by Brougham shows that the monthly sunshine-hours give an indication of the average daily quantity of radiation energy received. The 1958-59 monthly sunshine hours suggest that there would be little variation between months in the average daily levels of radiation. Lowest values would be expected in Oct., 1958.

Average daily anemometer readings for four particular periods are given in Table 18.

TABLE 18.

Average daily anemometer readings.
(wind-run miles per 24 hours.)

Date	Average daily readings.
18-29 Jan. (incl.)	120
3-10 Feb. (incl.)	111
13-18 Feb. (incl.)	174
26 Feb. - 11 Mar. (incl.)	137

These figures are probably conservative estimates due to the sheltered site of the recording instrument.

P A R T IX

Pasture Diseases and Pests.

A. Crown Rust.

Crown Rust (*Puccinia coronata*)was first reported on perennial ryegrass in New Zealand by Cunningham (1922). Cruickshank (1957) reported that the disease was widespread throughout New Zealand pastures and usually occurs in the late summer and early autumn of a warm dry year. From field observations and trial work he noted that it may be an important factor in affecting herbage yield as well as rendering the pasture unpalatable to stock.

Crown rust was observed on the plots during January. Reference to Fig. 17 indicates that conditions had been relatively dry prior to this date, since Sept; therefore providing suitable environmental conditions for crown rust. The incidence appeared to be more severe when pasture growth was more advanced, (i.e. on the 6 in. treatment). It is suggested that crown rust may have been responsible for the reduction in dry matter and leaf area growth noted in the latter stages of curve Ia.

B. Incidence of the Lucerne Flea.

Small damaged areas were observed on clover leaves taken from the plots during January. Examination of these leaves under a microscope showed that green mesophyll tissue had been destroyed leaving the veins and leaf cuticle remaining. This is typical of the injury caused to leaves of Leguminoscae by the lucerne flea, (*Smynthurus viridis*). The presence of the lucerne flea was confirmed when some of the insects were later caught and identified, (Gurr, 1959).

It is suggested that two factors were primarily responsible for encouraging the infestation of these plots by the lucerne flea:

1. Microenvironment of the pasture favoured the lucerne flea.
2. The absence of the grazing animal allowed numbers to build up to proportions beyond those normally found in a grazed pasture.

Dumbleton (1938), suggested that heavy stocking reduced the infestation through trampling and opening up the sward, thereby rendering the insect more susceptible to heat and dryness.

C H A P T E R V

DISCUSSION.

This section will be presented in six parts:

I. The Experiment.

II. Prevailing Climatic Conditions and Pasture Growth.

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P A R T I

The Experiment.

The experimental treatments used represent two possible grazing systems to which a perennial ryegrass/white clover pasture may be subjected during its first twelve months of growth. The conclusions drawn from this work are strictly applicable only to sheep-grazed pastures of the same botanical composition, growing under similar climatic conditions and on a similar soil type. Although the change from grazing to cutting in January may have had an effect on the pasture itself, it should be possible to apply certain conclusions to grazed sheep pastures.

The late sowing date reduced the opportunity for pasture growth prior to the winter months, thereby delaying establishment. Normal pasture sowing date for this district is towards the end of March. (Brougham, 1954).

Sheep were used to defoliate the plots during the intermediate period. In this way the selectivity of grazing as compared with cutting was introduced. The treading effect of the grazing animal assisted pasture establishment. The natural return of dung and urine avoided the need for allowing clippings to decay on the plots, or the removal of clippings and replacement of nutrients lost in this way with artificial fertilisers or collected animal excreta.

However, after four months the difficulties of using the grazing animal on small plots were apparent. Uneven grazing, particularly the avoidance of excessive growth over urine patches left a non-uniform sward for sampling. A trimming-cut after grazing failed to substantially reduce variability of pasture growth.

Two alternatives were possible to overcome this problem. The first was to increase the number and/or size of samples per plot, and the second alternative was to change to cutting, thereby eliminating the stock grazing variable. The second alternative was chosen and the plots were cut with a rotoscythe from Jan. to March (incl.) This reduced the variability of pasture growth on the plots.

The incidence of crown rust, which reduced the palatability of the grass would in any case have increased the difficulties of using sheep to defoliate the pasture. There was no indication of possible effects on growth form of the pasture plants which could be attributed to the change to cutting. It is probably that continued grazing would have reduced the incidence of the lucerne flea.

An accurate assessment of pasture height to gauge the time of grazing was difficult. The height of the pasture canopy varied considerably over the plots and grazing time was based on the average of several random readings from each of the four plots. Each reading was based largely on the height of the clover canopy, except where that canopy was ill-defined and the average grass leaf height had to be taken. This must be regarded as essentially a subjective method of measurement.

Difficulty was experienced in keeping the number of 3 in. grazings in direct proportion to the number of 6 in. grazings. Eventually this procedure had to be abandoned and consequently it has not been possible to make direct comparisons of yield and L.A.I. between treatments continually throughout the experiment. It should be noted that the intermediate period is six days longer under the 3 in. treatment. In order to obtain a direct comparison of treatment yields over the final two weeks, the last growth period under the 3 in. treatment was extended by seven days beyond the 3 in. height.

When pasture height is used to determine the time of cutting or grazing of each treatment, then considerable difficulty will be experienced in attempting to manage all plots so that they can be cut or grazed simultaneously.

The modified Australian difference method of estimating plot yields was not entirely satisfactory. This could largely be attributed to the unevenness of grazing and non-uniform recovery growth. The S.E. of the treatment mean based on eight samples per treatment ranged between 2% and 10%. The highest S.E.'s were obtained at the post-grazing cut.

PART II

Prevailing Climatic Conditions and Pasture Growth.

An indication of possible climatic limitations to plant growth can be obtained from inspection of the meteorological data provided in section VIII of the Ch. IV.

Low rainfall was recorded during the months of Sept., Oct., and Nov. However, heavy Aug. rains would have placed the soil at or above field capacity, and this together with the rainfall experienced during the following four months would probably have been sufficient to keep the soil moisture level adequate for good pasture growth. Between Jan. and March (incl.) there was sufficient rainfall to keep the soil moisture status below pF 3.4 The results of other workers, reviewed in Chap. II, Part III, suggest that growth is not limited appreciably at pF levels about or below 3.4.

Fig. 17 illustrates the considerable variation in weekly sunshine hours. Monthly sunshine-hours give an indication of the average daily solar radiation experienced during that month. Inspection of Table 17 suggests that low daily solar radiation values were obtained in Oct. and probably Dec.

The 4 in. soil temperature curve (Fig. 16) commenced at a weekly mean of 44.5°F. in Sept. and rose to a maximum of 69.5°F. in Jan., then declined to 58.5°F. in March. It is unlikely that soil temperatures between Sept. and March would unduly check pasture growth as Gloyne (1950) observed that soil temperatures above 42.0°F did not check germination and active growth of grasses. On the other hand it is unlikely that maximum soil temperatures, sufficient to inhibit growth, were reached.

The weekly mean maximum air temperature rose to 70.5°F.

in the New Year from a Sept. value of 60.0°F. having remained about 70.0°F. for Nov. and Dec. Subsequently the temperature ranged from 70°F - 77°F. until late March when it commenced to decline.

The weekly mean minimum air temperature rose from 40°F. in Sept. to 55.0°F. in early Dec. After this it fluctuated between 55.0 and 60.0°F. until falling again in late March.

Controlled climate studies by Mitchell (1956) show that the most favourable temperature for growth of perennial ryegrass is 60°F. but that the rate of growth is relatively constant over the temperature range 55°F - 85°F. On the other hand, white clover has a favourable range of 65°F. - 85°F. and an optimum growth temperature of 75°F.

The temperature data indicates that mean air temperatures until the end of Dec. were likely to favour grass growth, but after this date both grass and clover growth would be favoured.

PART III

Population Changes of Grass and Clover Tillers.

Definite trends in tiller densities were observed in this experiment. The absolute tiller densities recorded are low compared with those obtained for an established sheep pasture by Mitchell and Glenday (1958).

Fig. 10 illustrates the decrease in grass tiller desnity over the Aug. - March period, which was accelerated under the 6 in. grazing treatment. This trend was apparently reversed following the March sampling as a tendency for tiller density to increase was evident at the June sampling. By contrast, the clover node population rapidly increased from Aug. to Nov. and then more slowly until March, after which numbers were stationary until June, 1959. This changing balance of grass/clover tillers with a spring grass maximum and declining to low autumn figures, paralleling an increasing clover tiller population from spring to an autumn maximum, is reported by Mitchell and Glenday (1958) from a study of a short-rotation ryegrass/white clover pasture.

Two compatible explanations of the declining grass tiller population can be put forward. The first is that the competitive - advantage of the clover increased towards March thereby accelerating the rate of senescence and decay of grass tillers in relation to the rate of tiller formation. The second explanation postulates a seasonal decline in grass tiller numbers independent of the presence of clover in the sward. Individual plant and pure sward studies by Schwass (1955) and Langer (1956, 1958), on several grass species have produced supporting evidence.

Schwass (1955) considered that an explanation in physiological terms, of changes in the number of tillers per grass plant appeared most likely per medium of the phenomenon of apical dominance. Changes in grass tiller density in a sward may be similarly explained. This phenomenon is defined as the limitation or complete inhibition by a vigorous terminal bud of the development of lateral buds. Removal of the terminal bud permits one or more of the lateral buds close to the top of the stem to commence development or grow with increased vigour. Once growing vigorously these in turn will limit the growth of the lateral buds below them. Mitchell (1953) found that the development of lateral buds was hindered by a rise in temperature, decline in light quantity, or partial defoliation of the plant.

Langer (1958) points out that the tiller decline comes at a time when conditions are most favourable for active dry matter production. The same observation is made by Schwass (1955) and the results of this work also support that conclusion.

Schwass (1955) suggests that the active growth of the apical meristem during the spring and summer places heavy demands on the supply of energy substrate required for merestimatic activity. Consequently lateral tiller growth is suppressed or inhibited through starvation. However, during winter when leaf growth is greatly reduced, the demand for metabolites by the central tillers is not so strong, thereby allowing initiation and development of lateral tillers.

The rise in soil and air temperatures during the period of the grass tiller population decrease could also be of significance for Mitchell (1953) found in controlled climate studies that the development of lateral buds of the ryegrasses was reduced by a temperature rise from 57°F. to 72°F. Fig. 15 illustrates that a rise in mean air temperature of a similar order (15°F.) took place between Sept. and Feb. It is likely that the temperature of the actual microenvironment at the plant base i.e. the region of tiller initiation;

would be appreciably higher during summer than the air temperature as measured in a standard Stevenson screen four feet above the soil surface. Therefore the effective temperature rise may have exceeded the rise indicated by the mean air temperature. Another possible factor responsible for the decrease in tiller density is the tendency for tillers to grow more erect under warmer temperatures and therefore become more susceptible to defoliation. (Mitchell, 1956).

The change within the plant from a vegetative to reproductive state may also account for lower tiller densities in the summer and Langer (1958) has suggested a need for further experimentation along these lines.

Any theory advanced in explanation of the decline in grass tiller numbers must also be reconciled with the observed slower decline under the 3 in. grazing treatment. Langer (1959), and, Baker and Garwood (1959), found that grass tiller numbers declined under a frequent grazing system. It is probably that the longer period of uninterrupted growth permitted under the 6 in. treatment, encouraged the expression of apical dominance thereby furthering the suppression and inhibition of lateral tiller formation.

The location of the dead and dying tillers cannot be stated with any certainty. The observations by Schwass and Langer on individual plants suggests that each plant would lose a limited number of tillers. On the other hand, the loss of tillers through the death of complete plants within the sward cannot be ignored. Such a theory is not entirely compatible with the view that the tiller is the pasture unit. However under certain conditions, the plant must be regarded as a pasture unit composed of a group of tillers as the "ultimate" or smaller units. Particularly is this the case during the early months of pasture establishment for, at this stage, the identity of the plant is more important than in later years when a good ground cover of tillers is obtained. The reaction of the plant as a whole rather than individual tillers, to certain environmental conditions has already been noted by Mitchell and Coles (1955). The presence of clumping on the plots illustrates that tiller cover of the ground was far from complete and suggests that under the existing conditions the individual grass plant could well be a definable unit.

There was a marked increase in the coefficients of variation of grass tiller numbers per plug as the experiment advanced. (Appendix 14). Both the loss of tillers from individual plants and the death of complete plants would increase the variability of the estimates, but the latter cause would probably be a more potent force in this increase. This increased variability could also be attributed to some plants being more prone to lose tillers than others.

The count of clover nodes taken at the end of the establishment period was virtually one of single plants as stem elongation had not commenced. Low temperatures and inter-specific competition for light probably delayed clover growth. The leaf area measurements at the beginning of Oct. showed that there had been very little further development of the clovers. However, prior to the November count there was a considerable increase in clover development through stem elongation and rooting at the nodes. Reference to Fig. 14 shows that there was a rise in soil and air temperatures between 2nd. Oct. and 19th Nov., which resulted in the achievement of temperatures more favourable for clover growth.

The possibility of grass growth reducing the levels of available - nitrogen in the soil and thereby favouring clover growth in inter-specific competition must not be overlooked.

The high light requirements of the clover plants were emphasised in Ch. II. It is probably that during late spring the light requirements of the plant were more immediately satisfied under the 3 in. treatment where the period of grass shading was shorter than under the 6 in. treatment. Flagging of grass leaves under the 6 in. treatment would reduce the available light for clover growth. Consequently, a greater number of clover nodes was counted under the 3 in. treatment ($p = 0.09$). Baker and Garwood (1959) noted a similar delay in the increase of the clover node population under the tall pasture compared with the more frequently grazed pasture. There was no treatment effect at subsequent samplings suggesting that once established the clover was able to successfully compete with the grass in both swards.

The clover tiller distribution diagrams in Fig. 9 give a picture of the method by which clover plants colonised the sward. A random distribution of clover plants within the plots was found at the Aug. sampling. Evidence of a loss of randomness is shown in the diagrams for the Nov. and Jan. samplings. This probably can be attributed to the stem elongation and node development of the clover plants during these months. Colonisation of the sward proceeded radially from the randomly distributed clover plants of the Aug. sampling. The colonisation-phase was indicated by the presence of considerable clumping of nodes at the Nov. and Jan. samplings. It was judged that this phase was complete once the random distribution of clover nodes within the sward had been achieved in March. Supporting evidence of this change from single isolated plants to large numbers of nodes attached to these "parent" plants is given by the increase in clover density from 12-13 plants per sq. ft. in Aug. to 69-79 plants per sq. ft. in March.

The trend from dominant ryegrass in Aug. to dominant clover in March and even extending into June is illustrated in Fig. 9

In Aug. the grass tillers were evenly spread throughout the swards but by March this distribution had partially disappeared and an even distribution of clover nodes was obtained. This change occurred during Nov., Dec., and Jan.

The use of clumping indices on the tiller distribution data has been discussed above. These results suggested that an index which assumed that the grass tiller distributions fitted a Poisson model was unsatisfactory. It is suggested that the grass tiller distribution is a contagious one. (Bliss and Calhoun, 1954). On the other hand, the assumption that the clover node distributions fitted the Poisson model and the use of indices based on a test of the departure from this model was satisfactory.

P A R T IV

Leaf Area and Dry Matter Yields.

Prior to the first grazing in Sept. the plots had achieved a L.A.I. 2.56 with a grass/clover leaf area ratio of 88:12. Comparison with the optimum L.A.I. estimates made by Brougham (1958) for several species, suggests that an optimum L.A.I. had not been reached at the time of grazing. These figures emphasise the slowness of pasture establishment and the importance of grass in the sward at this stage. After one month's growth following two grazings of the 3 in. treatment plots and one of the 6 in. treatment, the swards had attained L.A.I. values of 2.02 and 3.95, respectively.

A linear regression of L.A.I. on time (days after defoliation) was obtained, under both treatments, from data collected during the final period. Failure to obtain an exponential increase in leaf area following defoliation may be attributed to lack of experimental precision. There was a tendency under the 6 in. treatment for the rate of leaf area increase to decline once a L.A.I. of 3.75 - 4.60 had been achieved. Brougham (1958) termed this the critical L.A.I. and found it to vary considerably with species. The critical L.A.I. for white clover was considerably below that of the grasses. The trend noted under the 6 in. treatment could be explained in terms of complete light interception by the pasture canopy at the critical L.A.I., thereby introducing inter-and intra-specific competition for light with a subsequent reduction in the rate of leaf area expansion. Under the 3 in. treatment the critical L.A.I. was not reached. Failure to achieve the critical L.A.I. in cycle III may be attributed to the percentage of grass present in the sward. The light-interception capacity of clover leaves (area for area) exceeds that of grass leaves

(Brougham 1958) and consequently in the case of cycle III where grass forms a large % of the total leaf area of the sward the critical L.A.I. is raised, whereas the higher % of clover under the 6 in. treatment lowers the critical L.A.I.

The rate of leaf area growth as determined from the regression lines was similar under both treatments. The actual leaf area at any one time is a function of both rate of growth and length of the growing period.

There was a tendency for L.A.I. measured immediately after defoliation to be similar under both treatments.

The total leaf/stem ratios and those of the clover components are presented in Figs. 7 and 8. In the grass spp. leaf growth following defoliation is much more rapid than stem growth which results in a large proportion of leaf to stem after several weeks' growth. On the other hand the leaf/stem ratio of clover remains relatively stable ranging from 1:1 to 3:1. This low clover ratio is a reflection of the growth form of the plant, requiring as it does a considerable petiole to elongate and allow successive leaves to open above the canopy. Brougham (1956) found that the percentage of leaf ranged from 49.7% to 68.1% of the total herbage. In this experiment, the percentage leaf ranged from approx. 20%, to 80% under the 3 in. treatment, and 75% under the 6 in. treatment. Maximum values were reached after 21-28 days and thereafter decreased, a point found also by Brougham (1956). In this experiment the decrease could be attributed to the increase in percentage weight of the clover petiole as the pasture height increased. (Brougham 1958).

Sears (1956) has discussed, from the viewpoint of pasture and animal management, the desirability of maintaining a satisfactory grass/clover balance in the sward, without allowing clover to dominate. He stated that summer spelling pastures usually results in clover dominance. Prior to January the plots, under both treatments, were grass dominant. Subsequently a 50:50 ratio was quickly achieved following defoliation, but a further swing to clover dominance was noted in the tall pasture, which could be attributed to the longer spelling period. The clover dominant sward of the 6 in. treatment and the balanced pasture obtained under the 3 in. treatment, photographed on 17th March are shown in Fig. 18. A significant increase in L.A.I. within the 3 in. height between Oct. and March samplings was obtained. This could be attributed to an increase in clover leaf as there was no change in the grass L.A.I. Although not significant the same trend was evident under the 6 in. treatment. In this case there was a significant increase in clover L.A.I. between Oct. and March but a tendency for the grass L.A.I. to decline. An approximate between-treatment comparison at the 3 in. height showed no effect of treatment on spatial density.

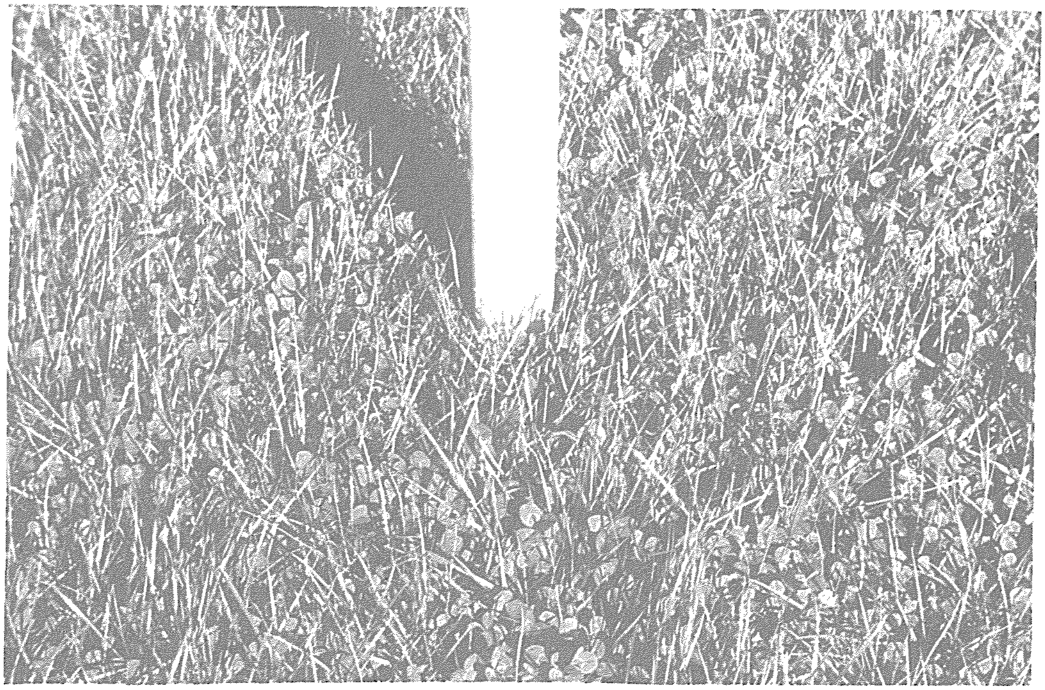
The increase in spatial density between Oct. and March could be attributed to either the change in botanical composition through the increase in clover or to the normal development of an establishing pasture.

The constancy between dates of the grass L.A.I. under the 3 in. treatment, despite the decline in tiller numbers, is in keeping with the observations of Schwass (1955) who found a negative correlation between leaf yield and tiller numbers of perennial ryegrass plants. It is probably that the 6 in. treatment follows the same pattern.

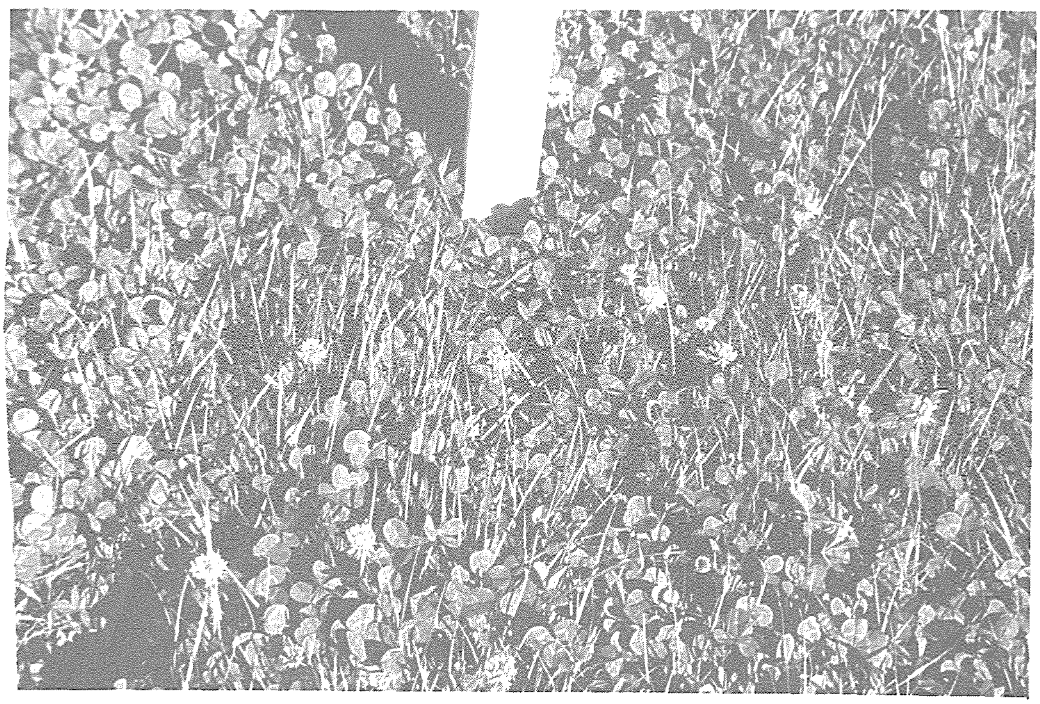
The increase in clover L.A.I. can be attributed largely to the increased population of clover nodes from spring to autumn.

FIGURE 18.

3 inch Treatment, March, 1959.



6 inch Treatment, March, 1959.



Herbage production under the two treatments for each of the three experimental periods is shown in Table 5. 1340 lb. D.M. per acre was produced during the 18 week establishment period. No affect of grazing frequency was found on production during the intermediate 17 week period. During the following ten weeks the tall sward significantly ($p = 0.05$) outyielded the shorter pasture.

The lowest average weekly dry matter production was recorded during the establishment period and the highest during the following 17 weeks, with the final period intermediate. These trends applied to both treatments although the difference between the intermediate and final periods was greater under the 3 in. than the 6 in. treatment. Weekly production figures and average R.G.R. were lower under the 3 in. treatment during the final period as compared with the intermediate period. The average R.G.R. values recorded under the 6 in. treatment from Sept. - Dec. were lower than the Jan. - March estimates.

Total yield for any given period is a function of R.G.R. and length of the uninterrupted growth period. Therefore, despite the lower average R.G.R. estimates recorded under the 6 in. treatment during the intermediate period, and because of the longer spell between grazings, these plots equalled the yield of the 3 in. treatment.

The main climatic differences between the intermediate and final periods lay in the higher soil and air temperatures of the final period which encouraged vigorous clover growth.

A linear regression of dry matter production on time (days after defoliation) was obtained. Failure to obtain an exponential increase in yield following defoliation is attributed to lack of experimental precision. Such a curve may have been obtained with more frequent and intensive sampling. It is suggested that the length of the growing period between defoliation was insufficient under both treatments to enable the signoid pattern of growth described by Brougham (1955) to be obtained.

A significant linear regression for each treatment was established for D.M. yield on L.A.I. Watson (1947) investigating the growth of field crops including wheat, potatoes, and sugar beet, and Brougham (1956) who undertook a similar study on short-rotation ryegrass/red and white clover pasture, established similar relationships. The treatment regression lines were similar. (Fig. 9). Failure of these lines to pass through the origin may be attributed to the considerable weight of stem and other non-leafy material below sampling height, which was not measured.

PART V

Root Yields.

Root yields within the 0-12 in. profile were similar under both pastures being 3732 lb. D.M. per acre under the 3 in. treatment and 4009 lb. D.M. per acre under the 6 in. treatment. The distribution of the roots among the different horizons within the 0-12 in. profile follows the general pattern of pasture root distribution found by other workers. (Jacques, 1943),(Troughton, 1951), (Low and Armitage, 1959.; Baker and Garwood, 1959). Approximately 67% by weight, of the roots were found in the 0-3 in. horizon and 16% in the 3-6 in. horizon and the remainder in the 6-12 in. horizon. The assumption that root penetration below 12 in. was not great in terms of dry weight of roots recovered, appears likely to be valid in view of the rapid decline in root material with depth. Under these conditions the different frequencies of pasture defoliation had no significant treatment effect on the root weights recovered from each of the three horizons measured. This agrees with the findings of Baker and Garwood (1959), although other workers have found treatment effects.

P A R T VI

Soil Moisture.

Earlier in this discussion it was concluded that there was generally adequate water for plant growth throughout the experiment. Assuming active growth continues, then a steady pF increase would be expected as a result of water loss through transpiration. An apparent contradiction of this assumption was observed at the 2 in. depth, for pF values remained stationary between pF 3.32 and pF 3.40 for six days (24-29 Jan.) following a steady daily pF increase. No affect on D.M. production was observed by inspection of curves I and Ia in Fig. 5. It appeared that plants were able to satisfy their requirements from regions with a lower pF than was found in the 2 in. layer.

Examination of the pF curves in Fig. 12 and 13 illustrates that water is removed more rapidly from the upper than from the lower depths. Water removal from the soil may occur through drainage, evaporation from the soil surface, or transpiration through the plant.

Once the soil has dried to field capacity drainage losses will be virtually nil. Therefore soil moisture losses from soils drier than field capacity will occur primarily through evaporation or transpiration. However, if the soil surface has a complete foliage cover it is likely that direct evaporation losses will be negligible. Under these conditions the major channel for removal of water from the soil would be through the plant. The differential rate of water loss from the soil horizons would be associated with the water absorption activity of the roots in each horizon. Root activity is greatest under conditions of high soil - O tension and low CO_2- tension. (Gingrich and Russell, 1956; Mitchell and Butler, 1956). The most favourable conditions for root activity, when moisture is ample, prevail near the soil surface rather than at greater depths. It is suggested that the quicker drying out at the lesser as compared with the greater depths, can be attributed to the greater concentration of root material and the more favourable conditions for root activity near the soil surface. As the soil moisture tension of the upper horizons increases with water removal, the roots then take up water from a greater depth where the tension is less. Removal of water from the soil pores permits percolation of soil - O to greater depths allowing greater activity of the deeper roots. This progressive increase in water removal from the soil at greater depths, as the soil moisture tension increases, is well illustrated in Fig. 14.

Jacques (1956) pointed out that older grass roots in the upper layers of the soil lost much of their absorptive capacity during summer through sloughing of the cortex and suggested that most of the summer water absorption took place in the roots present in the deeper soil layers. Secondary root hairs, reported by Jacques (1939, 1956), to have developed from the cortical epidermis at the proximal end of the root, may absorb quantities of water. Jacques (1956) mentions the development of a new vigorously absorbing root system from the crown of the plant, following autumn rains. These new roots grow quickly from dormant primordia at rates up to ½ in. per day. (Jacques, 1959). Therefore the secondary root hairs, and the developing root system together, may have been responsible for the removal of water from the upper horizons.

Little is known of the rooting system of clovers in relation to water absorption. Jacques (1943) places the distribution of clover roots in the upper soil horizons at a slightly higher figure than the ryegrass roots.

The general removal of moisture from the soil through the transpiration of plants has been discussed.

The L.A.I. is a measure of the transpiring surface of a pasture and therefore, neglecting evaporation losses, more rapid removal of moisture from the soil would be expected to occur under a high L.A.I. than a low one.

On three occasions during the final period there were marked differences between treatments in the L.A.I. measured during the time of soil moisture loss. (Table 11.)

From 18-29th Jan. there was no marked differences between treatments in either L.A.I. estimates or pF-curves. On the following three occasions noted in Table 11, there were marked differences between treatments in L.A.I. estimates recorded. However, only the 13-18th Feb. period showed between treatment differences in pF - curves. (Figs. 13 and 14.) Analysis of these differences showed that they were significant at the 2 in. ($p = 0.001$), 4 in. ($p = 0.01$), and 8 in. ($p = 0.05$) depths, but not significant at the 16 in. depth.

It is difficult to attribute this apparent inconsistency in the relationship between L.A.I. and pF to any one factor. Estimates of the average daily potential evapotranspiration rates calculated according to Thornthwaite's formula were similar for all periods. (Appendix 19). Daily anemometer figures from Grasslands' Division showed that the average daily wind-run was higher over 13-18th Feb. than during the other periods. (Table 18.) The more rapid removal of water vapour from the pasture layer by wind, may have increased the quantity of water transpired by the high L.A.I. sward in relation to that lost through transpiration and evaporation from the low - L. A.I. sward.

Mitchell and Closs (1956) observed a similar relationship between pasture cover and soil moisture status in the spring. Later in the year (Jan.- March), they found that water loss was greater under the shorter pasture. Goode (1956) found that water could be conserved by close and frequent mowing better than under uncut pastures, which support the results of this experiment. Mitchell and Closs have suggested that the temperature of the leaf surfaces would be the same under the tall and short pastures, under certain conditions. However, as the area of leaves exposed to the air is greater in the long pasture than in the short pasture, more water should be lost from the long pasture. High wind velocities would accelerate this difference. The difficulty of the defoliated plant in extracting water from the soil, which was observed by Jantti and Kramer (1956) may also have been a factor in contributing to the measurements recorded on 13-18th Feb.

The achievement of a significant linear regression of measured pF on calculated soil moisture deficit, according to a modification of Thornthwaite's formula, for the range of data available, demonstrated the potential of this method for calculating irrigation requirements. One of the immediate difficulties, and afactor responsible for considerable error in these estimates, is that no allowance is made for the soil being wetter than field capacity through heavy rain. Another factor which will have to be considered in future work is the effect of vegetative cover on soil moisture status.

CHAPTER VI

SUMMARY.

1. A study has been made of the effect of two grazing treatments on the yield, leaf area index, and tiller population of a perennial ryegrass/white clover pasture.

2. Considerable difficulty was experienced in successfully managing sheep to defoliate the plots and during the latter stages the plots were cut with a mower.

3. Prior to January the treatments had no effect on yield, but during the final 10 weeks the 6 in. treatment outyielded the 3 in. treatment.

4. The average weekly D.M. increment was greatest between Sept. and Dec. (inclusive).

5. The grass tiller population showed a pronounced decline from a spring maximum to an autumn minimum.

6. The grass tiller density was less under the 6 in. grazing treatment than under the 3 in. grazing treatment.

7. The clover node population increased from spring to an autumn maximum.

8. The balance of species changed from grass dominance in winter, spring and early summer, to grass and clover as co-dominants in the autumn.

9. A linear regression of D.M. production on leaf area index was obtained.

10. A significant difference in the L.A.I. within the 3 in. treatment height was detected between the Oct. and March samplings. No significant difference was detected under the 6 in. treatment.

11. Following rain, soil moisture loss was greatest and most rapid at the shallower depths.

12. A linear regression of measured pF values on calculated soil moisture deficit indicated the potential of meteorological data as a basis for calculating irrigation requirements.

13. The treatments had no significant effect on weight of pasture roots or their distribution within the soil.

14. The perennial ryegrass was affected by Crown Rust and the white clover attacked by lucerne flea.

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LIST OF APPENDICES.

moisture deficit.

20. Analyses of regression of measured pF on calculated soil moisture deficit (ins.).

APPENDIX 1

The convential abbreviations used in the text are as follows:

N.S.	results not statistically significant.
*	results statistically significant at the 5% level.
**	results statistically significant at the 1% level.
F.	the variance ratio for specified conditions.
$d_{0.05}$	difference required between two means for that difference to be significant at the 5% level.
$\bar{x}$	mean value.
S.E.	standard error of the mean.
V	Coefficient of variation.
b	regression coefficient.
p	probability value.
s^2	variance.
d.f.	degrees of freedom.
SS.	sums of squares.

APPENDIX 2

Yields of herbage produced between grazings from September to March. (lb. D.M. per acre).

2.1. Intermediate period (3 in. treatment.)

Plot No. \ Grazing Period.	(1) 2 Sept. 16 Sept.	(2) 16 Sept 4 Oct.	(3) 4 Oct. 16 Oct.	(4) 16 Oct. 24 Oct.	(5) 24 Oct. 7 Nov.	(6) 7 Nov. 24 Nov.	(7) 24 Nov. 21 Dec.	(8) 21 Dec. 13Jan	Tot
1	324	670	687	224	476	501	1311	740	4933
3	471	514	535	*	333	926	1378	1590	5747
5	316	231	580	316	269	597	1320	1422	5051
7	284	674	932	152	216	806	1414	1258	5736
$\bar{x}$	349	522	683	173	323	707	1356	1252	5365

*On this date the post-grazing samples exceeded the pre-grazing samples, and consequently no yield was recorded.

2.2. Intermediate period. (6 in. treatment.)

Plot No. \ Grazing Period.	(1) 2 Sept. 4 Oct.	(2) 4 Oct. 24 Oct.	(3) 24 Oct. 24 Nov.	(4) 24 Nov. 7 Jan.	Total.
2	793	1377	1573	2910	6653
4	531	1045	1100	1932	4608
6	910	974	608	2377	4869
8	1309	1275	1324	2797	6705
$\bar{x}$	886	1168	1151	2504	5709

2.3. Final period. (3 in treatment.)

Plot No. \ Cutting Period.	(9) 13 Jan. 3 Feb.	(10) 3 Feb. 24 Feb.	(11) 24 Feb. 24 Mar.	Tot.
1	407	544	1025	1976
3	616	644	966	2226
5	397	695	748	1840
7	403	682	893	1978
$\bar{x}$	456	641	908	2005

(6 in. Treatment.)

Plot No. \ Cutting Period.	(5) 7 Jan. 12 Feb.	(6) 12 Feb. 19 Mar.	Total
2	1456	1273	2729
4	1207	1322	2529
6	1529	1445	2974
8	1409	1399	2808
$\bar{x}$	1400	1360	2760

APPENDIX 3

3.1. Analysis of variance of dry matter production during the intermediate and final periods.

Source	SS.	d.f.	M.S.	F.value	F required	Result
Block	1941652	3	647217	0.63	10.10(34.10)	N.S.
Treatment	2406817	1	2406817	2.35	10.10(34.10)	N.S.
Error	3071848	3	1023949			
Total	7420317	7				

V = 12.8%

3.2. Analysis of variance of dry matter production for May - Sept.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	48087	3	16029	<1.00	10.10	N.S.
Treatment	21	1	21	<1.00	10.10	N.S.
Error	277121	3	92374			
Total	325229	7				

V = 22.7%

3.3. Analysis of variance of dry matter production for Sept. - Jan.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	1989750	3	663250	<1.00	10.10	N.S.
Treatment	234127	1	234127	<1.00	10.10	N.S.
Error	2379776	3	793259			
Total	4603653	7				

V = 16.1%

3.4. Analysis of variance of dry matter production for Jan. - March.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2271	3	757	<1.00	10.10	N.S.
Treatment	1136779	1	1136779	18.84	10.10(34.10)	*
Error	181058	3	60353			
Total	1320108	7				

V = 10.3%

APPENDIX 4

Dry matter yields on which the calculated relative growth rates are based.
(lb. D.M. per acre.)

3 in. Treatment | 6 in. Treatment.

Period	W_1	W_o	Δ DM.	W_1	W_o	Δ DM.	Period.
2 Sept - 16 Sept.	721	371	350	1437	550	887	2 Sept. - 4 Oct.
16 Sept - 4 Oct.	836	320	516				
4 Oct - 16 Oct.	1177	495	682	1872	704	1168	4 Oct. - 24 Oct.
16 Oct. - 24 Oct.	1092	942	150				
24 Oct - 7 Nov.	1185	866	319	2030	878	1152	24 Oct. - 24 Nov.
7 Nov - 24 Nov.	1202	499	703				
24 Nov - 21 Dec.	1996	640	1356	3390	887	2503	24 Nov. - 7 Jan.
21 Dec - 13 Jan.	2286	1036	1250				
13 Jan - 3 Feb.	1335	878	457	2004	601	1403	7 Jan. - 12 Feb.
3 Feb - 24 Feb.	1151	507	644				
24 Feb - 24 Mar.	1386	478	908	1612	252	1360	12 Feb. - 19 March
			7335			8473	

W_1 = samples taken on final day of each period.

W_o = samples taken on first day of each period.

D.M.= $(W_1 - W_o)$

APPENDIX 5.

Herbage yield data recorded over Jan. - March period.

(gm./18 in. square.)

5.1. 3 in. Treatment

Plot No.	13 Jan.	13 Jan.	21 Jan.	27 Jan.	3 Feb.	3 Feb.	10 Feb.	17 Feb.	24 Feb.	24 Feb.	3 March	10 March	17 March	24 March
1	57.0	23.7	17.9	24.8	28.5	13.0	18.3	21.6	25.0	10.4	16.7	17.9	24.5	39.3
	27.0	18.0	23.9	25.0	32.3	13.1	19.7	25.6	26.6	14.7	15.4	20.8	24.8	33.9
3	61.0	20.9	16.6	24.8	37.0	11.6	18.5	26.3	27.2	8.2	13.8	21.9	20.6	31.6
	60.0	16.1	20.5	26.4	28.9	10.5	20.2	26.8	25.1	11.5	15.4	19.3	23.3	33.4
5	53.2	23.6	21.8	27.9	30.2	12.5	18.8	25.7	24.8	14.3	14.6	21.2	21.7	29.2
	63.9	20.4	16.1	26.6	32.4	8.5	19.2	22.6	28.8	7.9	14.6	18.2	21.8	28.1
7	50.0	21.7	23.2	21.9	32.1	11.9	19.6	22.0	29.9	11.9	15.6	21.5	22.9	32.7
	56.8	20.6	19.5	23.5	29.1	14.3	19.1	21.7	28.3	10.8	19.7	21.2	23.2	31.9
$\bar{x}$	53.6	20.6	19.9	25.1	31.3	11.9	19.2	24.0	27.0	11.2	15.7	20.3	23.0	32.5
	±4.1	±1.2	±1.2	±0.3	±1.2	±0.6	±0.3	±0.6	±0.6	±1.4	±0.6	±0.6	±0.4	±0.7

5.2. 6 in. Treatment

Plot No.	7 Jan.	7 Jan.	15 Jan.	22 Jan.	29 Jan.	5 Feb.	12 Feb.	12 Feb.	19 Feb.	26 Feb.	5 March	12 March	19 March
2	98.5	14.5	15.8	21.6	42.0	33.9	49.4	7.6	18.0	18.5	28.0	26.6	39.5
	85.4	13.0	17.7	21.6	30.6	34.7	46.4	8.8	17.2	19.7	23.5	34.5	36.6
4	60.9	11.3	11.5	19.7	39.8	41.0	40.2	5.4	15.7	17.2	24.8	27.8	34.0
	76.8	16.0	15.7	26.9	34.1	34.8	43.7	6.1	18.9	16.9	22.5	35.6	39.5
6	71.2	15.6	16.6	25.1	38.2	39.6	50.6	5.4	17.5	19.1	24.8	35.1	38.4
	77.7	12.9	15.7	19.9	38.7	39.3	49.6	7.3	16.8	17.9	25.7	19.5	42.1
8	80.4	16.4	17.2	23.5	37.4	39.9	45.2	3.4	13.4	15.1	22.4	35.4	35.2
	85.3	13.2	17.0	21.3	34.0	38.4	50.5	2.9	15.2	24.0	22.7	29.3	36.7
$\bar{x}$	79.5	14.1	15.9	22.5	36.9	37.7	47.0	5.9	16.6	18.6	24.3	30.5	37.8
	±2.8	±0.8	±0.6	±1.2	±1.7	±0.8	±0.9	±0.3	±0.5	±1.1	±0.7	±2.5	±0.9

Conversion factor: gm. / 18 in. square $\rightarrow$ lb./acre.
x 42. 64.

APPENDIX 6

Measurements of leaf area index. (Treatment means and their standard errors.)

6.1.

3" Treatment

Sampling date	Leaf area index: Grass	Clover	Total	Grass/Clover ratio
2nd Sept.	2.14 ± 0.060	0.27 ± 0.033	2.41 ± 0.078	89 : 11
4th Oct.	1.71 ± 0.099	0.31 ± 0.046	2.02 ± 0.074	85 : 15
13th Jan.	0.59 ± 0.086	0.150 ± 0.025	0.74 ± 0.099	80 : 20
21st Jan.	0.86 ± 0.040	0.65 ± 0.075	1.51 ± 0.065	57 : 43
27th Jan.	1.30 ± 0.113	1.25 ± 0.092	2.55 ± 0.121	51 : 49
3rd Feb.	1.57 ± 0.154	1.93 ± 0.101	3.50 ± 0.153	45 : 55
3rd Feb.	0.10 ± 0.050	0.06 ± 0.032	0.16 ± 0.081	61 : 39
10th Feb.	0.73 ± 0.112	0.88 ± 0.063	1.62 ± 0.052	45 : 55
17th Feb.	1.15 ± 0.121	1.27 ± 0.090	2.42 ± 0.151	47 : 53
24th Feb.	1.56 ± 0.142	1.54 ± 0.203	3.10 ± 0.187	50 : 50
24th Feb.	- -	-	-	-
3rd Mar.	0.52 ± 0.031	0.55 ± 0.056	1.07 ± 0.043	49 : 51
10th Mar.	0.87 ± 0.021	1.20 ± 0.054	2.07 ± 0.059	42 : 58
17th Mar.	1.88 ± 0.082	1.70 ± 0.094	3.58 ± 0.133	52 : 48
24th Mar.	3.08 ± 0.091	2.31 ± 0.205	5.38 ± 0.242	57 : 43

6.2. 6" Treatment

Sampling date	Leaf area index: Grass	Clover	Total	Grass/Clover ratio
2 Sept.	2.37 ± 0.161	0.330 ± 0.049	2.70 ± 0.196	88 : 12
4 Oct.	3.30 ± 0.316	0.65 ± 0.071	3.96 ± 0.303	83 : 17
8th Jan.	0.28 ± 0.055	0.07 ± 0.021	0.34 ± 0.073	81 : 19
15th Jan.	0.65 ± 0.035	0.28 ± 0.031	0.93 ± 0.012	70 : 30
22nd Jan.	1.12 ± 0.064	1.09 ± 0.104	2.21 ± 0.110	51 : 49
29th Jan.	1.79 ± 0.059	1.96 ± 0.065	3.75 ± 0.035	48 : 52
5th Feb.	1.86 ± 0.169	2.19 ± 0.056	4.05 ± 0.213	46 : 54
12th Feb.	2.04 ± 0.314	2.46 ± 0.147	4.50 ± 0.290	45 : 55
12th Feb.	- -	-	-	-
19th Feb.	0.24 ± 0.021	0.60 ± 0.030	0.84 ± 0.030	29 : 71
26th Feb.	0.69 ± 0.140	1.07 ± 0.085	1.76 ± 0.126	39 : 61
5th Mar.	1.16 ± 0.113	2.06 ± 0.178	3.22 ± 0.109	36 : 64
12th Mar.	1.65 ± 0.069	3.01 ± 0.185	4.66 ± 0.214	35 : 65
19th Mar.	2.24 ± 0.257	2.93 ± 0.120	5.16 ± 0.214	43 : 57

APPENDIX 7

Analysis of regression of leaf area index on time based on weekly measurements obtained during the final ten week period and which have been presented in Appendices 5.1. and 5.2.

7.1. 6 in. Treatment. y = Leaf area index x = time (days)

Linear Regression: $(y - \bar{y}) = b\,(x - \bar{x})$.

SSy = 29.3437 SSx = 1381 SPxy = 196.480

$$b = \frac{SPxy}{SSx} = 0.1424.$$

SS due to regression of y on x = bSPxy = 27.9788.

Test of significance of b:

Source	SS.	d.f.	M.S.	F.	F required	Result
Lin. Reg.	27.9788	1	27.9788	184.4	$5.12_{(10.60)}$	**
Error	1.3649	9	0.1517			
Total	29.3437	10				

$$b = \pm\sqrt{\frac{0.1517}{1381}} = \pm 0.0105.$$

$$\therefore y = 0.1424\,x - 0.088$$

7.2. 3 in. Treatment: y = Leaf area index x = time (days)

Linear regression: $(y - \bar{y}) = b\,(x - \bar{x})$.

SSy = 22.9581 SSx = 866 SPxy = 136.909

$$b = \frac{SPxy}{SSx} = 0.1581$$

SS due to regression of y on x = bSPxy = 21.6453.

Test of significance of b:

Source	SS	d.f.	M.S.	F.	F required	Result
Lin. Reg.	21.6453	1	21.6453	164.9	$4.96_{(10.00)}$	**
Error	1.3128	10	0.1313			
Total	22.9581	11				

$$b = \pm\sqrt{\frac{0.1313}{866}} = \pm 0.0123.$$

$$y = 0.1581x + 0.095$$

APPENDIX 8.

8.1. Analysis of variance for total L.A.I. at 4th Oct. and 17th March. (3 in. treatment.)

Source	SS.	d.f.	M.S.	F. Value	F required	Result
Blocks	0.470	3	0.123	< 1.00	10.10	N.S.
Treatment	8.211	1	8.211	15.67	10.10 (34.10)	*
Error	1.573	3	0.524			
Samples	0.743	8				
Total	10.997	15				

S.E. = ± 0.21.

8.2. Analysis of variance for total L.A.I. at 4th Oct. and 17th March. (6 in. Treatment.)

Source	SS.	d.f.	M.S.	F value	F required	Result
Blocks	1.435	3	0.478	< 1.00	10.10	N.S.
Treatment	5.849	1	5.849	3.33	10.10	N.S.
Error	5.266	3	1.755			
Samples	4.372	8				
Total	16.922	15				

S.E. = ± 0.44

8.3. Analysis of variance for grass L.A.I. at 4th Oct. and 19th March. (6 in. Treatment.)

Source	SS.	d.f.	M.S.	F value	F required	Result
Blocks	0.699	3	0.233	< 1.00	10.10	N.S.
Treatment	4.542	1	4.542	3.52	10.10	N.S.
Error	3.872	3	1.291			
Samples	5.245	8				
Total	14.358	15				

S.E. = ± 0.40

8.4. Analysis of variance for clover L.A.I. at 4 th Oct. and 19th March.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.325	3	0.108	< 1.00	10.10	N.S.
Treatment	20.700	1	20.700	77.24	10.10 (34.10)	**
Error	0.805	3	0.268			
Samples	0.619	8				
Total	22.449	15				

APPENDIX 9

Analysis of regression of dry matter yield on leaf area index based on data contained in appendices 5 and 6. (Dry matter yields were converted to lb./ac. before analysis).

9.1 3 in. Treatment. y = dry matter yield. x = leaf area index.

SSy = 515837 SSx = 11.6034 SPxy = 2137.806

$$b = \frac{SPxy}{SSx} = 184.2.$$

SS. due to regression of y on x = b SPxy = 393784

Test of significance of b:

Source	SS.	d.f.	M.S.	F.	F required	Result.
Lin. Reg. Error	393784 122053	1 9	393784 13561	29.04	$5.12_{(10.60)}$	**
Total	515837	10				

$$S_b = \pm\sqrt{\frac{13561}{11.6034}} = \pm 34.2.$$

$$y = 184.2x + 544.$$

9.2. 6 in. Treatment. y = dry matter yield x = leaf area index.

SSy = 2246208 SSx = 36.8096 SPxy = 7317.072

$$b = \frac{SPxy}{SSx} = 198.8$$

SS.due to regression of y on x = bSPxy = 1454634

Test of significance of b:

Source	SS.	d.f.	M.S.	F	F required	Result
Lin. Reg.	1454634	1	1454634	16.56	$5.12_{(10.60)}$	**
Error	791574	9	87842			
Total	2246208	10				

$$S_b = \pm\sqrt{\frac{87842}{36.8096}} = \pm 48.9$$

$$y = 198.8x + 602.$$

APPENDIX 10

Tiller numbers per square foot. (Plot figures and Treatment means with standard errors.)

	Plot Nos.	25. 8. 58	19.11.58	6. 1. 59	31. 3.59	9. 6.59
GRASS TILLERS	1	229	265	197	113	138
	3	305	191	143	97	91
	5	185	216	162	125	147
	7	269	177	230	104	156
	$\bar{x}$	247 ± 26	212 ± 19	183 ± 19	109 ± 6	133 ± 11
	2	207	159	126	56	64
	4	218	188	97	73	129
	6	274	160	163	52	72
	8	269	170	195	103	105
	$\bar{x}$	242 ± 17	169 ± 6	140 ± 18	71 ± 12	93 ± 15
CLOVER TILLERS	1	10	74	57	86	73
	3	15	96	74	70	83
	5	9	71	54	105	59
	7	14	49	58	75	59
	$\bar{x}$	12 ± 2	72 ± 10	61 ± 4	84 ± 8	69 ± 6
	2	13	53	59	70	90
	4	13	59	48	71	72
	6	15	41	51	80	99
	8	13	52	53	95	55
	$\bar{x}$	13 ± 1	51 ± 4	48 ± 6	79 ± 6	79 ± 10
TOTAL TILLERS	1	239	339	254	199	211
	3	320	287	217	167	174
	5	194	287	216	228	206
	7	283	226	288	179	215
	$\bar{x}$	259 ± 35	284 ± 25	244 ± 17	193 ± 13	202 ± 6
	2	220	202	185	126	154
	4	231	247	145	144	201
	6	289	201	214	132	171
	8	282	222	208	198	158
	$\bar{x}$	255 ± 20	220 ± 10	188 ± 17	150 ± 15	172 ± 16

APPENDIX 11

Grass tiller distributions. (see fig. 9).

11.1 2 x 6 Contingency Table.

Test of change in distribution of grass tiller numbers per plug between August and June samplings. (3 in. treatment).

Class / Date	0	1-2	3-6	7-14	15-30	31-62	Total
Aug. 1958	10	12	26	63	132	77	320
June 1959	9	10	22	23	30	6	100
TOTAL	19	22	48	86	162	83	420

$\chi^2 = 40.064$ d.f. = 5 $p < 0.001$

11.2 2 x 6 Contingency Table.

Test of change in distribution of grass tiller numbers per plug between August and June sampling. (6 in. treatment).

Class / Date	0	1-2	3-6	7-14	15-30	31-62	Total
Aug. 1958	5	7	32	72	135	69	320
June 1959	24	16	17	20	19	4	100
TOTAL	29	23	49	92	154	73	420

$\chi^2 = 110.081$ d.f. = 5 $p < 0.001$

APPENDIX 12

Grass Tiller Distributions.

12.1 2 x 6 Contingency Table.

Test of treatment effect on distribution of grass tiller numbers per plug at the January sampling.

Treatment \ Class	0	1-2	3-6	7-14	15-30	31-62	Total
3 in.	8	5	16	25	32	14	100
6 in.	16	3	12	35	29	5	100
TOTAL	24	8	28	60	61	19	200

$\chi^2 = 8.212$ d.f. = 5 $p > 0.05$

12.2 2 x 5 Contingency Table.

Test of treatment effect on distribution of grass tiller numbers per plug at the March sampling.

Treatment \ Class	0	1-2	3-6	7-14	15-30	31-62	Total
3 in.	17	11	38	59	35		160
6 in.	25	14	49	60	12		160
TOTAL	42	25	87	119	47		320

$\chi^2 = 14.538$ d.f. = 4 $p = 0.01$

12.3 2 x 6 Contingency Table.

Test of treatment effect on distribution of grass tiller numbers per plug at the June sampling.

Treatment \ Class	0	1-2	3-6	7-14	15-30	31-62	Total
3 in.	9	10	22	23	30	6	100
6 in.	24	16	17	20	19	4	100
TOTAL	33	26	39	43	49	10	200

$\chi^2 = 11.924$ d.f. = 5 $p = 0.05$

APPENDIX 13

Clover Node Distributions.

13.1. 2 x 2 Contingency table.

Test of change in distribution of clover node numbers per plug between August and June samplings.

(3 in. treatment).

Date \ Class	0	1-2	3-6	Total
Aug. 1958	-	277	43	320
June 1959	-	10	90	100
TOTAL		287	133	420

$\chi^2 = 203.3$
d.f. = 1.
$p < 0.001$

(6 in. treatment).

Date \ Class	0	1-2	3-6	Total
Aug. 1958	-	276	44	320
June 1959	-	10	90	100
TOTAL		286	134	420

$\chi^2 = 203.0$
d.f. = 1
$p < 0.001$

13.2 2 x 3 Contingency table.

Test of treatment effect on distribution of clover node numbers per plug at the August sampling.

Treatment \ Class	0	1-2	3-6	Total
3 in.	134	143	43	320
6 in.	107	169	44	320
TOTAL	241	312	87	640

$\chi^2 = 2.60$
d.f. = 2
$p > 0.05$ (N.S.)

13.3 2 x 5 Contingency table.

Test of treatment effect on distribution of clover node numbers per plug at the November sampling.

Treatment \ Class	0	1-2	3-6	7-14	15.30	Total
3 in.	59	35	86	115	24	319
6 in.	67	53	97	86	17	320
TOTAL	126	88	183	201	41	639

$\chi^2 = 10.00$
d.f. = 4
$p < 0.05$

13.4 2 x 4 Contingency table.

Test of treatment effect on distribution of clover node numbers per plug at the January sampling.

Treatment \ Class	0	1-2	3-6	7-14	Total
3 in.	17	41	68	74	200
6 in.	15	52	94	39	200
TOTAL	32	93	162	113	400

$\chi^2 = 16.44$
d.f. = 3
$p < 0.001$

13.5 2 x 3 Contingency table.

Test of treatment effect on distribution of clover node numbers per plug at the March sampling.

Treatment \ Class	0-2	3-6	7-14	Total
3 in.	9	57	94	160
6 in.	9	67	84	160
TOTAL	18	124	178	320

$\chi^2 = 0.68$
d.f. = 2
$p > 0.05$ (N.S.)

13.6 2 x 3 Contingency Table.

Test of treatment effect on distribution of clover node numbers per plug at the June sampling.

Treatment \ Class	1-2	3-6	7-14	Total
3 in.	10	52	38	100
6 in.	10	34	56	100
TOTAL	20	86	94	200

$\chi^2 = 7.20$
d.f. = 2
$p < 0.05$

APPENDIX 14

Coefficient of variation of tiller numbers per plug, and numbers of plugs collected per sampling.

Species	Treatment	Sampling Date	25.8.58 n.	25.8.58 V.	19.11.58 n.	19.11.58 V.	6.1.59 n.	6.1.59 V.	31.3.59 n.	31.3.59 V.	9.6.59 n.	9.6.59 V.
Grass	3 in.		80	63.7	80	67.0	25	78.1	40	75.8	25	88.8
	6 in.		80	64.9	80	66.7	25	79.7	40	97.1	25	113.3
White	3 in.		80	103.8	80	87.0	50	77.7	40	40.3	25	45.0
Clover	6 in.		80	94.0	80	91.5	50	81.7	40	47.8	25	44.9

V = coefficient of variation.

n = number of plugs collected per plot
(4 plots per treatment.)

APPENDIX 15

15.1. Soil moisture date.

pF means* for January.

Date	3 in. Treatment				6 in. Treatment			
Jan.	2 in.	4 in.	8 in.	16 in.	2 in.	4 in.	8 in.	16 in.
6	3.02	2.87	2.72	2.71	2.94	2.88	2.75	2.75
7	3.00	2.85	2.71	2.66	2.95	2.93	2.78	2.73
8	3.01	2.91	2.79	2.66	3.00	2.96	2.80	2.75
9		RESISTANCE		BRIDGE	UNDER	REPAIR.		
10								
11	3.21	3.25	3.07	2.86	3.26	3.24	2.97	2.94
12								
13	2.67	2.69	2.60	2.62	2.60	2.64	2.62	2.64
14								
15	2.67	2.71	2.70	2.68	2.70	2.70	2.68	2.68
16	2.67	2.66	2.65	2.59	2.67	2.65	2.66	2.58
17	(2.56)	(2.43)	2.49	2.47	2.54	2.48	2.45	2.55
18	2.80	2.68	2.74	2.73	2.78	2.79	2.72	2.73
19	2.89	2.79	2.76	2.74	2.89	2.82	2.75	2.74
20	2.92	2.82	2.75	2.73	2.96	2.85	2.76	2.75
21	2.97	2.84	2.79	2.74	3.03	2.88	2.78	2.75
22	3.07	2.88	2.80	2.72	3.08	2.93	2.78	2.74
23	3.18	2.93	2.85	2.77	3.23	2.97	2.85	2.78
24	3.32	2.97	2.93	2.81	3.40	3.02	2.92	2.82
25	3.34	3.01	2.92	2.80	3.39	3.11	2.95	2.87
26	3.32	3.09	2.91	2.78	3.37	3.22	2.93	2.89
27	3.39	3.22	2.95	2.82	3.39	3.30	2.96	2.90
28	3.37	3.24	3.00	2.83	3.39	3.36	3.01	2.96
29	3.37	3.34	3.07	2.89	3.39	3.36	3.14	2.98
30								
31	2.79	2.77	2.80	2.76	2.81	2.79	2.78	2.78

* Each figure is the mean of 8 readings.

Three gypsum blocks failed during the experiment. In each case the missing block was given the same value as the remaining member of the pai

APPENDIX

15.2. Soil moisture date.
pF treatment means for February.

Date	3 in. Treatment				6 in. Treatment.			
Feb.	2 in.	4 in.	8 in.	16 in.	2 in.	4 in.	8 in.	16 in.
1								
2	2.83	2.82	2.80	2.79	2.85	2.84	2.78	2.77
3	2.81	2.79	2.76	2.74	2.84	2.82	2.77	2.75
4	2.89	2.84	2.79	2.75	2.85	2.85	2.80	2.77
5	2.92 ±0.02	2.84 ±0.02	2.79 ±0.03	2.74 ±0.02	2.90 ±0.02	2.89 ±0.02	2.78 ±0.03	2.77 ±0.03
6	2.94	2.85	2.78	2.75	2.92	2.89	2.82	2.78
7	2.95	2.83	2.79	2.74	2.94	2.90	2.84	2.80
8								
9	3.26 ±0.04	2.98 ±0.04	2.96 ±0.04	2.88 ±0.04	3.16 ±0.04	3.02 ±0.04	2.98 ±0.04	2.91 ±0.04
10	3.31 ±0.06	3.01 ±0.02	2.95 ±0.03	2.86 ±0.02	3.27 ±0.06	3.05 ±0.03	2.96 ±0.03	2.94 ±0.02
11	2.74	2.76	2.77	2.72	2.80	2.81	2.75	2.76
12	2.80	2.78	2.74	2.70	2.82	2.80	2.76	2.74
13	2.78	2.75	2.71	2.67	2.76	2.80	2.74	2.71
14	2.88	2.77	2.71	2.65	2.79	2.76	2.71	2.70
15								
16	3.00 ±0.02	2.86 ±0.02	2.76 ±0.03	2.66 ±0.02	2.83 ±0.02	2.79 ±0.02	2.71 ±0.02	2.68 ±0.03
17	3.16 ±0.05	2.91 ±0.02	2.81 ±0.04	2.69 ±0.02	2.85 ±0.02	2.83 ±0.03	2.73 ±0.02	2.72 ±0.02
18	3.12 ±0.03	2.94 ±0.03	2.81 ±0.03	2.65 ±0.03	2.86 ±0.03	2.79 ±0.03	2.70 ±0.03	2.68 ±0.03
19	2.76 ±0.02	2.77 ±0.02	2.74 ±0.02	2.64 ±0.02	2.75 ±0.02	2.76 ±0.02	2.70 ±0.02	2.69 ±0.02
20	2.83	2.80	2.74	2.66	2.74	2.74	2.71	2.71
21	2.71	2.70	2.69	2.59	2.69	2.71	2.67	2.64
22								
23	2.74	2.75	2.70	2.64	2.72	2.75	2.63	2.63
24	2.75	2.72	2.70	2.63	2.70	2.73	2.68	2.66
25	2.76	2.73	2.69	2.65	2.72	2.71	2.66	2.63
26	2.73	2.73	2.68	2.61	2.72	2.68	2.64	2.62
27	2.75	2.73	2.68	2.64	2.75	2.72	2.66	2.66
28	2.76	2.70	2.66	2.63	2.76	2.68	2.63	2.63

Average S.E. = ± 0.03

APPENDIX

15.3. Soil moisture data.

pF Treatment means for March.

Date	3 in. Treatment				6 in. Treatment			
March	2 in.	4 in.	8 in.	16 in.	2 in.	4 in.	8 in.	16 i
1								
2	2.80	2.74	2.68	2.61	2.82	2.75	2.66	2.61
3	2.86	2.75	2.72	2.60	2.82	2.75	2.65	2.65
4	2.88	2.79	2.71	2.60	2.80	2.75	2.64	2.60
5	2.97	2.87	2.80	2.68	2.94	2.83	2.72	2.67
6	3.09	2.94	2.89	2.78	3.00	2.94	2.83	2.79
7	3.09	2.94	2.91	2.74	3.03	2.88	2.80	2.76
8								
9	3.19	2.99	2.89	2.78	3.12	3.01	2.86	2.70
10	3.34	3.14	2.97	2.80	3.23	3.03	2.90	2.83
11	3.16	3.14	2.99	2.81	3.23	3.07	2.90	2.83
12	2.83	2.84	2.82	2.79	2.85	2.96	2.85	2.82
13	2.78	2.74	2.78	2.71	2.82	2.83	2.79	2.82
14	2.80	2.79	2.79	2.75	2.81	2.83	2.79	2.81
15								
16	2.80	2.78	2.81	2.78	2.82	2.82	2.83	2.83
17	2.80	2.79	2.81	2.74	2.81	2.80	2.80	2.81
18								
19	2.80	2.81	2.78	2.70	2.79	2.82	2.74	2.76
20	2.77	2.75	2.76	2.70	2.78	2.76	2.70	2.71
21								
22								
23								
24	2.83	2.77	2.76	2.71	2.82	2.76	2.73	2.72

APPENDIX 16

Root yields. (Dry weight - gm./100cm.^{3} soil).

Plot	3 in. Treatment			Plot			
No.	0-3 in.	3-6 in.	6-12 in.	No.	0-3 in.	3-6 in.	6-12 in.
1	0.471	0.104	0.044	2	0.420	0.086	0.067
	0.337	0.066	0.042		0.430	0.077	0.048
3	0.571	0.083	0.032	4	0.461	0.120	0.064
	0.281	0.066	0.027		0.286	0.087	0.050
5	0.291	0.076	0.037	6	0.328	0.112	0.040
	0.238	0.109	0.038		0.407	0.028	0.037
7	0.376	0.102	0.042	8	0.296	0.065	0.055
	0.225	0.068	0.052		0.351	0.072	0.067
$\bar{x}$	0.349	0.084	0.039	$\bar{x}$	0.372	0.081	0.054
	$\pm$0.045	$\pm$0.008	$\pm$0.002		$\pm$0.025	$\pm$0.011	$\pm$0.003

APPENDIX 17

17.1. Analysis of variance of dry weight of roots, within 0-3 in. horizon.

Source	SS	d.f.	M.S.	F value	F required	Result
Blocks	0.035156	3	0.011719	2.91	9.28	N.S.
Treatment	0.002233	1	0.002233	1.00	10.10	N.S.
Error	0.012103	3				
Plugs within depths	0.084828	8				
TOTAL	0.134320	15				

S.E. = ± 0.022

17.2. Analysis of variance of dry weight of roots within 3-6 in. horizon.

Source	SS	d.f.	M.S.	F value	F required	Result
Blocks	0.000312	3	0.000156	1.00	9.28	N.S.
Treatments	0.000046	1	0.000046	1.00	10.10	N.S.
Error	0.001942	3	0.000647			
Plugs within depths	0.005768	8				
TOTAL	0.008068	15				

S.E. = ± 0.009

17.3. Analysis of variance of dry weight of roots within 6-12 in. horizon.

Source	SS	d.f.	M.S.	F value	F required	Result
Blocks	0.000579	3	0.000193	1.77	9.28	N.S.
Treatments	0.000841	1	0.000841	7.72	10.10	N.S.
Error	0.000326	3	0.000109			
Plugs within depths	0.000428	8				
TOTAL	0.002174	15				

S.E. = ± 0.004

APPENDIX 18

Weather Data, Grasslands Division Meteorological Station.

	Week ending.	Mean weekly values. Temperatures (°F.)				Weekly Totals		
		Max.	Min.	Soil 4 in.	Grass min.	Rainfall in.	Evaporation in.	Sunshine hrs.
1958	Sept. 9	60.1	38.7	44.6	30.5	-	0.387	64.0
	16	59.4	43.1	48.6	36.8	0.19	0.512	44.7
	23	61.4	46.0	49.7	37.1	0.05	0.586	56.8
	30	60.8	38.8	49.8	29.8	-	0.763	52.4
	Oct. 7	69.3	48.5	55.1	38.5	-	0.573	46.1
	14	57.3	45.4	53.8	38.7	0.66	0.641	6.3
	21	67.7	53.1	56.6	45.1	0.54	0.570	38.9
	28	69.0	50.1	58.0	43.2	0.82	0.601	33.1
	Nov. 4	66.0	50.5	60.3	47.1	0.43	0.547	33.0
	11	70.1	49.5	61.2	39.9	0.22	1.054	53.7
	18	69.5	51.2	63.7	44.5	0.79	0.990	38.3
	25	69.3	47.0	61.0	39.2	0.01	1.268	58.8
	Dec. 2	69.6	52.4	63.3	42.9	0.18	1.040	37.7
	9	70.1	52.2	65.9	43.4	0.17	(0.353)	39.1
	16	74.3	56.4	65.4	50.1	2.71	0.659	24.9
	23	70.6	57.2	65.8	49.8	2.97	0.642	26.6
	30	70.5	58.6	65.8	49.8	0.83	0.951	42.0
1959	Jan. 6	70.2	54.2	67.8	44.8	0.10	1.736	63.7
	13	75.1	56.0	68.0	51.6	3.40	1.011	50.7
	20	77.3	58.9	69.6	53.1	-	1.399	69.4
	27	76.6	56.5	69.5	51.1	-	1.317	52.3
	Feb. 3	72.8	57.5	67.3	53.4	2.87	0.873	37.2
	10	76.1	57.4	69.4	54.2	1.36	1.061	53.8
	17	72.4	56.1	65.3	49.1	0.04	(0.970)	62.5
	24	77.1	55.1	63.7	49.7	1.48	1.198	19.7
	March 3	70.7	50.4	60.7	43.6	0.11	1.166	58.0
	10	72.6	55.5	63.3	50.6	0.14	0.999	31.8
	17	71.1	60.7	64.6	56.8	1.89	0.604	17.8
	24	69.8	52.5	60.9	46.9	1.14	0.661	48.7
	31	65.6	49.4	58.6	43.7	0.31	0.880	40.8

APPENDIX 19

Daily potential evapotranspiration values and calculated soil moisture deficits. (Def.)

Schwass (1959).

Estimates given in ins.

Date	January, 1959.		February, 1959.		March, 1959.	
	P.E.	Def.	P.E.	Def.	P.E.	Def.
1			0.094	0.212	0.115	0.534
2			0.090	0.302	0.089	0.623
3			0.130	0.422	0.073	0.696
4			0.126	0.548	0.101	0.747
5			0.112	0.660	0.090	0.837
6	0.101	1.180	0.146	0.806	0.097	0.934
7	0.094	1.274	0.143	0.949	0.129	0.043
8	0.119	1.393	0.127	1.076	0.088	1.081
9	0.131	1.524	0.158	1.234	0.112	1.193
10	0.134	1.658	0.119	0.000	0.117	1.290
11	0.162	0.274	0.115	0.115	0.107	0.977
12	0.144	0.000	0.127	0.242	0.106	0.533
13	0.164	0.084	0.121	0.363	0.086	0.359
14	0.155	0.239	0.112	0.475	0.114	0.593
15	0.139	0.378	0.106	0.581	0.125	0.638
16	0.130	0.508	0.118	0.699	0.140	0.708
17	0.129	0.637	0.120	0.779	0.124	0.202
18	0.159	0.796	0.120	0.419	0.082	0.000
19	0.141	0.937	0.104	0.463	0.082	0.082
20	0.149	1.086	0.130	0.000	0.092	0.174
21	0.152	1.238	0.127	0.127	0.089	0.263
22	0.131	1.369	0.078	0.000	0.095	0.358
23	0.125	1.494	0.070	0.070	0.097	0.455
24	0.137	1.631	0.073	0.143	0.092	0.457
25	0.124	1.743	0.073	0.216		
26	0.139	1.868	0.102	0.318		
27	0.148	1.986	0.099	0.417		
28	0.167	2.120	0.112	0.529		
29	0.146	0.000				
30	0.138	0.000				
31	0.118	0.118				

APPENDIX 20

Analysis of regression of measured pF on calculated soil moisture deficit (ins.) based on data presented in appendices 15 & 19.

20.1. 17th - 28th Jan.* y = measured pF x = calculated soil moisture deficit.

SSy = 0.4834 SSx = 2.54690 SPxy = 1.10211

$$b = \frac{SPxy}{SSx} = \frac{1.10211}{2.54690} = 0.4327$$

SS due to regression of y on x = b SPxy = 0.4769.

Test of significance of b.

Source	SS	d.f.	M.S.	F	F required	Result
TOTAL Lin. Reg. Error	0.4769 0.0065	1 10	0.2596 0.0007	367.0	4.84 (9.65)	**
TOTAL	0.4834	11				

$$S_b = \pm \frac{0.0007}{2.5469} = \pm 0.0166$$

$$y = 0.4327\,x + 2.49.$$

20.2. 25th Feb. - 10th March. *y = measured pF x = calculated soil moisture deficit.

SSy = 0.3127 SSx = 1.2861 SPxy = 0.6115

$$b = \frac{SPxy}{SSx} = \frac{0.6115}{1.2861} = 0.4755$$

SS due to regression of y on x = b SPxy = 0.2908

Tests of significance of b

Source	SS	d.f.	M.S.	F	F required	Result
Lin. Reg. Error	0.2908 0.0219	1 10	0.2908 0.0022	132.2	4.84 (9.65)	**
TOTAL	0.3127	11				

$$S_b = \pm \frac{0.0022}{1.2861} = \pm 0.0131$$

$$y = 0.4755\,x + 2.55$$

* measured pF = average of the two treatment means at the 2 in. and 4 in. depth.