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A STUDY OF THE REACTION

OF

FOUR GRASS SPECIES

PERENNIAL RYEGRASS (*LOLIUM PERENNE L.*)

TIMOTHY (*PHLEUM PRATENSE L.*)

COCKSFOOT (*DACTYLIS GLOMERATA L.*)

AND

BROWNTOP (*AGROSTIS TENUIS SIBTH.*)

TO AN ARTIFICIAL TREADING TREATMENT

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

J.A. Lancashire

- 1961 -

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CHAPTER I

INTRODUCTION

The dependence of New Zealand's economy upon grassland has frequently been emphasized.

The main features of the pastoral farming systems are; high production pastures, grass/clover combinations, mineral fertilisers, and all-the-year outdoor grazing at relatively high stocking rates (Sears, 1959). Corkill (1957) has demonstrated the role of pasture plant breeding and seed certification. Sears (1953) has shown the importance of pasture top-dressing, the grazing animal, and white clover in the improvement of soil fertility. However, many other methods of increasing the production and utilisation of herbage are under investigation (Evans, 1960).

In general, grazing techniques have been based on a rotational system for it was believed that this method had important advantages over continuous grazing systems (Levy, 1950). However, the work of McMeekan (1960) and Freer (1960) with dairy cows, and Lambourne (1956) with sheep, showed that wide differences in grazing technique have comparatively little effect on yield/acre of pasture and stock. The production efficiency was mainly dependent on a high stocking rate.

There is little information to indicate the upper limits of the stocking rate. At Ruakura, stocking levels of 1¼ cows/acre have not reduced pasture production (Campbell, 1961); and Freer's studies on irrigated grassland in Victoria, have not produced evidence of sward deterioration after two years of grazing at 2 cows/acre. However, Edmond (1958a) and Mitchell (1960) have suggested that treading may place a ceiling on total herbage productivity.

In a review of literature, Edmond (1958b) observed that although the occurrence, general importance, and some of the special effects of treading had been studied by several workers, no attempt had been made to distinguish between the overall treading effects and those of excretion and defoliation. Therefore a technique was developed to study treading as a single factor (Edmond loc. cit.). A preliminary experiment showed that treading damaged pasture, and increased treading had an increased influence on plant and soil. Further work showed that pasture species varied considerably in their reaction to treading (Edmond, 1960). These variations have been discussed in terms of the physiological and morphological state of the plant. Bates (1937) emphasized the importance of the position of the growing point.

In Edmond's treading studies it was assumed that sheep walked 1.7 miles/day. Thus, by defining the width of narrow fenced plots a 'stocking rate equivalent' of n sheep/acre could be imitated by walking nd sheep once along the plots every d days. In practice, mobs of about 30 sheep were walked several times in each direction. Although there were some problems, it was suggested that treatments were similar to a special kind of mob stocking (Edmond 1958b).

The continued elucidation of the treading effect depends on the precise definition of the factors involved in that effect. The initiating point of treading is the hoof; and it was considered that in this thesis some useful information could be gained from the reaction of several pasture species to a closely defined force. Thus, an artificial hoof was used to apply pressures which bore some relationship to those produced by a mature sheep walking on pasture.

The growth curves of the species, as affected by treatments in the Autumn and Spring of 1961, were followed. Measurements of some of the components of this growth data were taken, and an attempt to define the position of the growing point in relation to ground level was made. Finally, changes in soil density due to the treading treatment were measured.

CHAPTER II

REVIEW OF LITERATURE

This review is presented in four parts, as follows:

I The Recognition of the Treading Effect.

II The Influence of the Animal on the Treading Effect.

III The Effectsof Sheep Treading on Plant and Soil.

IV Sheep Treading Studies and Pasture Yield.

PART I

The Recognition of the Treading Effect

The first practical utilisation of treading occurred with the development of the folding system on light arable land in England in the 19th century (Fraser, 1954). The "daily confinement of the flock on an area of feed crop" often involved a stocking rate of 1500 sheep/acre (Thomas, 1930). The manuring and treading of sheep were greatly valued on this type of land.

Similarly in pasture management, the hoof has been considered an excellent implement of cultivation (Armstrong, 1937), although the damaging effects of winter "pugging" have often been stressed. Sears (1953) considered that stock grazing and treading were important factors in maintaining a ryegrass/white clover pasture at high productivity. The main effect is to keep the sole of the pasture open and free from mat-forming species.

Levy (1940) found that treading helped to improve hill country by crushing out some weed species which were more susceptible to damage than desirable plants. Bates (1935) studied the vegetation of road verges and animal pathways. It was observed that pasture species differed in resistance to treading, and under continued treading, changes in botanical composition could be induced. The species which persisted in these heavily trodden habitats possessed adaptations of life form and leaf structure which enabled them to resist injury.

Lieth (1954) concluded from a brief review of German literature that treading caused a reduction in the pore space of the soil. In his own experimental work he showed a relationship between pore space in the 0-5cm layer and the distribution of different grassland plants. It was considered that treading influenced pasture composition through this factor.

In most of these observations, treading has only been considered as part of general ecological and grazing studies, and the type of stock are rarely mentioned. However, it has been confirmed by Edmond (1958b), that when sheep treading is the chief effect, the plants are influenced both directly and indirectly through the soil. He has also noted the lack of animal behaviour data, which is a major drawback to any assessment of the treading effect. It is this causative factor - the animal - that is considered in Part II.

PART II

The Influence of the Animal on the Treading Effect

A. Method of Locomotion

The series of photographs by Muybridge (1899) is still considered to be the authoritative work on the gaits of animals (Ottaway, 1955). When an animal is grazing its supports are provided by alternations of three and four feet. In the normal walk supports are provided by alternations of two and three feet; in the trot the legs are lifted in diagonal pairs and in mid-stride all four limbs are off the ground together; and in the gallop the feet reach the ground in irregular sequence and are bunched together with long spaces between each stride (Muybridge loc.cit.). Thus, considerable variation in the pressure under an animal's foot will occur. However, it is assumed that the grazing sheep usually alternates between a normal and a very slow walk.

Ottaway (1955) has shown that the complete action of any one limb consists of a phase of 'elevation' and a phase of 'contact'. In 'elevation', the limb is lifted off the ground, carried forward on the body, and placed on the ground. In 'contact', there is a period of initial contact, a period of main weight-bearing, and a period of propulsion. Clearly continual changes in hoof pressure will result.

Sisson (1959) has stated that structures important in countering concussion are found in the heel. Trauttman and Fiebiger (1957) showed that there are considerable similarities in the hooves of sheep, goats and cattle. Although Muybridge (loc.cit.) did not study the sheep, his work indicated that hooved animals tend to place the foot down 'heel' first.

In all cases the foot was also lifted 'heel' first. It is assumed that the sheep conforms to this pattern.

Two other factors which are partly the result of movement by the animal, are the penetration of hooves into the soil in wet weather (Gradwell, 1956) and their cutting and dislodging effect on the topsoil (Campbell, 1950).

B. The Hoof Load

Myers (1955) made a study of several hoof features of the dairy cow in relation to treading. For mature Jersey and Friesian cows the static unit hoof load averaged 16.2 p.s.i.* It was noted that the hoof print area (enclosed area) was usually 20 per cent higher than the bearing area. Lull (1959) measured hoof prints of sheep and related them to body weight. However, his value of 9.2 p.s.i. for the static unit hoof load may be lower than the true value.

Myers (loc.cit.) showed that breed differences in static unit hoof load were slight. The weight of the heavier Friesian cows was compensated for by a larger hoof bearing area. Similarly the greater weight of the fore-portions of the animal was carried on a larger hoof. A ten-fold increase in hoof load occurred between calves and mature animals.

It was considered that the unit hoof load of a mature cow grazing pasture may be 45-50 p.s.i. However, due to body weight changes and hoof growth and wear, unit hoof loads may vary throughout the season, and between and within days. No estimate of these changes was made. Moreover, in cattle the hoof is concave so pressures may still be variable even if the unit load is calculated.

No such detailed investigations of the loads on the sheep's hoof

* pounds weight per square inch.

have been made, but it was noted above that the hooves of sheep and cattle are structurally similar.

C. Treading Behaviour

It appears that no experiments have been specifically designed to study this factor. Further, only a few grazing behaviour studies are amenable to statistical interpretation, and these have been concerned, in the main, with dairy cows (Hancock, 1950). In this work the activity of the animal divided into three parts and the features relevant to this review are presented below.

1. Grazing time - includes short periods of walking while selecting suitable grass.
2. Loafing time - the time spent standing and walking while not grazing.
3. Lying time.

(After Hancock, 1953)

A value for the treading time (the total period the animal spends on its feet) can be derived from these behaviour studies. However, it has been shown that movement has a considerable influence on the pressures under the hoof, and these definitions do not distinguish between moving and standing times. Measurements of distances travelled give an indication of the amount of movement, but may not be related to moving times.

England (1954) compared the grazing behaviour of one sheep from each of the Blackface, Clun, Spanish and Suffolk breeds. They were observed during two 24 hour periods; the first on a 'good' pasture under fair weather conditions, and the second on a 'poor' pasture in showery conditions. Increases in distances travelled and total treading time were observed in the second period. These were attributed to more selective grazing on the 'poor' pasture, and to increased standing time due to adverse weather. As the animals were observed to range over a wider area of pasture, it follows that treading would also be spread over a wider area. Further, although the Blackface had similar treading times to the other breeds, it never travelled so far. It was observed that a smaller area of pasture was grazed, with the result that treading was also confined to a smaller area. Although this was a very limited study, it showed that depending on the conditions, variable intensities of treading may occur within a given area of pasture. It is not known how this influences the total treading effect.

The analysis of grazing behaviour studies can yield some useful information on treading behaviour, but it is suggested that a more logical approach is to determine the factors that constitute the total treading effect. A treading behaviour study could then be designed to discover the external factors which influence the magnitude of these effects.

With these reservations, it is still important to know the factors that affect the general activity of the sheep. Thus, some of the relevant points from a review by Tribe (1955) are now presented.

In hot weather, grazing animals are frequently unsettled and there is often an increase in the distance travelled. Grazing times are reduced during the day, but a part of this is regained by longer grazing at night. Similar effects are noted in cold and wet weather, although in this case much of the loss in grazing time is regained when the weather improves. However, in both cases the provision of shelter in the paddock may reduce the amount of movement.

Although quality and quantity of herbage are interdependent, it was suggested by Tribe that grazing times and distances travelled increase when the quantity of feed available is low and/or the quality poor. In addition, the larger the area of pasture the further the animal will walk. The effect of the system of grazing management on activity is obviously closely related to these points.

In an experiment with identical twins, Hancock (1950) showed that inherited variability in grazing behaviour was by far the largest source of variation between individuals. A part of these inherited differences could be explained by relating them to differences between the physiological requirements of the individual animal. Cresswell (1960) suggested that it is probable that increased nutritional requirements during growth, pregnancy or lactation may result in increased grazing times.

Farris (1954) showed that the activity (number of steps) of several dairy cows increased by 50 per cent at oestrous, but the day before and the day after were of low activity.

Cresswell (loc.cit.) designed an experiment to find the weekly mileages travelled by small flocks of Cheviot and Romney ewes under different conditions. The Cheviots travelled eight miles on the hill compared with 5.1 miles by the Romneys, but under lowland conditions the Romneys travelled 8.1 miles and the Cheviots 9.8 miles. Only general conclusions could be drawn from these weekly totals, but it was suggested that the results contradicted the idea that the Romney has adapted itself to hill conditions. Further, only on the hill were larger and sparser pastures associated with greater distances. No increases occurred during lactation, but a considerable rise in activity took placee at tupping, and in pregnant animals as parturition approached.

Hughes and Reid (1951) observed the distances travelled by single sheep of some Down breeds during 24 hour periods. There was no replication in terms of the animals used so the results are of limited value. However, in all studies, the distance travelled in grazing during daylight, exceeded that travelled in walking idle (loafing).

It is apparent from this review of the animal factor, that not only is the unit load on the hoof of the sheep during treading dependent on a constantly changing equilibrium of forces and vectors, but also the total expression of this load on the pasture is dependent on a wide range of external factors.

PART III

The Effects of Sheep Treading on Plant and Soil

Introduction

It was noted in Part I that sheep treading affects both plant and soil. Crocker, (1952) has emphasized that the interdependence of plant and soil is so great that it is not possible to recognize them as "discrete natural units". However, for the purpose of this review treading effects on plant and soil are considered, as far as possible, in two sections:

1. Soil Effects

(A) The Effect of Sheep Treading on Soil Properties

Keen and Cashen, (1932) studied the effect of sheep folding on a light sandy soil in early winter. Stocking equivalents of 880 lamb days and 1760 sheep days/acre produced compaction of the soil to a depth of 10cm. The greatest compaction occurred at the 3-4cm depth. Increases in crumb size were also noted, and the total effect of sheep folding on this soil type was believed to be beneficial.

Packard, (1957) suggested that compaction by stock treading may improve the moisture availability of light pumice soils.

Edmond, (1958b) found that treading at field capacity increased the density of the upper 6cm. of a high fertility silt loam. Increases in treading rate from 0 - 20 sheep-equivalents/acre produced increased density in this zone.

Gradwell, (1956) showed that the total air space in this soil type seldom rose above 5 per cent in the winter. Sheep grazing at this time reduced the mean total porosity from 55.4 per cent to 53.1 per cent, and the mean airspace from 5 per cent to 4.1 per cent. No statistically significant differences between stocking rates of 4, 12 and 20 sheep/acre could be detected.

In a parallel study, it was observed that cattle treading did not decrease total porosity when surface water was present. Severe puddling and mixture of water with the soil were noted, and visible signs of poor drainage and aeration were most evident under this treatment (Gradwell, loc. cit.).

Baver (1959) stated that when the soil is compressed at moisture contents at or near saturation, lower densities are obtained than with drier soil. At high moisture levels the soil reacts to increases in pressure by re-orientation of its particles. This causes a reduction in the amount of non-capillary (large) pores and an increase in the water saturation of the system. The amount of capillary (small) pores increases, but these are unsatisfactory for drainage and aeration. This treading effect, which does not involve compaction, is termed true "puddling" by Gradwell (loc. cit.)

Edmond (1957) noted that under wet conditions, sheep treading damaged aggregates in the surface soil. At high treading rates, or when surface water was present, most of the aggregates were destroyed and puddling resulted. This appeared to be accompanied by deficient aeration of the soil. It was suggested that compaction and puddling usually occur together. However, an experiment to compare artificial puddling and compaction showed that the two soil treatments were different in effect. (Edmond, 1958c). Domby and Kohnke (1956) showed that the puddled soils form crusts which can restrict diffusion of both gases and water. It appears probable that the dense layers which can develop beneath the soil surface under treading, may heighten the efeect of true "puddling" as defined by Gradwell.

It follows that density and porosity measurements may not be reliable indices of the treading effect on soils.

Gradwell (1960) studied changes in the "free-draining pores" of the top 1½in. of a pasture on Manawatu silt loam. Least drainage was found after periods of heavy sheep treading in wet weather. It was shown that this loss of free-draining properties can take some time to regain, even after dry weather has returned and in the presence of vigorous pasture growth. The mechanism of this improvement is not understood. The decline in drainage of the topsoil is cumulative as it leads to increased wetness of the soil and thus more severe puddling on further treading.

Gradwell (1961) made a preliminary study of diffusion of oxygen through pasture topsoils. It was considered that this may prove more satisfactory than measures of water percolation rates, for detection of differences between treading treatments.

It is concluded that sheep treading can affect the soil through a disturbance of the soil surface and compaction of the underlying soil. The severity of the effect appears to depend on stocking rate, soil moisture content and soil type. The main factors that are influenced by these effects are aeration and drainage.

(B) The Influence of Soil Characteristics on the Treading Effect

(i) Introduction

The development of an understanding of soil mechanics has been largely based on laboratory studies and compaction by machines in the field. However, from the reviews of Lull (1959) and O'Connor (1956), it appears justifiable to assume that the effects of treading on the soil conform to the same general principles.

(ii) Soil texture, structure and density.

When the soil is compacted, particles are brought closer together, and fine grains are forced into the voids between coarse grains causing an increase in the soil density (Lull, loc. cit.). In addition, there may be an interlocking of particles under stress (Buchanan, 1942).

Krynine (1951) showed that maximum densities decrease in the order of decreasing grain size from gravel to clay.

Huberty (1944) found that soils with a wide range of particle size (medium-textured soils) compact to much greater densities than soils of uniform grain size.

Soil aggregates appear to act differently from soil particles in their resistance to stress. Blair (1937) found that soils of good tilth gave a stress-compression curve with a step-ladder effect. It is suggested that this may be due to the collapse of the aggregates in the soil, and may indicate a soil of good structure (Lull, loc. cit.).

Day and Holmgren (1952) showed that under stress, aggregates flatten against each other and cause a more uniform distribution of the load.

Under equal stress and with other conditions similar, compression is a function of initial density. The less the density the greater the compression. Lull (loc.cit.) pointed out that in this sense, soils of good structure and low density have a higher potential for compaction that dense structureless soils. However, Clement and Williams (1958) have emphasized the importance of high aggregate stability in the surface soil in resisting soil compaction and dispersion by treading.

(iii) Soil moisture

Buchanan (1942) stated that under dry conditions the resistance of soil particles to re-arrangement is great, for the thin water films provide little lubrication. In addition, the effect of surface tension is so pronounced that stress is partially neutralised. Li (1956) pointed out that the addition of moisture improves lubrication and reduces the surface tension force, so that compaction is more easily achieved. With further increases in moisture content, a critical point is reached at which a maximum of the smaller particles have been forced into the voids between the coarse grains. At this point the maximum density is reached (Li, loc.cit.). The effect of further compression was discussed above.

The greatest compaction is usually achieved when the moisture content is near the lower plastic limit (Markwick, 1945), and this principle has been widely used in soil engineering. Lull (loc.cit.) stated that the same amount of damage can be inflicted on wet soils with light equipment as on much drier soils with heavier equipment.

O'Connor (1956) reported that aggregate destruction may be greatest under very dry or very wet conditions.

(iv) Organic matter content

The greater the content of organic matter in the soil, the smaller the maximum compaction and the greater the moisture content required for maximum compaction (Free et al, 1947).

In contrast, O'Connor (loc.cit.) found that low density silty clay loam, containing 9 per cent organic matter well mixed in the surface soil, was greatly deformed and compacted by the treading of dairy cows.

(C) The Recovery of the Soil from Treading Effects

Robinson and Alderfer (1952) found that freezing and thawing increased the water infiltration of compacted pastures. Sillanpaa (1961) noted that freeze/thaw has a beneficial effect on soils of high aggregation capacity but low on aggregation level. In a general article, Thomas (1960) suggested that frost could remedy the worst effects of treading in temperate climates. The development of wet compact soils in tropical areas was due to the lack of freeze/thaw. However, other factors such as very heavy rainfall or very dry conditions are probably important.

The great persistence of compaction effects in dry climates has been observed (Lull, 1959). In general, wetting-drying cycles improve aggregation of the soil (Sillanpaa and Webber, 1961). It has also been shown that shrinkage of a soil on drying, favours formation of aggregates from large masses of soil initiallt poor in structure (Davidson and Page, 1956).

Other factors that may be important are the activity of earthworms, the growth of roots and the influence of decaying organic matter (Ashley, 1961).

(D) The Relation of Soil Physical Changes Induced by Treading to the Growth of Grass Species

(i) Introduction

Shaw (1952) reviewed the effect of "soil physical conditions on plant growth". A sealing and compaction of surface soil layers could adversely affect plant growth through mechanical impedance of roots, decreased soil aeration and adverse soil moisture relationships. The importance of these factors to plant growth was emphasized, but the critical levels at which each became a limiting factor was not known. Still less was known of the probable interactions between these factors and other climatic and edaphic factors. Further, it appeared that very few workers had studied the effect of these conditions on the growth of grass species.

Edmond (1958c) investigated the effect of soil physical treatments on seedlings of perennial ryegrass (*Lolium perenne L.*) and short-rotation ryegrass (*Lolium perenne L. X Lolium multiflorum Lam.*). The single plants were grown for nine weeks in Manawatu silt loam hydraulically compressed in steel pipes at pressures of 25, 50, 100 and 200 p.s.i. Moderate compaction caused an increased root weight in the 0 - 4cm layer, and it was suggested that root penetration may have been impeded. Top yields were unaffected, but some growth habit changes were observed. The tolerance of ryegrass to soil compaction was confirmed, but the failure of the heavier pressures to affect yield may have been due to the relatively small differences in the volume weight of the soil which were produced.

In a further study (Edmond, *loc.cit.*), seedlings of the same species were planted at 9 inch spacings in small field plots. These had previously been subjected to four soil treatments; control, puddled by raking when wet, compacted, and compacted three weeks after puddling. Compaction was effected by walking over the plots on short stilts designed to give a pressure of 50 p.s.i. With both species, compaction produced a highly significant increase in herbage yield. Puddling reduced yield, but the combined treatment raised yield over puddling alone. Both compaction and puddling increased the volume weight and resistance to penetration of the soil. It was noted that the puddled soils were compacted and the compacted soils puddled to some extent. It was suggested that the puddled soils probably restricted gaseous diffusion, and that a decrease in the oxygen and/or an increase in the carbon dioxide content of the soil may have affected yield. In the case of the combined treatment, compaction may have broken the surface crust of the puddled soil and thus improved permeability.

This trial indicated that grass growth can be affected by soil conditions similar to those produced by treading, The effects of some of the components of these soil conditions on growth were discussed, and these are considered below in separate sections. In cases where clarity warrants plants other than grass species will be discussed.

Clearly, the soil condition has its main effect on the roots of the plant, but Troughton (1957) has stressed that all parts of the plant are mutually interdependent.

(ii) Mechanical Impedance of Roots

In a review Troughton (loc.cit.) stated that root growth is reduced when grasses are growing in a compact soil. It was suggested that this may be due to mechanical resistance or to a change in aeration.

Wiersum (1957) found that young roots of *Avena sativa* seedlings, when growing in a rigid medium, did not pass through pores smaller than the root tip. However, roots penetrated media that could easily be pushed aside, even when pore size was less than the root-tip diameter.

In the Netherlands Goedewaagen (1943) found that grass roots did not penetrate a compact sandy layer underlying clay.

Gill and Miller (1956) found that the capability of the corn root to develop its growing pressure was reduced by a decrease in the oxygen content of the soil.

Lugo-Lopez (1960) studied the root growth of three grasses in seven clay soils which had developed soil pans. It was found that root development of Para Grass (*Panicum purpurascens*) and Bermuda Grass (*Cynodon dactylon*) was restricted, but Guinea Grass (*Panicum maxima*) was able to send roots through the dense horizons. It was suggested that this might explain in part the drought tolerance of this grass.

(iii) Soil Aeration

(a) Introduction

Adequate oxygen is essential for all roots (Cannon, 1925), and within the temperature limits for root growth, the greater the soil temperature the greater must be the concentration of oxygen for normal growth (Troughton, *loc. cit.*).

The problem of soil aeration is not restricted to sufficiency of oxygen for root respiration, but is related to the concentration of carbon dioxide and reduction products in the soil. However, the same soil conditions control all three factors (Wiegand and Lemon, 1958)

Diffusion is recognised as the principal mechanism of soil aeration. It is affected by volume of air-filled pores, size of aggregates, soil moisture tension and the pressure of surface crusts (Domby and Kohnke, 1956).

(b) Air-filled pores

Oxygen enters the soil mainly by gaseous diffusion through these pores, displacing carbon dioxide which tends to diffuse in the opposite direction. This diffusion is blocked equally by soil solids and by water (Russell, 1952).

Gradwell (1961) found that in pasture topsoils a high and fairly constant proportion of air pores were inefficient as channels of aeration. Thus, studies which have reported a relationship between total pore space and grass growth or species distribution must be treated with caution.

Kopecky (1927) stated that the optimum air-capacity (air-space after 24 hours drainage) for grass ranged from 5% to 10%.

The work of Lieth (1954) was noted in Part I. It was found that except for a few species of universal significance, the distribution of grassland plants could be related to the total pore space in the soil. Perennial ryegrass was tolerant of low pore space.

(c) Soil aggregation

Doyle and Maclean (1958) showed that the diffusion of oxygen was directly proportional to aggregate size, and growth of tomatoes increased with both aggregate size and oxygen diffusion.

Many workers have shown that grasses improve the aggregation of the soil (Troughton, 1957).

In a review, Greacen (1958) stated that after the initial improvement in aggregation and organic matter under grass, there was compaction of the soil by grazing animals, machinery, and the grass roots themselves.

Troughton (1961) found that as pasture aged, the percentage of roots in the upper three inches increased. It was suggested that due to compaction of the soil the roots had been forced to grow nearer the surface in order to obtain sufficient oxygen. This may restrict plant growth and could account for the decreases in herbage yield which have been shown to occur as the sward ages. (Pollitt, 1947; Paterson, 1959).

(d) Soil moisture tension

There is an inverse relationship between soil moisture tension and aeration. The moisture content largely controls the rate of diffusion through soils by its influence on the amount of air-filled pore space in the soil volume (Russell, 1952). Thus, a water-table may reduce the aeration of the soil (Wiersma, 1959).

Eden *et al* (1951) studied the effect of varying ground water levels on the productivity and composition of Italian ryegrass grown on a calcareous light peat. A high water level (15 inches below ground surface), reduced yields by 50 - 60 per cent of that on medium and low water levels (24 inches and 38 inches below ground surface respectively). The high water level apparently interfered with nitrogen metabolism, as the crude protein content of the grass was greatly reduced in this treatment. Further, the root system showed very shallow development. It was suggested that anaerobic conditions in the topsoil may have reduced the uptake of nutrients.

Baumann and Klauss (1955) compared the root development of 42 grasses under controlled conditions in 'groundwater tubs'. The water table was maintained at 36 cm. below the surface. From the results obtained the species were classified into three main groups.

The 'Lolium' types (including *Lolium perenne*, *Lolium multiflorum*, *Festuca pratensis*, *Phalaris arundinacea*, *Agrostis alba*, *Holcus lanatus*) showed vigorous root development through the whole profile and into the region of highest moisture content. In the 'Poa' types (including *Poa pratensis*, *Poa palustris*, *Alopecurus pratensis*, *Festuca rubra*, *Phleum pratense*) only some of the roots grew into the water-table.

The 'Dactylis' group (including *Dactylis glomerata*, *Bromus inermis*, *Arrhenatherum elatius*, *Festuca ovina*) only grew in the zone of medium water content and the roots died near the water table.

The different species reaction was explained in terms of deficient aeration, with particular emphasis on the accumulation of carbon dioxide in the soil.

Michael and Bergmann (1954) studied the root growth of rye seedlings (*Secale cereale*) in soil in glass cylinders. Several soil treatments reduced the rate of root elongation, and it was suggested that the harmful effects of standing water, heavy soil and soil compaction were due to an increase in the level of carbon dioxide in the soil.

However, most workers consider that under field conditions high carbon dioxide levels are of minor significance (Slatyer, 1960).

Soper (1959) compared the anatomy of the mature parts of the roots of *Lolium perenne*, *Dactylis glomerata*, *Glyceria fluitans* and *Alopecurus pratensis*. It was found that regularly arranged large lacunae were well developed in the roots of Glyceria and Alopecurus. It was considered that they would be of value in the maintenance of maximum oxygenation of the cortex under conditions of water-logging. Considerably fewer lacunae were found in the other species, but Lolium tended to have more than Dactylis.

The effect of flooding on the plants is the result of a complex interaction of many factors, but it is broadly considered to be a problem of deficient aeration (Colman and Wilson, 1960).

Several studies have compared the flooding tolerance of grassland species (Davis and Martin, 1949; Finn et al, 1961; Luthin, 1957; Colman and Wilson loc.cit.). Grasses reported to be relatively resistant to flooding include *Alopecurus pratensis*, *Festuca pratensis*, *Phleum pratense*, *Phalaris arundinacea*, and *Lolium perenne*. Grasses that are susceptible to flooding include *Dactylis glomerata*, *Festuca rubra*, and *Bromus* species.

(e) Soil crusts

Domby and Kohnke, (1956) showed that soil crusts could restrict the diffusion of gases, but only when the underlying soil was very wet.

The significance of soil crusts in plant growth has usually been discussed in relation to the seedling emergence and establishment of crop plants (Millington, 1959; Morton and Buchele, 1960).

Millington, (1960) showed that the root growth of subterranean clover (*Trifolium subterraneum*) in pot culture was substantially reduced by the sealing of the surface soil. Although up to 90 per cent of the surface was sealed, oxygen concentration in the soil was only slightly depressed. It was stated that despite the limitations of the measurements used, restriction of root development could occur without large deviations in the oxygen concentration. However, in this study the roots had exploited a relatively constant environment.

It was suggested that if root exploitation occurs under conditions of good soil aeration, then rapid changes in air-filled porosity may give greater plant responses than those found here (Millington, loc.cit.)

(iv) General Conclusions

It has been shown that soil conditions similar to those produced by sheep treading can affect grass species.

Species appear to differ in reaction to these conditions.

It is probable that soil aeration is the chief factor.

(2) The Direct Effects of Sheep Treading on Grass Species

As information on this subject is very limited, several analagous studies are also discussed.

(A) Type of Damage

Edmond, (1958b) stated that sheep treading damaged and buried tillers of short-rotation ryegrass; but that under favourable growing conditions the reduction in the tiller density soon disappeared. This was explained in terms of Brougham's work (1956), which showed that in similar pasture rate of plant growth per unit area increased until all light energy is intercepted.

O'Connor, (1958) studied the effects of cattle and tractor treading on swards dominated by cocksfoot. The treading of unmown pastures had no apparent effect on production, but considerable reductions in yield were caused by treading on mown pastures. These were attributed to direct mechanical injury to the freshly-cut tillers of the grasses and not to soil compaction.

Underwood, (1956) observed that stock treading under dry summer conditions in Western Australia could destroy a large proportion of dry and brittle herbage.

Gullickson et al (1954) noted that cattle treading caused considerable wastage of tall herbage.

Perring, (1959) observed that the growth of the stoloniferous Phleum nodosum was encouraged through breaking of the sward by galloping horses.

(B) Plant Characters which favour Resistance to Direct Treading Damage

(i) Introduction

It has been shown that grass species differ in their reaction to soil conditions produced by treading. However, some authors have considered these species differences in terms of the plant structure above the ground with little reference to these soil factors. Thus, their observations should be interpreted with caution.

Although a similar criticism may be made of Lieth's work (Lieth, 1954), it was pointed out that the susceptibility of some species to treading was inexplicable in terms of pore space.

Furthermore, the plant types found in severely trodden areas may not be a true reflection of the resistance of the species to treading. Levy (1940) has shown that the winter treading of cattle may indirectly encourage the germination of weed seeds in the soil. Moreover, many other factors may affect the zonation of plant types (Davies, 1954).

Although Ellenberg (1952) made a more comprehensive study, the main findings were still based on "treading plant populations". It was considered that treading tolerance occurred in most important grassland plants. The characteristics of resistant plants were listed as follows:

1. Annual species with flexible stems and narrow or lacerated leaves.
2. Rosette plants with flat leaves but very tough vascular bundles.
3. Fast-growing bottom grasses with good regeneration and tillering ability.

4. Shallow rooted turf plants with creeping rhizomes or stolous.

It was suggested that although the first two groups tolerated the strongest mechanical stress, because of competition for light and nutrients, they may be displaced by the perennial species of Groups 3 and 4 when treading is less severe.

In addition it was stated that species most susceptible to treading were found in "pure mowing meadows". The main features of these species were listed as follows:

1. Tall growing stemmy plants.
2. Climbing plants.
3. Plants with a high basal leaf.
4. Slow-growing species with limited regenerative ability.

Some of these characters are now considered in relation to grass species.

(ii) <u>The position of the growing point</u>

When the tiller is vegetative, the growing point of most grasses is at or slightly below ground level (Campbell, 1961). As the stem elongates prior to flowering, it is raised well above ground level and becomes more susceptible to removal by grazing (Branson, 1953). If this occurs there is no further growth or development of the shoot, and new growth will come from vegetative tillers at the base (Davies, 1956). However, the regrowth of an undamaged shoot is far quicker than the new growth from these basal buds (Davies, <u>loc.cit.</u>).

Bates (1935) classified grass species according to the position of the growing point in relation to the soil surface. It was considered that this position was important in resistance to treading damage.

The species found in heavily trodden habitats such as footpaths, animal pathways, and road verges represented a synusia of crytophytes. Examples given included Dactylis glomerata, Lolium perenne, and Poa pratensis. Davies, (1938) and Thomas. (1959) observed that Phleum pratense and Poa annua were also common in heavily trodden areas.

The species which were sensitive to treading, and thus did not appear in these habitats, were reported to be chamaephytes. These included Agrostis spp., Festuca ovina, Holcus spp. and Agropyrou repens. (Bates loc.cit.).

These observations appear to be an over-simplification of the treading effect. Moreover, there may be only small differences in the vulnerability of the growing point in the vegetative state.

(iii) General discussion

Edmond (1960) studied the reaction of several species to different intensities of sheep treading at field capacity. Prior to each treading all species were cut by a mower for yield determinations. As plants under the heavy treading treatments were observed to adopt a more prostrate habit of growth, the adoption of a standard cutting technique for all species and treatments is subject to serious criticism.

The most resistant species were perennial ryegrass, short-rotation ryegrass and timothy. Although Poa pratensis grew slowly throughout the experiment it was also fairly resistant. The reaction of Poa trivialis was variable, but cocksfoot, Yorkshire fog and browntop were sensitive to heavy treading. Some seasonal variations were observed, but the general conclusions on the relative resistance of the species appear valid under the existing experimental conditions.

The results have been partly discussed in terms of the direct effects (Edmond, loc.cit.). The resistance of perennial ryegrass has been explained by its tendency to adopt a rhizomatous growth habit (Mitchell, 1960). Poa pratensis also has this growth form (Hubbard, 1954), but it has not been observed in short-rotation ryegrass. The performance of timothy might be explained by the protection of the growing points by a thick pad of leaf bases, whereas those of cocksfoot appeared more accessible to the hoof. The resistance of the predominantly stoloniferous species, Yorkshire fog, browntop and Poa trivialis was variable.

Mitchell (1955) stated that the form of the grass tiller may be important. From studies with short-rotation ryegrass under controlled conditions, it was suggested that tillers grown under shaded conditions produce few roots and may be susceptible to treading damage. Further, after defoliation slender narrow-leaved tillers, which may be easily destroyed by treading, develop from buds that have probably been inhibited by the defoliation process.

Langer (1959a) showed that the least developed tillers in a pasture were most susceptible to adverse conditions.

(iv) Conclusions

Although the type, extent and resultant effects of direct treading damage were not clearly defined, it can be inferred that damage to the growing point may be involved. As grazing studies have shown that removal or damage to the growing point may affect grass growth, a study of this factor in relation to treading is indicated.

PART IV

Sheep Treading Studies and Pasture Yield

(A) Method of Study

The development of a technique for the study of sheep treading was described in the Introduction to this review. It was observed (Edmond, 1958) that the driven sheep walked in a different manner to the normal grazing sheep. Moreover, the complete treatment for a particular plot is usually applied within 5 - 10 minutes.

Herbage yields are obtained by mowing the plots prior to each treatment. O'Connor, (1956) has reported that long herbage may reduce treading damage, and this factor is now under investigation (Edmond, 1961).

In order to increase treatment effects, the treatments are repeated on all plots after a similar period. It is suggested that the cumulative effects of treading could be more correctly assessed, by subjecting differently trodden plots to different growth periods depending on plant density, production, etc. (Edmond, 1958).

However, it is considered that the technique permits the study of treading as the predominant influence on the sward (Edmond loc.cit.).

(B) Results

A preliminary study, (Edmond, loc.cit.) was made in the winter and spring of 1956, on a short-rotation ryegrass/white clover pasture on Manawatu silt loam. Stocking-rate equivalents of 0, 4, 8, 12, 16 and 20 sheep/acre were applied four times during this period. The soil moisture was always near field capacity (about 40 per cent for the top 3 inches)

It was found that increases in treading produced statistically significant and progressive reductions in yield of all species. There was a linear relationship between treading rate and yield. Most of the effect was produced by the first treading.

In general, a similar relationship was obtained for numbers of ryegrass tillers and white-clover nodes. Poa spp. were affected in the same way as ryegrass.

The botanical composition of the pasture was altered by repeated treadings, and these changes were more persistent than reductions in yield. Three weeks after the final treading there were no significant differences in total yield due to treatment, except in the case of white clover. The failure of this species to recover was probably due to winter dormancy.

In a further study, similar pastures were trodden at three levels of soil moisture under summer conditions. The stocking-rate equivalents were 0, 6 and 12 sheep/acre, and the moisture levels, which were dry, moist and wet (free surface water), were created by the use of spray irrigation. Treading reduced yield irrespective of soil condition, but in contrast to white clover, short-rotation ryegrass was particularly susceptible. It appeared that treading damage was more severe in wet soil conditions (Edmond, 1957).

The general results of a trial designed to compare the relative resistance of pasture species, were discussed in Part III. These results were modified by season (Edmond, 1960).

The seasonal effect has been studied with perennial and short-rotation ryegrass pastures (Edmond loc.cit.). A rate of 10 sheep equivalents/acre was used with the soil at different levels of wetness appropriate to the season. The recovery growth in trodden plots was consistently delayed in summer, autumn and winter, but in the spring the results were inconclusive. Treading reduced growth less than in previous experiments. It was noted that the soil type used in this experiment was less likely to become saturated than that type used in the other trials.

(C) Conclusions

Under the conditions of these experiments it is concluded that the main pasture species used in New Zealand are the least sensitive to treading damage. Soil moisture, soil type and the season may influence the treading effect.

CHAPTER III

MATERIALS AND METHODS

This section is presented in four parts, as follows:

I The Development of the Artificial Hoof.

II The Experiment.

III A Description of the Area used, Layout and Establishment of Plots, and the Application of Treatments.

IV Sampling Methods and Experimental Techniques.

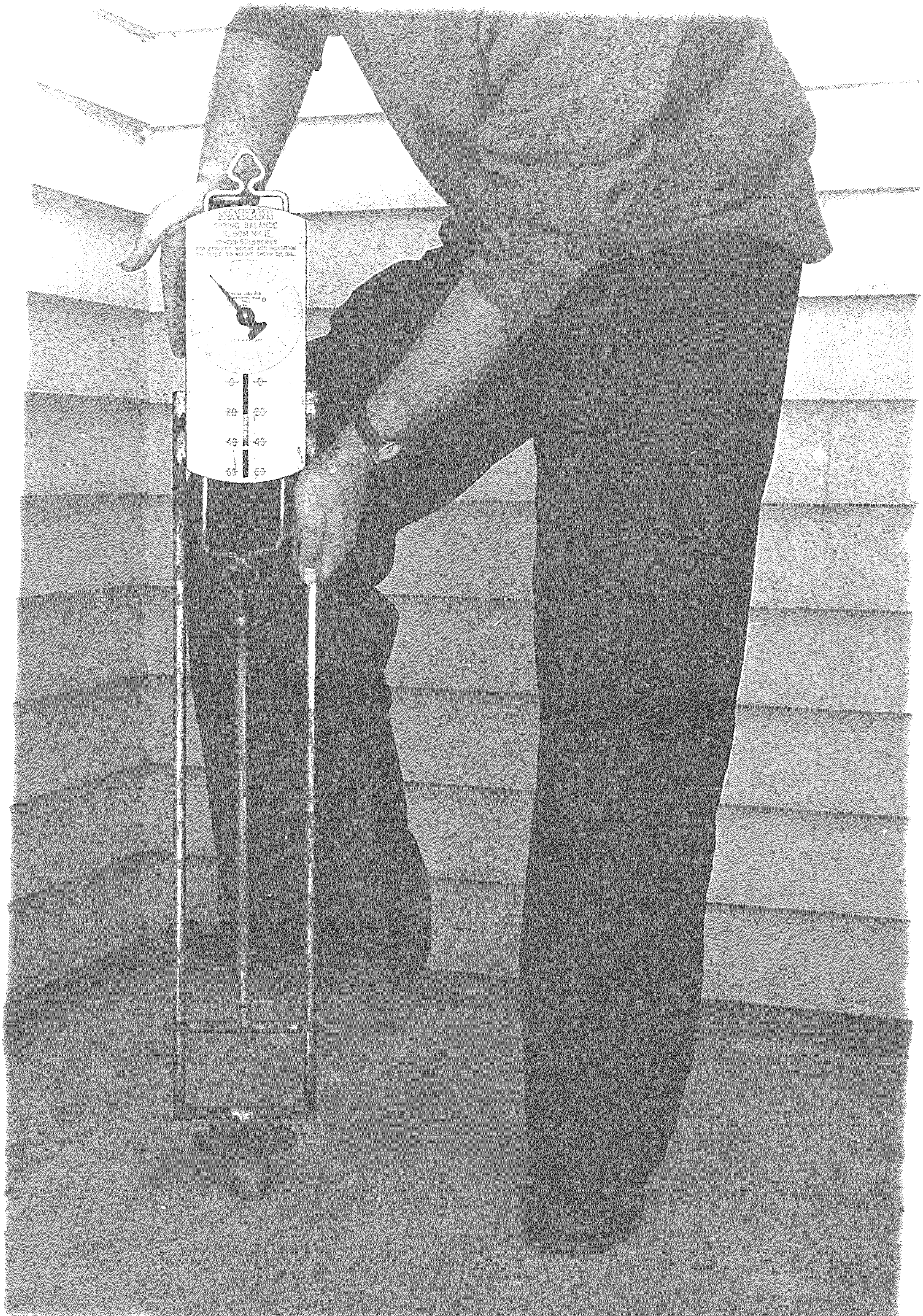

Fig. 1   The Artificial Hoof

PART I

The Development of the Artificial Hoof

A. The bearing area of the sheep's hoof

Myers (1955) suggested that in 'normal' soil the hoof print area of dairy cows was 20% greater than the apparent bearing area.

It was assumed that this would also apply to sheep. Therefore, measurements were made of clearly defined hoof prints in a paddock grazed by Two-tooth Romney wethers, on the Crop Demonstration Area, Massey Agricultural College. The area of each print was calculated from the mean of four length and four breadth measurements. It was realized that the size of the print would vary according to the soil conditions and the weight and movement of the animals. The mean area of twenty hoof prints was 2.5 ± 0.13 sq. ins. (Appendix 2.1.). This was equivalent to a bearing area of 2.0 sq. ins., and was similar to values suggested by Sears (1956) and Seton (1958).

B. The hoof load of the grazing sheep

The implications of body weight changes and animal movement were discussed earlier. No direct evidence of the hoof load of the grazing sheep was found in the literature. However, it was concluded from the work of Myers (1955) and Lull (1959) that it was probably 20-30 p.s.i.

C. The design and operation of the artificial hoof

The apparatus was designed and built in the Agricultural Engineering Department, Massey Agricultural College. It is illustrated in Figure 1.

The spring balance, which could weigh up to 60 lbs., was supported by a frame made of $\frac{1}{2}$in. bright steel tubing. When the operator applied foot pressure to the central rod, it was possible to measure the total weight under the basal plate.

In a preliminary investigation, slow motion films (Chang, 1960) showed that the grazing sheep walked in the manner postulated by Muybridge (1899). A telescopic lens was used to obtain a close view of the hoof, but due to the continual movement of the animals and the length of the grass the results were unsatisfactory.

It was intended that the artificial hoof should apply a defined weight to the sward, and therefore it was decided that the hoof should be placed flat on the ground. There was little evidence of the precise effect of a 'heel first' action and it was considered that an attempt to imitate this motion was unjustified. Similarly, the effect of a 'twist' (Davies, 1938) as the hoof leaves the ground was ignored.

A sheep's hoof (including 1 in. of metacarpal bone), from a recently killed animal, was attached to the lower side of the basal plate with 'Araldite' adhesive. It was found that the hoof had retained its flexibility, and was severely damaged by repeated treading. Moreover, the metacarpal bone was fractured.

In the main experiment it was essential that the hoof should maintain its shape throughout the treatment period. It was decided not to use a 'soft' hoof, which would have taken account of factors like 'claw-spreading' (Myers, 1955).

A dried hoof was removed from the skin of a mature Romney wether. A black steel casing was made and welded to the centre of the basal plate.

This was filled with 'Araldite' and the metacarpal bone inserted. The hoof was reinforced with the adhesive to give a solid flat surface of 2 sq. ins. As this structure was quite different from a 'normal' flexible hoof, it was decided to terminate the study of the sheep's hoof.

In order to avoid undue strain on the balance springs it was resolved to apply 20 p.s.i. through the artificial hoof.

As the bearing area of the hoof was 2 sq. ins., a weight of 40 lbs. on the balance would give the required effect. The reading on the spring balance was noted when equilibrium was reached with a 40 lb. weight on a Fairbanks scale balance. The data for this repeatability test are shown in Appendix 2.2. The mean value was 40 ± 0.2 lbs., an error of about 3%, which was considered a reasonable standard of accuracy. Thus, the mean weight under the hoof was about 20 p.s.i.

PART II

The Experiment

The object of this experiment was to study the reaction of five pasture species - Lolium perenne L., Phleum pratense L., Dactylis glomerata L., Agrostis tenuis Sibth. and Poa pratensis L. - to an artificial treading treatment. These species had shown variable resistance to sheep treading (Edmond, 1961). They probably differed in the relative positions of the growing points (Hubbard, 1954; Branson, 1953). Unfortunately the combined effects of poor establishment and an attack of Puccinia coronata (Cruickshank, 1957) eliminated Poa pratensisL. from the experiment.

A simple comparison was made between untrodden (UT) and trodden (T) areas of each species. A weight of 20 p.s.i. was applied with the artificial hoof; and this was repeated four times on each trodden sub-plot. The treatment was carried out in the Autumn and Spring of 1961.

The species yield of dry herbage, for UT and T sub-plots, was measured in the Autumn and Spring at regular intervals over a period of several weeks. It was postulated that the resulting growth curves would give an indication of the severity and duration of the treading effect. Tiller counts for ryegrass, timothy and cocksfoot were made at each sampling date.

A technique was developed to show the percentage of tillers with their growing point above the ground. In the Spring trial, changes in this position were followed, and the percentage of tillers showing internode elongation and flowering were noted.

The compaction of the soil at different depths was measured by bulk density determinations. The soil moisture content at each treading was recorded.

PART III

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

A. The Experimental Area

The experiment was conducted on part of the Crop Demonstration Area, Massey Agricultural College, which, in 1957-58, had grown drills of cereals, legumes and forage crops, and had then been left in fallow.

The area sloped gently to the north-east, and the soil type was similar to that described in the Soil Bureau bulletin No. 5 (1954) as an Ohakea Loam. In describing the soil, Pollock (1959) stated that it was 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 of the intermediate terrace comprises a fairly heavy silt loam (0.8 in.) overlying a silty clay loam to clay loam subsoil which extends to a depth of 20 - 30 ins. This is underlain by a claying gravel which becomes straight gravel with depth.

The Crop Demonstration Area was tile-drained in 1948 at intervals of approximately 30 ft.

B. Experimental Layout

A simple randomized split plot layout was used in this experiment.

After a consideration of the size of the area, species comparisons, and the single treading treatment, it was decided to divide the split plot layout into four 'blocks'. Figures available at Grasslands Division, Palmerston North, showed that, in a randomized block design, 4 - 5 replicates

Ba — PERENNIAL RYEGRASS.
Bd — TIMOTHY
Bc — COCKSFOOT

Bt — BROWNTOP
Bp — POA PRATENSIS

UT — CONTROL.
T — TRODDEN

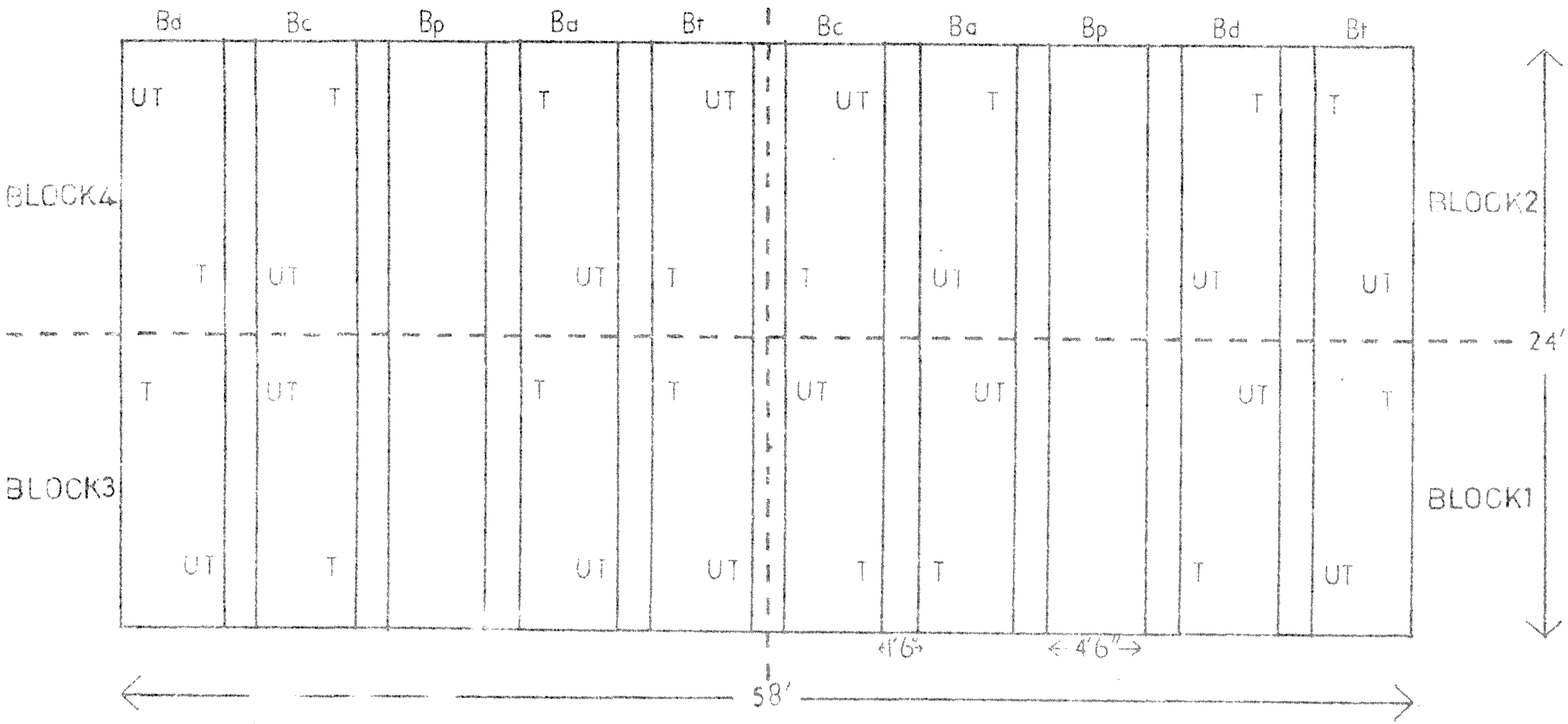

FIG.2 PLAN OF EXPERIMENTAL AREA

LAYOUT FOR THE AUTUMN TRIAL

were satisfactory in sheep treading trials.

Cochran and Cox (1957) have discussed the relative merits of split plot and randomized block layouts.

It was suggested (Glenday, 1960) that the randomization of treatments within each 'block' would be the most efficient design for this experiment.

The plots were laid out on an area 24 ft. by 58 ft.. The ten species plots measured 4 ft. 6 in. by 24 ft., and an 18 in. headland was left between each plot. It was considered that cultivation of this headland would reduce the spread of volunteer white clover.

The layout for the Autumn trial is shown in Figure 2.

C. Establishment of the Plots

The area was rotary-hoed and rolled in April, 1960.

Seeds of the species were broadcast by hand on April 28th, 1960 as follows:

N.Z. Cert. Perennial Ryegrass	-	equivalent	to	30 lbs/acre.
N.Z. Cert. Timothy	-	"	"	15 lbs/acre
N.Z. Cert. Cocksfoot	-	"	"	20 lbs/acre
N.Z. Standard Browntop	-	"	"	10 lbs/acre
Poa pratensis	-	"	"	17 lbs/acre

As stated earlier the *Poa pratensis* seed, which came from Iowa, failed to establish satisfactorily, and was excluded from the experiment.

Each plot was individually raked after sowing.

The equivalent of 3 cwt. superphosphate/acre, 1 cwt. sulphate of potash/acre and 1 cwt. sulphate of ammonia/acre was broadcast by hand on to the seed-bed on April 29th.

The four remaining species established satisfactorily. The plots were twice mown to be a height of 2ins. during the Spring. Inter-plot cultivation and weeding was also carried out. The plots were grazed by sheep for two short periods during the Summer. By March, 1961, all four species showed satisfactory development. Perennial ryegrass was affected by Puccinia coronata, but recovered by the start of the Autumn trial.

Prior to the Spring treading, the plots were top-dressed with the equivalent of 3 cwt. sulphate of ammonia/acre.

D. Application of Treatments.

The treatments were applied on April 12-13 and September 12-13. In each case approximately ½ in. of rain had fallen 2-3 days earlier, but none fell during the treatment periods.

Prior to each treatment the plots were mown to a height of 1 in. with a 'Lawnmaster' mower. It was assumed that roller compaction was spread equally over the area.

In order to avoid the excessive growth on the edge of the plots, the control and trodden sub-plots (each 5ft. x 1ft.) were placed 1ft. from the cultivated ground.

In the treading treatment it was intended to cover the complete area of each species sub-plot with a weight of 20 p.s.i. repeated four times. The hoof was placed on the ground and pressure applied until the balance read 40 lbs. As the breadth of the hoof was almost 1.25 ins. a 1 ft. ruler was placed across the plot and the area trodden at 1.25 ins. intervals. The ruler was then moved down the plot 1.75 ins. (length of hoof - 1.7 ins.) and the process repeated. The plot was then trodden in the reverse direction. A similar method was followd in the two lengthwise treadings of the plot.

The entire treatment was completed in two days. The four'blocks' were trodden in random order (4, 2, 3, 1), and to minimize any differential effect of regrowth during the treatment period, the plots were trimmed back to 1 in. when the treatment was completed. All the plots were subsequently sampled on the same date.

PART IV

Sampling Methods and Experimental Techniques

A. Method of sampling each sub-plot

The following information was sought:

1. Yield of dry weight of the sown grasses, other grasses and other species.
2. Tiller counts of perennial ryegrass, cocksfoot, timothy and other grasses.
3. Definition of the position of the growing point of the sown grasses in relation to ground level.

The requirements of 2. and 3. indicated the use of a plug technique. The tiller plugs described by Mitchell and Glenday (1958) were unsatisfactory for growing point determinations, because the soil surface was deformed by the sampling technique.

Figures available at Grasslands Division, suggested the ryegrass yields and tiller counts obtained from 1 sq.ft. quadrats gave a coefficient of variation of 20% - 30%. In a consideration of sub-plot size and a convenient sample size, it was decided that a quadrat of $\frac{1}{4}$ sq.ft. would have to suffice in this experiment.

Therefore, at all sampling dates a plug of 7 ins. x 7 ins. x $1\frac{1}{2}$ ins. was removed from each sub-plot with a spade; any damage to the remainder of the area being reduced by lifting the plug from the side of the sub-plot. A minimum distance of 6 ins. was allowed between samples in any one sub-plot. All the required data were obtained from a 6ins. sq. quadrat within the 7ins. sq. plug. At each sampling date the surrounds of the sub-plots were cut to 1 in. with hand shears.

The 32 plugs were removed to the laboratory and stored in a refrigerator at 2°C. In the analysis period of 4 - 5 days there was probably little change in the material.

In the Autumn trial the plots were sampled at monthly intervals over a period of three months. In the Spring trial the plots were sampled five times over a period of two months.

B. Yield measurement

A 6ins.sq. quadrat was cut at ground level from the plug at each sampling date, and dissected into sown grasses, other grasses and other species. The herbage was dried in a Wilco Electric oven for 24 hours at 105°C., and then removed to a desiccator for 1 hour. The dry weight yields (to .01gm) were obtained by using a Mettler B.6 balance. 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. Tiller counts

The value of the tiller as a unit of measurement in pasture studies was pointed out by Mitchell and Glenday (1958), but Langer (1959a) stated that tiller counts gave no indication of qualitative changes.

In this study a tiller was defined as a live shoot which, by inspection, appeared to have an individual existence. However, the rooting habit of each tiller was not observed. Moreover, Langer (1959b) has pointed out that very young tillers may depend partly upon nutrient supplies from elsewhere in the plant for their production in the early stages of growth.

Tiller counts of perennial ryegrass, timothy, cocksfoot and other grasses, were made at all sampling dates from the 6in.sq. quadrat used for yield determinations.

D. Growing point measurements

The work reported by Bates (1935) did not give any details of the experimental method.

The technique used in this experiment was developed during the Autumn trial. At the final sampling date, it was used to show the percentage of tillers of the sown grasses with their growing points above the soil surface. In the Spring trial this measurement was made at all sampling dates, and tillers that showed internode elongation and flowering were also noted.

The growing points were divided into two classes according to their position above or below the soil surface. 75 tillers were cut at ground level from the centre of each 6in.sq. quadrat without regard for differences in the total number of tillers. If the tillers had been sampled from a standard area of the quadrat, the results would have been based on a variable number of tillers.

A pair of thin dissecting scissors was used to cut the tillers. If any part of the growing point was found at the base of the cut tiller, it was classed as above the soil surface.

The ground level was uneven, and in a few cases fresh worm casts buried several tiller bases. In order to avoid this effect these tillers were cut at the level of the surrounding ground. Older worm casts were regarded as part of the soil surface.

It was observed that individual grass plants often grew in a slight depression in the ground. This was assumed to be a change in ground level, and therefore the tillers were cut to this level.

E. Soil moisture measurements

One core was removed from each sub-plot with a standard soil moisture sampler. The samples were taken at the end of the first day of the Autumn and Spring treading treatments.

A sample representative of the $\frac{1}{2}$ - 2 ins. layer of the soil was weighed on a Mettler K7 balance (to 0.1gm.), and dried in a Wilco Electric oven for 24 hours at 105°C. The top $\frac{1}{2}$ in. of the core was removed, because it was considered that the large amount of plant roots in this zone would give a false value for the soil moisture.

The dried sample was weighed and the moisture content expressed as a percentage of the dried soil.

F. Bulk density determinations

A simple core sampler was used to remove one core of standard cross-sectional area (2.28sq.cm.) from each sub-plot. Each one was then carefully cut into sections representative of the 0 - 2cm., 2 - 4cm. and 4 - 6cm. layers of the soil. In the Spring trial the 6 - 8cm. layer was also sampled. In each case the samples were taken approximately one month after treading.

The wet and dry weights of each section were obtained using a Mettler B.6. balance and the Wilco oven. The bulk density was then calculated.

CHAPTER IV

Results and Discussion of the Autumn Trial

This chapter is presented in two parts as follows:

I Results

II Discussion

The results are presented in nine sections as follows:

A. The artificial treading treatment.

B. Statistical techniques.

C. The dry weight yield of each species.

D. Tiller counts of perennial ryegrass, timothy and cocksfoot.

E. The dry weight yield of other species.

F. The dry weight yield of *Poa spp*.

G. Growing point measurements.

H. Soil moisture data.

I. Bulk density measurements at three depths.

(For abbreviations used in this text, see Appendix 1.)

A. The artificial treading treatment

The treading treatment for each sub-plot was completed in $1\frac{1}{2}$ hours. It was noted that slight penetration of the soil surface occurred in the perennial ryegrass, cocksfoot and timothy plots, and the hoof prints were still visible at the end of the experimental period (July 6th).

Some tillers and leaves of these species were broken and/or pushed below the soil surface, but this effect soon disappeared. Close observation failed to reveal whether this was due to the death of the affected parts or to recovery growth.

The hoof did not penetrate the surface 'mat' of browntop, but the treading effect appeared to be more severe in this species.

B. Statistical techniques

In the statistical analysis of the results it was assumed that the layout of the experiment was a randomized block design (Glenday, 1961).

Each sown species was analysed individually at each sampling date.

If species appeared to differ in their reactions to treading, a combined analysis of variance of all species was performed. The validity of this analysis was dependent on the assumption that the data were homogeneous.

C. The dry weight yield of each species

The mean yields and standard errors, in lbs. dry weight per acre, are presented in a summarized form in Tables 1 - 4, together with the results of the analyses of variance. Further details are given in Appendices 3 - 6.

TABLE 1

Mean dry weight yield. Perennial ryegrass *

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	503	761	928	720
T	469 ±84	825 ±152	949 ±49	793 ±42
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 2

Mean dry weight yield. Timothy

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	515	763	1026	562
T	453 ±45	804 ±64	880 ±87	579 ±30
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 3

Mean dry weight yield. Cocksfoot

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	461	752	917	719
T	463 ±40	704 ±84	767 ±40	584 ±68
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.
			N.S.	

TABLE 4

Mean dry weight yield. Browntop

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	788	1466	1550	1076
T	855 ±52	1238 ±99	1123 ±155	820 ±39
Results of analysis of variance	N.S.	N.S.	N.S.	*
			*	

* UT - Control
T - Trodden

The results for April 13th represent the yield at the time of treading. No significant differences between UT and T sub-plots were detected.

There were no significant treatment effects at any stage in ryegrass and timothy. In cocksfoot there was a significantly higher yield (10% level) in U.T. plots on June 8th (Appendix 4.11). In browntop there was a significantly higher yield (5% level) in UT plots on July 6th.

It appeared that species differed in their reaction to treading. The variances obtained (Appendix 4) showed that at the third sampling date, browntop had a considerably higher variance than the other species. At the other post-treading sampling dates the differences were smaller.

The main results of the combined analyses of variance are shown in Table 5.

TABLE 5

Analyses of variance of the combined yield of all species at each sampling date

Results of Species X Treatment interaction

Date / F	11.5.61	8.6.61	6.7.61
F value	<1.00	3.13	5.02
F required	3.49	3.49	3.49 (5.95)
Result	N.S.	N.S.	*

Although the interaction was significant at the 10% level on June 8th, for the reasons outlined above, this result was interpreted with caution. However, the significant result obtained at the final sampling date was particularly important. Thus it was confirmed that species differed in

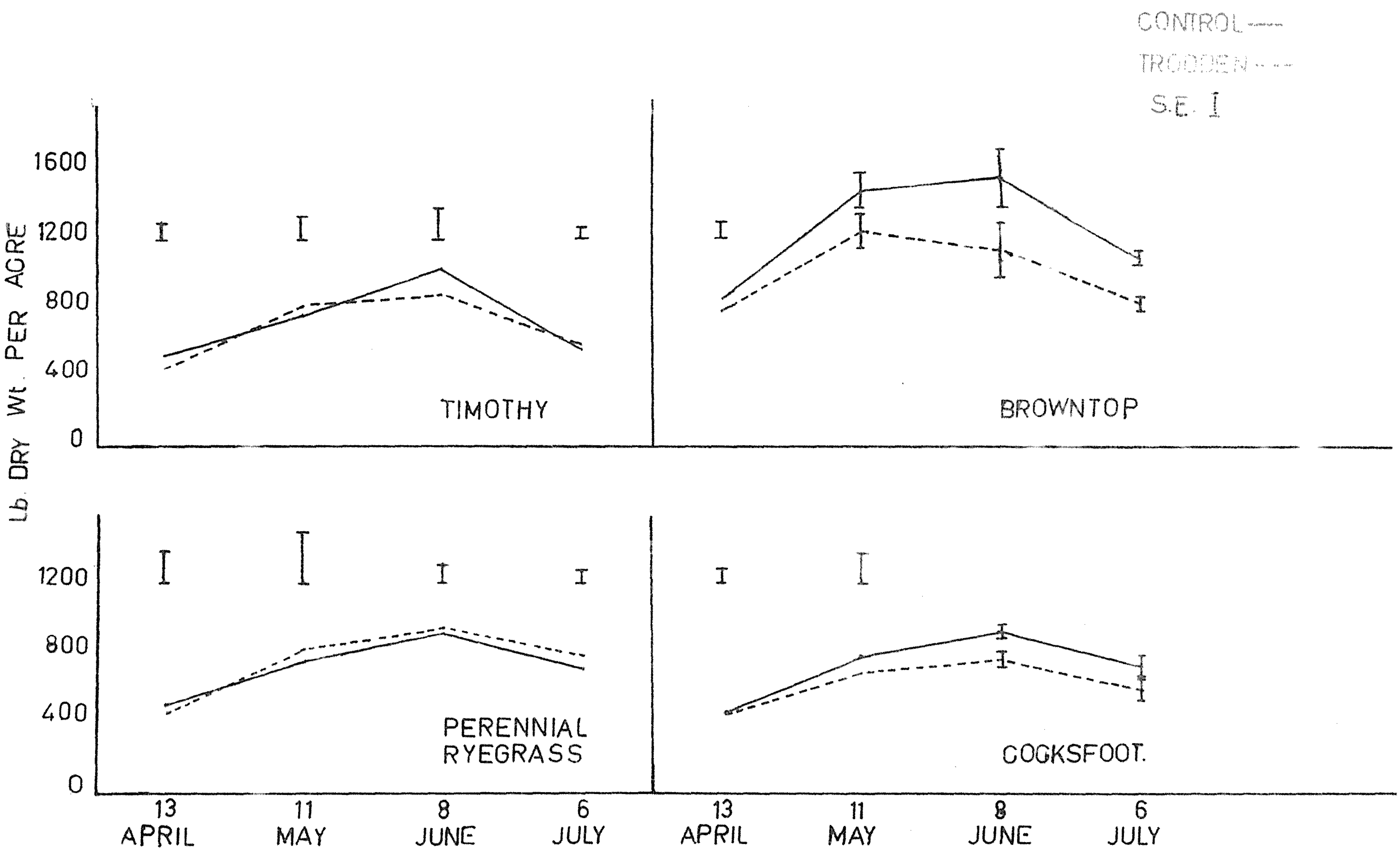

FIG.3. DRY WEIGHT PRODUCTION CURVES AUTUMN TRIAL.

their reaction to treading.

The individual analyses indicated that browntop was more severely affected than cocksfoot. In order to confirm this evidence, and also to test for changes in the treading effect with time, analyses of variance, of the combined yields over three sampling dates, was performed in each species (Appendix 6). There were considerable changes of variance in browntop over the period.

In cocksfoot the overall treatment effect approached significance at the 10% level, while in browntop the effect was significant at the 5% level. No dates x treatment interaction was found in either case. Although the validity of this test was doubtful, it was concluded from the overall evidence that browntop was more susceptible to treading than cocksfoot.

The growth curves of the species are shown in Figure 3. Significant dry weight changes between sampling dates were determined by using the following (Glenday, 1961b) approximate "t" test:

$$d_{0.05} \doteqdot t_{E.d.f.}\sqrt{\frac{S_1^2 + S_2^2}{n}}$$

In this experiment the degrees of freedom for error were 3; the number of observations n were 4; and S_1 and S_2 were the standard errors at adjacent sampling dates. It was realized that the result of this test only indicated general trends. Therefore, individual anomalies were interpreted with caution. The results are shown in Table 6.

TABLE 6

Results from testing for changes in mean dry weight yield with approximate "t" test.

Species	Treatment	13.4.61-11.5.61	11.5.61-8.6.61	8.6.61-6.7.61
Perennial ryegrass	UT	*	N.S.	**
	T	*	N.S.	*
Timothy	UT	**	*	**
	T	**	N.S.	**
Cocksfoot	UT	**	*	*
	T	**	N.S.	*
Browntop	UT	**	N.S.	**
	T	**	N.S.	*

It appeared that the pattern of growth, between species and between treatments, was very similar. In the first period all plots showed a significant increase in yield. In the second period only the UT plots of timothy and cocksfoot showed a significant increase in yield. In the final period all plots showed a significant decrease in yield.

D. Tiller count of perennial ryegrass, cocksfoot and timothy

The mean tiller numbers and standard errors per 36 sq.ins. at each sampling date, together with the results of the analyses of variance, are shown in Tables 7 - 9. Further details are given in Appendices 7 and 8.

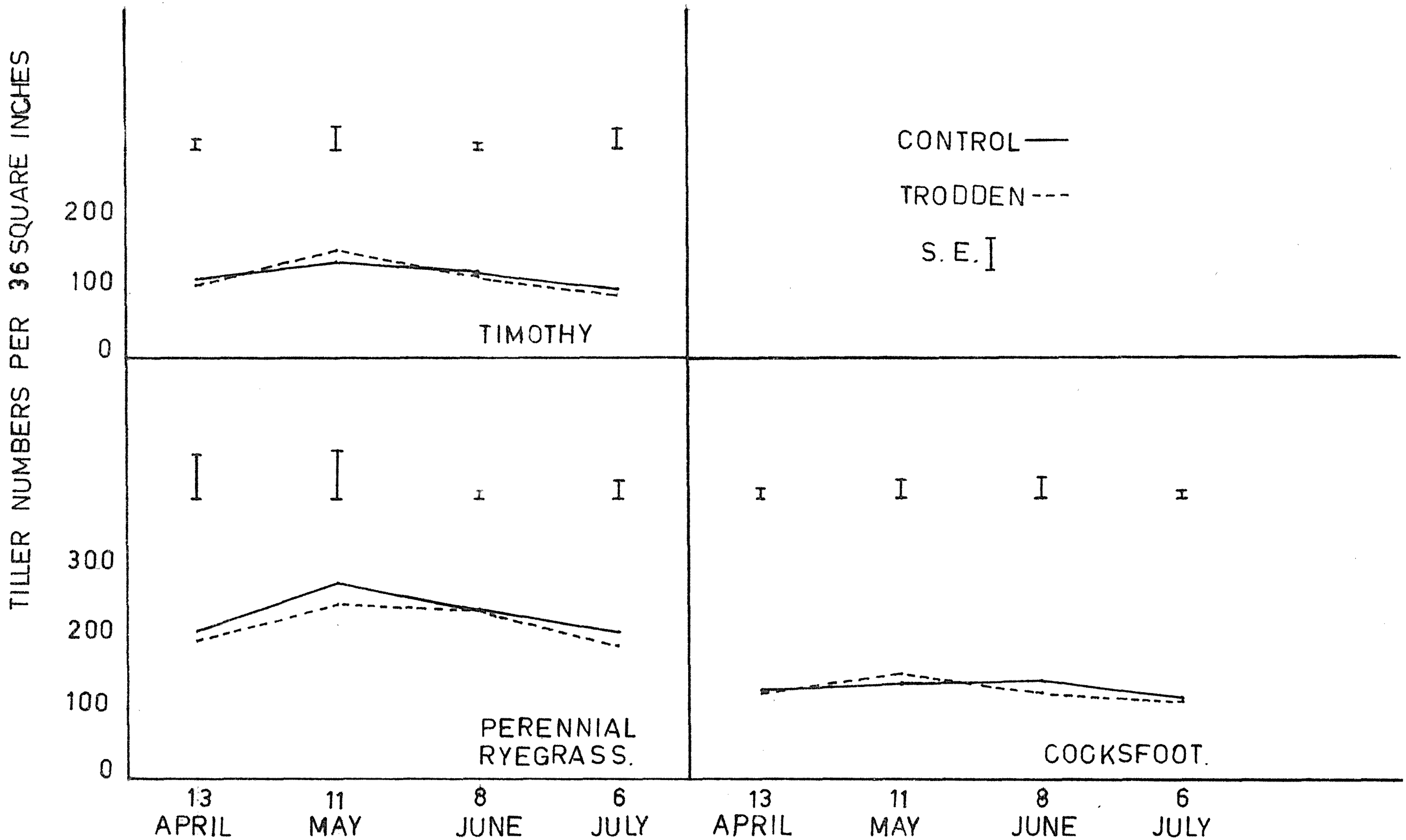

FIG.4 TILLER COUNTS. AUTUMN TRIAL

TABLE 7

Mean tiller numbers

Perennial ryegrass

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	210	281	243	212
	±31	±34	±6	±13
T	199	248	242	193
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 8

Mean tiller numbers

Timothy

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	116	141	125	100
	±8	±16	±4	±14
T	109	159	121	97
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 9

Mean tiller numbers

Cocksfoot

Date / Treatment	13.4.61	11.5.61	8.6.61	6.7.61
UT	126	139	141	114
	±8	±13	±15	±7
T	122	149	123	110
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

There were no significant treatment effects at any stage. The changes in tiller numbers over the experimental period are illustrated in Figure 4, and the results from using the approximate "t" test are presented in Table 10.

TABLE 10

Results from testing for changes in mean tiller number with approximate "t" test

Species	Treatment	13.4.61-11.5.61	11.5.61-8.6.61	8.6.61-6.7.61
Perennial ryegrass	UT	*	N.S.	*
	T	N.S.	N.S.	**
Timothy	UT	N.S.	N.S.	*
	T	*	*	*
Cocksfoot	UT	N.S.	N.S.	*
	T	*	N.S.	N.S.

In the first period the UT plots of perennial ryegrass, and the T plots of timothy and cocksfoot, appeared to show a significant increase in tiller numbers. In the second period the timothy T plots showed a significant decrease in tiller numbers. In the final period only the cocksfoot T plots failed to show a significant decrease in tiller numbers.

In some cases significance was only just reached, while in others it was only just missed. However, observation of the plots suggested that, in fact, the differences between the UT and T plots of timothy and cocksfoot did occur.

E. The dry weight yield of other species

The main species present were:

Sagina procumbens L. - Prostrate Pearlwort.

Trifolium dubium Sibth. - yellow suckling clover or little trefoil.

Trifolium repens L. - white clover.

Rumex acetosella agg. - sheep's sorrel.

Crepis capillaris (L.) Wallr.- Smooth Hawksbeard.

The mean yields and standard errors, in lbs. dry weight per acre of all other species within each sown species plot, at each sampling date, are shown in Tables 11 - 14. The results of the analyses of variance are also given. Further details are shown in Appendices 9 and 10.

TABLE 11

Mean dry weight yield of other species in Perennial ryegrass plots

Treatment / Date	13.4.61	11.5.61	8.6.61	6.7.61
UT	85	149	79	52
	±7	±22	±9	±31
T	70	67	83	81
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 12

Mean dry weight yield of other species in Timothy plots

Treatment / Date	13.4.61	11.5.61	8.6.61	6.7.61
UT	119	117	131	131
	±21	±17	±9	±8
T	141	138	78	150
Results of analysis of variance/	N.S.	N.S.	*	N.S.

TABLE 13

Mean dry weight yield of other species in Cocksfoot plots

Treatment / Date	13.4.61	11.5.61	8.6.61	6.7.61
UT	128	106	114	139
	±13	±22	±21	±28
T	34	14	73	85
Results of analysis of variance	*	N.S.	N.S.	N.S.

TABLE 14

Mean dry weight yield of other species in Browntop plots

Treatment / Date	13.4.61	11.5.61	8.6.61	6.7.61
UT	96	83	64	65
	±7	±32	±26	±5
T	104	64	87	82
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

In the cocksfoot plots there was significantly (5% level) more other species in the UT treatment at the time of treading, this difference being significant at the 10% level at the second and fourth sampling dates.

In the perennial ryegrass plots there was significantly (10% level) more other species in UT plots at the second sampling. In the timothy plots there was significantly (5% level) more other species in the UT plots at the third sampling. In the browntop plots there was significantly (10% level) more other species in the T plots at the fourth sampling.

As there were more other species in cocksfoot UT plots prior to treading, it was decided to exlude the data from these plots from any further analysis of the treatment effects.

It was observed that some of the species, within the other species group, were affected by treading. It was not possible to perform analyses of variance on the data for each of these species, as they were frequently absent from individual sub-plots. Thus, the mean and standard error of the yield of each species at the time of treading, was compared with the mean and standard error of the cumulative yield for the whole post-treading period (three sampling dates). The data (Appendix 11) were derived from yields in perennial ryegrass, timothy and browntop plots, and they are presented in a summarized form in Tables 15 - 19.

TABLE 15

Mean dry weight yield of Sagina procumbens L.

Date / Treatment	Time of treading 13.4.61	Post-treading period 11.5.61, 8.6.61, 6.7.61
UT	11	85
T	35	39
± S.E.	±11	±13
$d_{0.05} \doteq$ 3 S.E.	N.S.	*

TABLE 16

Mean dry weight yield of Trifolium dubium Sibth.

Date / Treatment	Time of treading 13.4.61	Post-treading period 11.5.61, 8.6.61, 6.7.61
UT	51	63
T	7	106
± S.E.	±7	±31
$d_{0.05} \doteq$ 3S.E.	*	N.S.

Table 17

Mean dry weight yield of Trifolium repens L.

Date / Treatment	Time of treading 13.4.61	Post-treading period 11.5.61, 8.6.61, 6.7.61
UT	86	95
T	109	146
± S.E.	±17	±28
$d_{0.05} \doteq$ 3S.E.	N.S.	N.S.

TABLE 18

Mean dry weight yield of Rumex acetosella agg.

Date / Treatment	Time of treading 13.4.61	Post-treading period 11.5.61, 8.6.61, 6.7.61
UT	48	112
T	61	119
± S.E.	±25	±23
$d_{0.05} \doteq$ 3S.E.	N.S.	N.S.

TABLE 19

Mean dry weight yield of Crepis capillaris (L) Wallr.

Date / Treatment	Time of treading 13.4.61	Post-treading period 11.5.61, 8.6.61, 6.7.61
UT	25	142
T	47	143
± S.E.	±15	±31
$d_{0.05} \doteq$ 3S.E	N.S.	N.S.

It was considered, that because of the large variation in yields and the method of grouping the harvests, only general conclusions were justified. However, it appeared that treading reduced the yield of *Sagina procumbens L.*, but increased the yield of *Trifolium dubium Sibth.* The other species appeared to be unaffected.

F. The dryweight yield of Poa spp.

The yield data of *Poa spp.* were treated in the same way as the individual species above, except that the results from the cocksfoot plot were also included. Only trace amounts were present at the time of treading.

The results are detailed in Appendix 12 and summarized in Table 20.

TABLE 20

Mean dry weight yield of Poa spp.

Treatment / Date	11.5.61	8.6.61	6.7.61
UT	73	79	101
T	53	67	170
	±23	±16	±37
$d_{0.05} \doteq 3.S.E.$	N.S.	N.S.	N.S.

There appeared to be a slight (non-significant) increase in *Poa spp.* in the T plots at the final sampling.

As the total yield was small no tiller counts were made. Other grass species were present in negligible amounts.

G. Growing point measurements

These data were expressed as the percentage of tillers with their growing point above the soil surface.

Snedecor (1959) stated that if the variable consisted of the proportion of individuals affected, the distribution tended to be binomial in form.

As a wide range of percentages was found in this work, the data were transformed to the angle whose sine is the square root of the percentage (Snedecor, loc. cit.).

The measurements were made on the final sampling date of the experimental period. It was realized that the method used to avoid the effects of fresh worm casts was subjective. However, as very few casts were observed on the soil surface in this period, the effect was probably small.

The means and standard errors of the transformed data (true percentages shown in brackets), together with the coefficients of variation and the results of the analyses of variance are shown in Table 21. Further details are given in Appendices 13 and 14.

TABLE 21

Transformed data and true mean percentages of growing points above the soil surface

Treatment \ Species	Perennial ryegrass	Timothy	Cocksfoot	Browntop
UT	56 (69)	52 (62)	62 (78)	50 (59)
	±1	±4	±3	±5
T	53 (64)	57 (70)	60 (75)	51 (60)
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.
Coefficient of variation (%)	3.6	15.4	10.9	19.3

There were slightly (approached the 10% level) more growing points above ground in the UT sub-plots of perennial ryegrass. There were no significant differences in the other species.

An analysis of variance (Appendix 14) of the combined species showed that there was a significant species difference (5% level). The transformed species means and standard errors are shown in Table 22.

TABLE 22

Relative mean occurrence of growing points above the soil surface

Species	Mean and S.E.
Perennial ryegrass	54.5 ± 0.7
Timothy	54.5 ± 2.8
Cocksfoot	61.0 ± 1.7
Browntop	50.5 ± 3.5

There were no significant differences between perennial ryegrass, timothy and browntop, but cocksfoot had significantly more growing points above the soil surface than browntop.

H. Soil moisture data

The measurements were made at the time of treading. The data were expressed as the percentage of oven-dried soil, and as the range of values was small (Appendix 15) they were not transformed.

Analyses of variance (Appendix 16) of the individual species did not reveal any differences between UT and T sub-plots and between species. The overall mean was 25.8%.

I. Bulk density measurements at three depths

These measurements were made one month after treading, and were expressed as grams per cubic centimetre of oven-dried soil.

The treatment means and standard errors for each species at each depth, together with the results of the analyses of variance are presented in Tables 23 - 26. Further details are shown in Appendices 17 and 18.

TABLE 23

Mean bulk density measurements. - Perennial ryegrass plots

Depth / Treatment	0 - 2cms.	2 - 4cms	4 - 6cms.
UT	1.21	1.20	1.16
	±0.013	±0.007	±0.024
T	1.40	1.28	1.25
Results of analysis of variance	**	**	N.S.

TABLE 24

Mean bulk density measurements. Timothy plots

Depth / Treatment	0 - 2cms.	2 - 4cms.	4 - 6cms.
UT	1.17	1.24	1.20
	±0.014	±0.014	±0.036
T	1.39	1.32	1.24
Results of analysis of variance	**	*	N.S.

TABLE 25

Mean bulk density measurements. Cocksfoot plots

Depth / Treatment	0-2cms	2 - 4cms	4 - 6cms
UT	1.20	1.24	1.18
	±0.039	±0.031	±0.019
T	1.40	1.32	1.27
Results of analysis of variance	*	N.S.	*

TABLE 26

Mean bulk density measurements. Browntop plots

Depth / Treatment	0 - 2cms	2 - 4 cms	4 - 6 cms
UT	1.19	1.20	1.18
	±0.039	±0.039	±0.024
T	1.29	1.30	1.26
Results of analysis of variance	N.S.	N.S.	N.S.

In perennial ryegrass treading caused significant increases in the bulk density in the 0 - 2 and 2 - 4 cms. depths. In the 4 - 6 cms. depth the increase was significant at the 10% level.

A similar result was obtained with timothy except that the result for the 4 - 6 cms. depth was non-significant.

In cocksfoot significant increases were found in the 0 - 2 cms. and 4 - 6 cms. depths. The increase in the 2 - 4 cms. depth approached significance at the 10% level.

In browntop the increases in the 0 - 2 cms. and 2 - 4 cms. depths approached significance at the 10% level. In the 4 - 6 cms. depth the increase was significant at the 10% level.

It was noted that there were differences in variation between species and between depths. These are shown in Table 27.

TABLE 27

Bulk density measurements. Coefficient of variation(%)

Depth / Species	0 - 2cms.	2 - 4cms.	4 - 6cms
Perennial ryegrass	2.0	1.1	3.9
Timothy	2.2	2.2	5.9
Cocksfoot	5.9	4.8	3.1
Browntop	6.2	6.2	3.9

Cocksfoot and browntop showed similar variation in the 0 - 2cms. and 2 - 4cms. depth, but there was a decrease in the 4 - 6cms. depth. Perennial ryegrass and timothy showed a reversal of this pattern.

PART II

DISCUSSION

The discussion is presented in eight sections as follows:

A. Total yield of sown species.

B. The effect of treatment on the yield of sown species.

C. Tiller counts.

D. Growing point measurements.

E. The yield of other species.

F. The yield of *Poa spp.*

G. Soil measurements.

H. Conclusions.

A. Total yield of sown species

The maximum yields obtained in this experiment were approximately 900 - 1000 lbs. dry weight per acre for perennial ryegrass, timothy and cocksfoot; and 1500 lbs. for browntop. These relatively low yields of the certified grasses were probably due to the low fertility of the area.

The plots were not top-dressed in the eleven month period from sowing date, and only two short periods of sheep grazing were carried out. Grass clippings were removed after mowing, and very little volunteer white clover was present.

A further indication of the level of fertility was provided by the higher yield of browntop, as Mouat and Walker (1959) have pointed out that this species has a competitive advantage over 'quality' grass species in low fertility areas, because of its low root cation-exchange capacity. Browntop was also favoured by the standard cutting height of 1in. as approximately twice as much dry weight, compared with the other grasses, was present on the sub-plots at the time of treading. This probably gave this species a greater capacity for regrowth (Brougham, 1956), before the onset of the adverse effects of low light intensities and low temperatures.

The yield decline in the final period was attributed to herbage losses due to decomposition (Brougham, 1957), together with leaching of soil nitrogen.

The technique of yield measurement appeared to be satisfactory, but because there was a considerable amount of dead material present, the dissection of the samples was a laborious process.

B. The effect of treatment on the yield of sown species.

The relative resistance of perennial ryegrass and timothy to treading, confirmed the observations of other workers (Edmond, 1960; Ellenberg, 1952).

The susceptibility of cocksfoot to treading agreed with Edmond's (1960) results, but differed from the observations of Ellenberg (1952) and Bates (1935), who considered that this species was 'very resistant to treading'.

The performance of browntop confirmed Edmond's and Bates' work, but differed from Ellenberg, who classed the species as 'fairly resistant to treading'.

It was considered that these comparisons illustrated the danger of classifying species on observations of 'treading plant populations'. Although the resistance of species may vary according to the conditions, it was suggested that studies where treading was the predominant effect were more useful, in elucidating the treading problem, than general ecological observations..

In this experiment the failure of browntop and cocksfoot to recover from the treatment was due to very slow growth during the second sampling period. However, the UT plots of both species showed slight increases in yield at this stage, while the T plots of browntop showed a slight decrease. There appeared to be an interaction between the treading effect and the adverse environmental factors.

Yield figures obtained by Edmond (1961), with a treading rate of 10 sheep equivalents/acre on a perennial ryegrass pasture in Autumn, showed an initial reduction of 10% due to treading. At the end of a 55 day regrowth period the trodden area had an advantage of 4%.

It was possible that treading effects on perennial ryegrass were not detected in the present experiment, because the first sampling was made 28 days after treading.

In the species trial (Edmond, 1960), 4 sheep equivalents/acre applied twice on soil at field capacity, reduced the yield of cocksfoot by about 15%.

In the artificial treading treatment, the yield reductions over the entire post-treading period were 14% in cocksfoot and 22% in browntop.

Differences in soil type between the two areas are considered in Section G, but it was concluded from the yield data that the artificial treading treatment had produced an effect similar to 8-10 sheep equivalent/acre.

C. Tiller counts

The changes in tiller number appeared to be related to yield changes. The increases recorded in the T. plots of cocksfoot and timothy over the first period, may have been due to a change in tiller quality. It was possible that treading caused an increase in the number of smaller tillers, which did not contribute much to the total yield.

D. Growing point measurements

Although consistent results were obtained for each species, some problems were encountered. In browntop it was very difficult to distinguish between the 'mat' of plant material and the soil surface.

As the species appeared to be predominantly stoloniferous, the result of 60% growing points above the soil surface was probably lower than the true figure.

In timothy, many small tillers arose from old stems and tillers which lay on, or just below, the soil surface. It was thus difficult to distinguish between the dead sheaths of the parent tillers and the ground.

The situation in perennial ryegrass and cocksfoot was simpler, and the percentages for these species were considered to be fairly accurate.

It was realized that the results for each species represented a sample of different types of tiller. The most obvious difference was observed between the single large parent tillers and their smaller axillary tillers.

The results for perennial ryegrass and cocksfoot were different from those of Bates (1935) who suggested that the growing points of these species were below the soil surface. However, his studies were made on heavily trodden habitats and it was possible that the growing points were pushed below ground under such conditions. There was some evidence of this effect in perennial ryegrass in this experiment.

Although there were only small differences in the position of the growing point, the species varied in their reaction to treading. Moreover, as the technique of measurement was unsatisfactory in two of the species, the implications of a possible relationship were not discussed.

E. The yield of other species

These results were based on highly variable material, and therefore only the general implications are discussed.

The tendency for an increase in other species in the T plots was reflected by the reaction of the predominant species. A comparison with the observations made by three other workers is shown in Table 28.

Key

1. Ellenberg (1952) - based on "treading plant populations".

2. Salisbury (1961) - trackway flora.

3. Edmond (1958) - sheep treading trials.

4. This study - artificial treading.

S = sensitivity to treading.

R = resistant to treading.

TABLE 28

Comparison of observations on the treading resistance of certain other species

Study / Species	1	2	3	4
Sagina spp.	-	R	-	S
Rumex spp.	R	R	R	R
T. repens L.	R	-	R*	R
T. dubium Sibth	-	R	-	R
Crepis spp.	S	-	R	R

* Sensitive in winter.

Salisbury (loc.cit.) noted that the Pearlworts (Sagina apetala and S. procumbens) often adopted a rosette habit on tracks. They produce large numbers of very fine seeds which are effectively broadcast by the wind. However, he also suggested that because of their dwarf-like habit they are intolerant of competition for light.

These observations emphasized the dangers of classifying trackway flora as treading resistant, as the occurrence of such species may be determined by many other factors. The variable reaction of pearlwort, shown in Table 28, may only be a reflection of the different conditions under which the observations were made.

There was, however, general agreement on the resistance of three of the species, and their growth characteristics agree with Ellenberg's classification (P.29). In contrast, the performance of *Crepis spp.*, browntop and cocksfoot in this trial, failed to confirm this author's observations.

It was considered that more concise information on the effect of treading on weed species, could only be derived from a specifically designed study.

F. The yield of Poa spp.

The main species present was *Poa annua L.*, which flowered throughout the post-treading period.

The slight increase of the species in the T plots was possibly due to the encouragement of seed germination (Levy, 1940) and/or reduced competition from the sown species.

It was observed that the growing points of the vegetative tillers were always well above the soil surface.

G. Soil measurements

As the treatment was applied in a standard manner, and soil moisture did not vary at that time, it was considered that the variation found in the bulk density measurements was probably due to a species effect.

The method used did not take account of differences in the amount of root material in the soil. It was possible that cocksfoot and browntop showed greater root development in the 0 - 4cm. layer than the other species.

This situation may have been reversed in the 4 - 6cm. layer. However, Robinson (1958) found little difference in the root weight of cocksfoot and perennial ryegrass in the 0 - 2in. layer. Furthermore, between species differences in bulk density values have not been found at Grasslands Division (Edmond, 1961).

The surface 'mat' of browntop may have reduced the compaction of the soil, but the plant cover in cocksfoot, timothy and perennial ryegrass plots was similar.

It was suggested that the different reaction of the species to treading, may possibly be explained in terms of the innate physical toughness of the plant, rather than in terms of soil compaction. However, it was shown (Gradwell, 1956) that compaction, as measured by bulk density, did not always give a satisfactory explanation of the reaction of the plant to the treading effect on soils. No puddling or crusting effect was observed in this experiment.

In order to assess the severity of the soil effect, a comparison was made of the bulk density values obtained under treading by 0 and 20 sheep equivalents/acre (Edmond, 1958). These are shown in Table 29.

TABLE 29

Comparison of bulk density values (gms./cc.)

Treatment	Depth	0-1.5cms.	1.5-3.0cms.	3.0-4.5cms.	4.5-6.0cms.
20 sheep/acre	UT	1.08	1.17	1.21	1.20
	T	1.16	1.26	1.28	1.28
Treatment	**Depth**	**0-2cms.**	**2-4cms.**	**4-6cms.**	
20 p.s.i.- 4 times	UT	1.19	1.22	1.18	
	T	1.37	1.31	1.26	

In Edmond's trial treading was carried out at a soil moisture content of approximately 40%, and the density measurements were obtained on September 2nd after treatments on July 31st and August 28th. The soil type was a Manawatu mottled silt loam, and the only mechanical analysis of this soil type available (Schwass, 1955) was obtained from a slightly 'lighter' area. However, this analysis, together with a similar analysis of the Ohakea silt loam (Robinson, 1955) is presented in Table 30.

TABLE 30

Comparison of mechanical analyses of soil types

Fraction % / Soil type	Manawatu silt loam	Ohakea silt loam
Clay	10.4	22.4
Silt	11.3	22.3
Fine sand	34.6	50.2
Coarse sand	30.0	2.6
Loss on ignition	3.5	7.9
Total	89.8	105.4

The samples for the Manawatu silt loam were taken from the 0-12in. depth, and for the Ohakea silt loam from the 0-6in. depth. Fife (1961) has suggested that the results for the Manawatu silt loam showed higher than 'normal' value for the sand fraction in this soil type. However, he confirmed that the Ohakea silt loam was the 'heavier' soil.

The soil moisture content at the time of the artificial treading was approximately 26%. It was considered that the potential for compaction, under the different conditions, was greater on the Manawatu silt loam. Therefore, it was concluded that the artificial treading treatment had produced compaction at least as great as 20 sheep equivalents/acre.

H. Conclusions

From the results obtained in this trial it was concluded that the main effects of sheep treading were produced by the artificial hoof.

There was some evidence to suggest that approximately similar increases in bulk density produced different effects on herbage yield. It was possible that puddling of the soil was more severe under the walking sheep.

In order to study the effect of the artificial treading during a period of rapid herbage growth, a Spring trial was carried out.

CHAPTER V

RESULTS AND DISCUSSION OF THE SPRING TRIAL

This chapter is presented in three parts as follows:

I Introduction

II Results

III Discussion

The results are presented in six sections as follows:

A. The artificial treading treatment.

B. The dry weight yield of each species.

C. Tiller counts of perennial ryegrass, timothy and cocksfoot.

D. Growing point measurements.

E. Soil moisture data.

F. Bulk density measurements at four depths.

Ba PERENNIAL RYEGRASS
Bd TIMOTHY
Bc COCKSFOOT
Bt BROWNTOP
Bp POA PRATENSIS
UT CONTROL
T TRODDEN

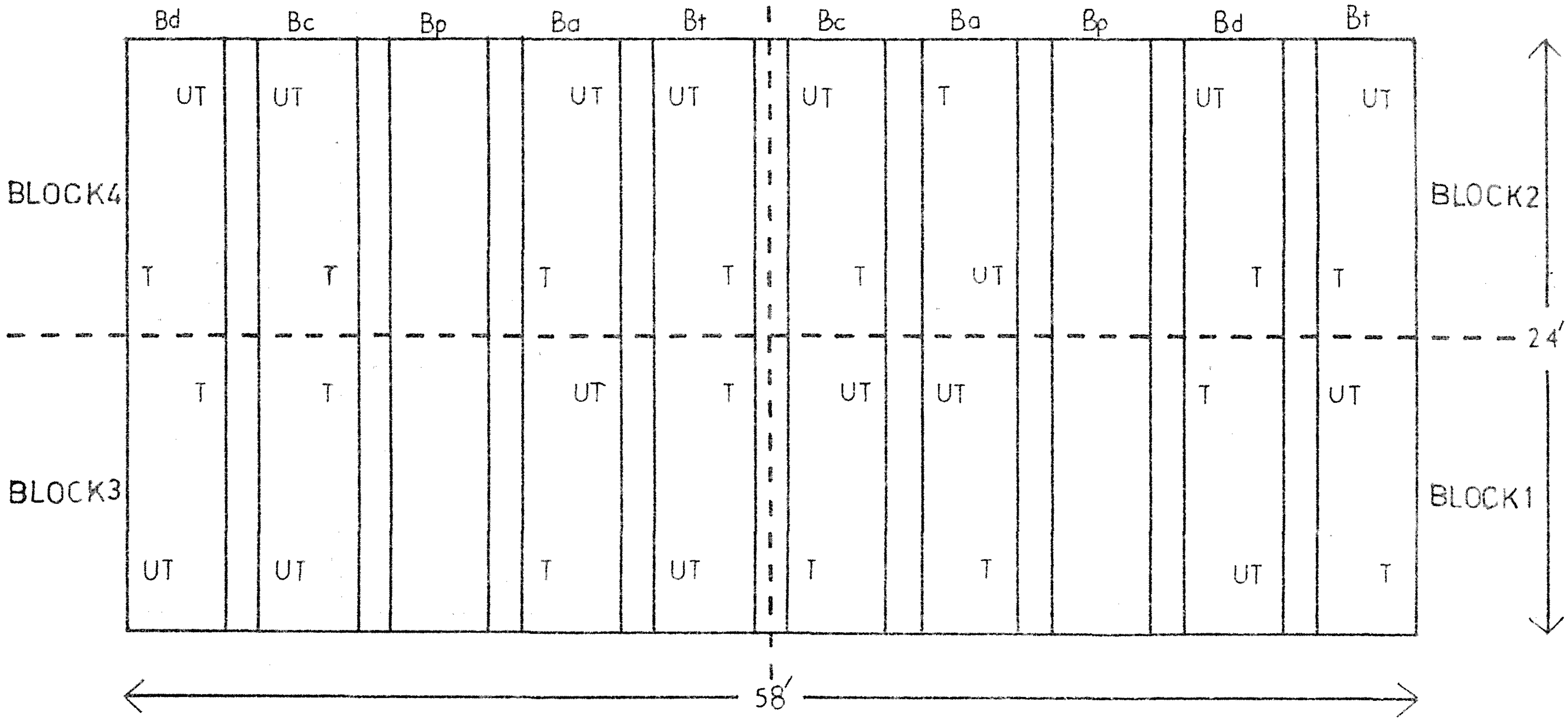

FIG 5 LAYOUT FOR THE SPRING TRIAL.

PART I

INTRODUCTION

The layout for this trial is shown in Figure 5.

The plots were sampled four times at ten day intervals, with a final sampling 24 days later.

The plots were top-dressed one month before treading with the equivalent of 3cwt. of sulphate of ammonia per acre.

As the percentage contribution to total yield of other species and Poa spp., appeared to have fallen to a very low level, no measurements were made of these components. Any found in the herbage dissection were discarded.

The other measurements were the same as for the Autumn trial, except that bulk density samples were taken from an extra depth (6 - 8cms.), and the growing point measurements were made at all sampling dates. Tillers that showed internode elongation and flowering were also noted.

PART II

RESULTS

A. The artificial treading treatment

The hoof penetrated the surface soil to a depth of 1 in. in perennial ryegrass, timothy and cocksfoot plots. Slight penetration also occurred in the browntop plots.

The burial of tillers was more severe than in the Autumn trial, and it was observed that many of them died.

Recovery growth appeared to be due to a combination of new tiller production and the growth of tillers that had survived the treatment.

B. The dry weight yield of each species

The mean yields and standard errors, in lbs. dry weight per acre, are presented in a summarized form in Tables 31 - 34, together with the results of the analyses of variance. Further details are given in Appendices 19 - 21.

TABLE 31

Mean dry weight yield. Perennial ryegrass

Treatment \ Date	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	785	1414	2433	4115	5905
	±29	±53	±203	±213	±285
T	858	906	1676	2967	5360
Results of analysis of variance	N.S.	**	N.S.	*	N.S.

TABLE 32

Mean dry weight yield. Timothy

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	940	1318	2199	3227	4173
	±80	±68	±184	±180	±301
T	879	908	1216	2287	4357
Results of analysis of variance	N.S.	*	*	*	N.S.

TABLE 33

Mean dry weight yield. Cocksfoot

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	928	1322	2711	3788	6435
	±41	±72	±348	±396	±636
T	889	865	1291	2024	4966
Results of analysis of variance	N.S.	*	N.S.	N.S.	N.S.

TABLE 34

Mean dry weight yield. Browntop

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	1048	1974	2727	3156	3651
	±30	±80	±56	±132	±108
T	1146	1300	1428	1961	3095
Results of analysis of variance	N.S.	**	**	**	*

The results for September 13th represented the yield at the time of treading. No significant differences between UT and T sub-plots were detected.

In cocksfoot on October 3rd and 13th, and in perennial ryegrass on October 3rd, the differences were significant at the 10% level.

Throughout most of the experimental period, only slight species differences in reaction to treading were detected. However, at the final

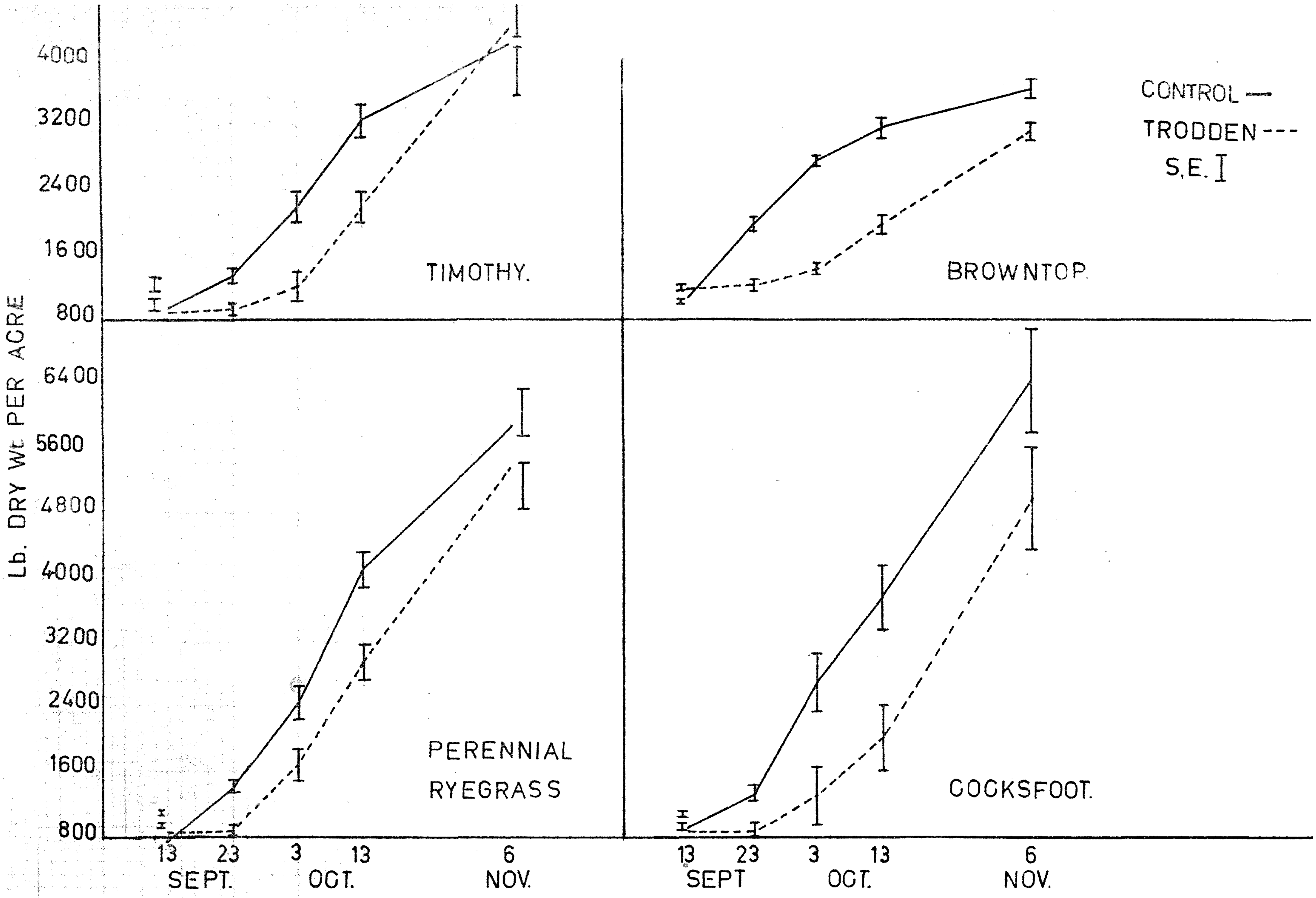

FIG.6. DRY WEIGHT PRODUCTION CURVES. SPRING TRIAL.

sampling date browntop appeared to be more severely affected.

It was observed that the variance of this species was considerably lower than the other species at the last three sampling dates. Thus, a combined analysis, to test for a species x treatment interaction, was subject to this limitation.

This analysis (Appendix 20) showed that the species x treatment interaction was not significant at the final sampling date. Thus, it was concluded that species differences in reaction to treading had not been demonstrated in this experiment.

The growth curves of the species are shown in Figure 6. An approximate "t" test over the first ten day period, indicated that the T plots of perennial ryegrass, timothy and cocksfoot failed to show a significant increase in yield. However, the increase in the T plots of browntop was significant. The use of this test, for species comparisons at subsequent sampling periods, was found to be unsatisfactory. This was probably due to the high and low standard errors of cocksfoot and browntop respectively.

An examination of the growth curves (Brougham, 1957) suggested that the reduction in significance of the treading effect at the final sampling date, occurred when the UT curves had entered phase 3 of growth (decline in growth rate), while the T curves were still in phase 2 (growth at a constant maximum rate). There did not appear to be any phase 1 (exponential increase in growth rate) in the UT plots of browntop.

C. Tiller counts of perennial ryegrass, cocksfoot and timothy

The mean tiller numbers per 36 sq. ins. and standard errors at each sampling date, together with the results of the analyses of variance, are shown in Tables 35-38. Further details are given in Appendices 22-24.

TABLE 35

Mean tiller numbers. Perennial ryegrass

Treatment / Date	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	333	436	417	376	176
	±15	±5	±18	±21	±12
T	344	300	345	322	192
Results of analyses of variance	N.S.	**	N.S.	N.S.	N.S.

TABLE 36

Mean tiller numbers. Timothy

Treatment / Date	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	132	161	170	165	99
	±4	±7	±11	±6	±7
T	125	116	125	136	120
Results of analyses of variance	N.S.	*	N.S.	*	N.S.

TABLE 37

Mean tiller numbers. Cocksfoot

Treatment / Date	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	205	226	256	173	123
	±11	±5	±20	±17	±12
T	195	177	192	139	94
Results of analyses of variance	N.S.	**	N.S.	N.S.	N.S.

On October 3rd the differences were significant at the 10% level in perennial ryegrass and timothy, and were almost significant at this level in cocksfoot. On October 13th differences approached the 10% level in perennial ryegrass, but were non-significant in cocksfoot. In timothy there were more tillers (approached the 10% level) in the T plots at this date. However, an examination of the data (Appendix 22.2) suggested that an irregular result in Block 3 probably caused this effect.

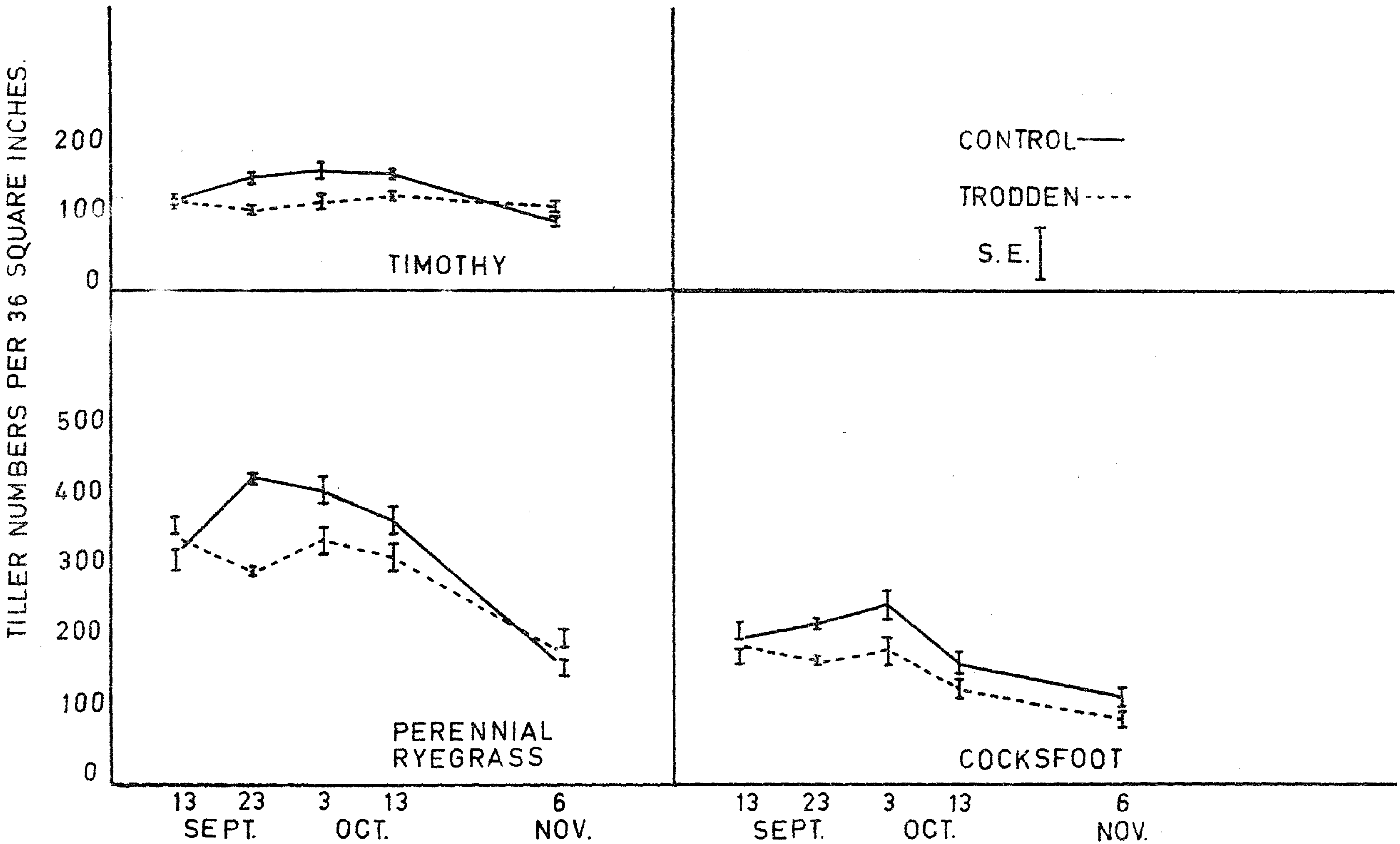

FIG.7. TILLER COUNTS. SPRING TRIAL.

The changes in tiller numbers over the experimental period are illustrated in Figure 7, and the results from using the approximate "t" are shown in Table 38.

TABLE 38

Results from testing for changes in mean tiller number with approximate "t" test

Species	Treatment	13.9.61 - 23.9.61	23.9.61 - 3.10.61	3.10.61 - 13.10.61	13.10.61 - 6.11.61
Perennial ryegrass	UT	**	N.S.	N.S.	**
	T	*	*	N.S.	**
Timothy	UT	**	N.S.	N.S.	**
	T	N.S.	N.S.	N.S.	*
Cocksfoot	UT	*	N.S.	*	*
	T	N.S.	N.S.	*	*

It appeared that treading caused a significant decrease in tiller number of perennial ryegrass and an almost significant decrease in cocksfoot, in the first period. The effect on timothy was less severe.

In the second period the UT plots of perennial ryegrass showed a non-significant decrease, and the T plots a significant increase in tiller number. In timothy and cocksfoot, UT and T plots showed a non-significant increase.

In the third period, only the T plots of timothy showed an increase (non-significant) in tiller number. The cocksfoot UT and T plots showed a significant decrease.

In the final period all species and treatments showed a significant decrease in tiller number.

It was observed at the first post-treading sampling date that some tillers in the T plots showed 'abnormal' development. Examples of these are illustrated in Figures 8 and 9. A count was made of the most obviously

Fig. 8a 'Abnormal' tillers of Perennial Ryegrass

Fig. 8b 'Abnormal' tillers of Cocksfoot

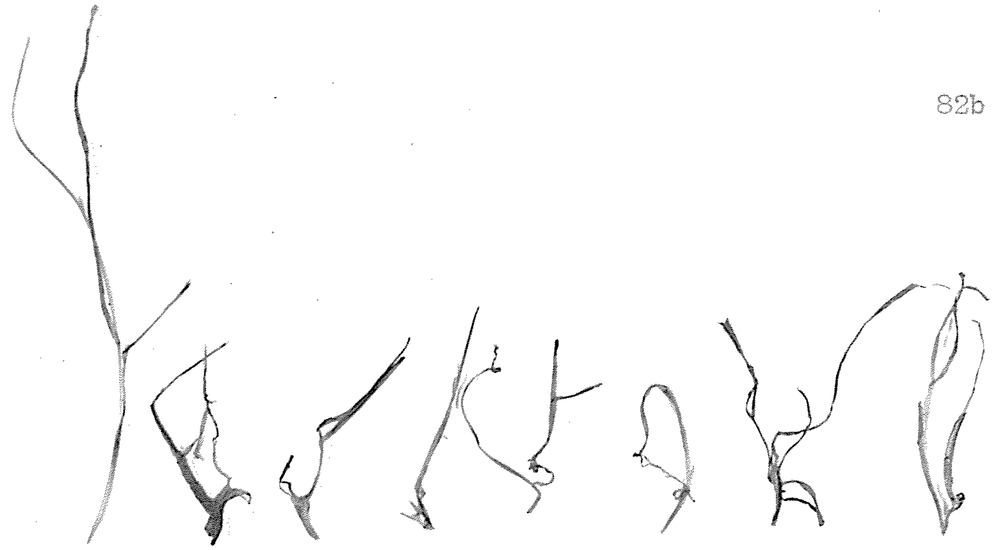

Fig. 9a 'Abnormal' tillers of Browntop

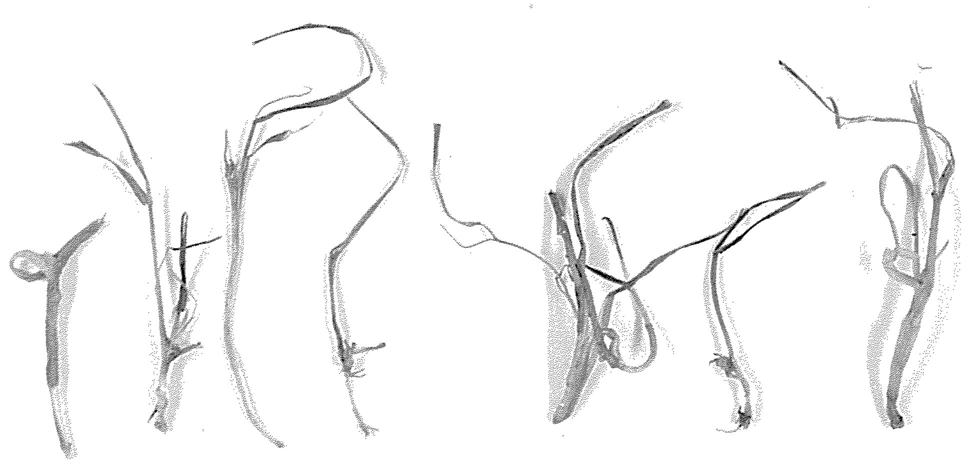

Fig. 9b 'Abnormal' tillers of Timothy

'abnormal' live tillers i.e. those that showed a split in the basal sheath with wrinkled leaves emerging. No tillers of this type were found in the UT plots. The results are shown in Table 39 and further details are given in Appendix 24.

TABLE 39

Mean percentage occurrence of 'abnormal' tillers in T plots

Species \ Date	23.9.61	3.10.61	13.10.61
Perennial ryegrass	3.6±1.1	0.8±0.5	-
Timothy	7.3±2.4	14.4±3.1	5.5±1.9
Cocksfoot	3.7±1.4	7.7±1.9	-

D. Growing point measurements

The means and standard errors of the transformed data (true percentages in brackets), of growing points above the soil surface, together with the results of the analyses of variance are shown in Tables 40 - 43. Further details are given in Appendices 25 and 26.

TABLE 40

Mean position of the growing point. (Transformed data)
Perennial ryegrass

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	48 (56)	56 (68)	58 (72)	63 (79)	80 (96)
	±2	±3	±4	±1	±2
T	53 (63	52 (62)	53 (63)	59 (73)	79 (94)
Results of analysis of variance	N.S.	N.S.	N.S.	*	N.S.

TABLE 41

Mean position of the growing point. (Transformed data)
Timothy

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	43 (46)	47 (54)	46 (51)	57 (69)	69 (86)
	±4	±4	±3	±4	±3
T	42 (44)	45 (50)	47 (54)	56 (68)	72 (90)
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.	N.S.

TABLE 42

Mean position of the growing point. (Transformed data)
Cocksfoot

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	52 (61)	61 (74)	60 (74)	70 (87)	71 (89)
	±3	±7	±2	±4	±1
T	52 (61)	47 (53)	52 (62)	50 (58)	77 (93)
Results of analysis of variance	N.S.	N.S.	N.S.	*	N.S.

TABLE 43

Mean position of the growing point. (Transformed data)
Browntop

Date / Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
UT	58 (71)	57 (71)	61 (75)	71 (88)	87 (99)
	±5	±2	±4	±3	±2
T	51 (60)	54 (65)	65 (81)	67 (85)	82 (97)
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.	N.S.

There were no differences in UT and T plots prior to treading. In cocksfoot, on October 3rd, there were significantly (10% level) more growing points above the soil surface in the UT plots. This difference was present (5% level) in both cocksfoot and perennial ryegrass on October 13th. At the final sampling date there were more (10% level) growing points above the soil surface in the T plots of cocksfoot.

A combined analysis, prior to treading, showed that the species differed (10% level) in the position of the growing point. This is shown in Table 44.

TABLE 44

Relative mean occurrence of growing points above the soil surface prior to treading. Transformed data

Species	Mean and S.E.
Perennial ryegrass	50.5±1.4
Timothy	42.5±2.8
Cocksfoot	52.0±2.0
Browntop	54.5±4.0

There were no significant differences between perennial ryegrass, cocksfoot and browntop, but timothy had significantly fewer growing points above the soil surface than the other species.

At subsequent sampling dates internode elongation of tillers was recorded. These data are summarized in Tables 45-48 and detailed in Appendices 27 and 28. The data were transformed in a similar way to the growing point percentages, and the true percentages are given in brackets.

TABLE 45

Mean percentage of tillers showing internode elongation.
Transformed data. Perennial ryegrass

Date / Treatment	23.9.61	3.10.61	13.10.61	6.11.61
UT	9 (2)	18 (10)	32 (28)	50 (59)
	±1	±4	±9	±7
T	10 (3)	18 (10)	28 (22)	48 (55)
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 46

Mean percentage of tillers showing internode elongation.
Transformed data. Timothy

Date / Treatment	13.10.61	6.11.61
UT	18 (10)	47 (51)
	±4	±5
T	5 (3)	41 (41)
Results of analysis of variance	N.S.	N.S.

TABLE 47

Mean percentage of tillers showing internode elongation.
Transformed data. Cocksfoot

Date / Treatment	13.10.61	6.11.61
UT	17 (10)	38 (38)
	±4	±7
T	5 (2)	53 (63)
Results of analysis of variance	N.S.	N.S.

TABLE 48

Mean percentage of tillers showing internode elongation.
Transformed data. Browntop

Date / Treatment	3.10.61	13.10.61	6.11.61
UT	12 (9)	32 (28)	63 (78)
	±8	±2	±6
T	5 (3)	26 (20)	50 (69)
Results of analysis of variance	-	N.S.	N.S.

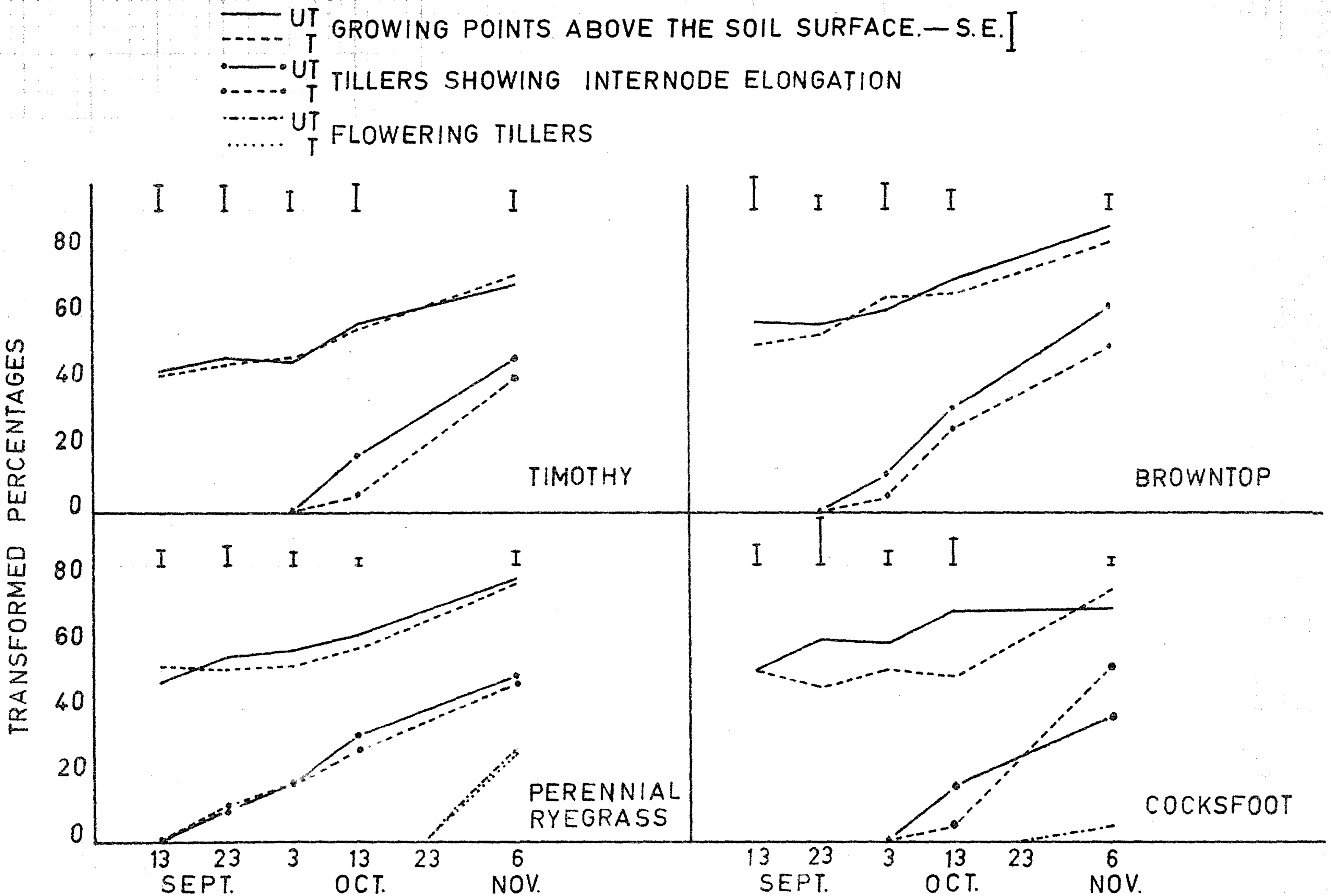

FIG.10 POSITION OF GROWING POINTS. SPRING TRIAL

There were no differences due to treatment in perennial ryegrass at any date. In timothy there were slightly (almost 10% level) more tillers showing internode elongation in the UT plot on October 13th. This difference was not shown at the final sampling date. In cocksfoot there were slightly (15% level) more tillers showing internode elongation in UT plots on October 13th, but this difference was reversed (10% level) at the final sampling date. In browntop, on October 13th, there was a slight (almost 10% level) difference in favour of the UT plots.

The percentage of perennial ryegrass tillers which had developed flowerheads at the final sampling date are shown in Appendix 27. There were no significant differences between treatments. In cocksfoot three flowering tillers were observed in UT plots.

The data for all these measurements are illustrated in Figure 10.

E. Soil moisture data

These measurements were made at the time of treading, and the results are shown in Appendix 29.

Analyses of variance (Appendix 30) of the individual species, showed that the soil moisture content of perennial ryegrass UT plots was significantly (5% level) higher than the T plots. A similar result was found in timothy (10% level). There were no differences in the other species.

The overall mean was 32.4%.

F. Bulk density measurements at four depths

These measurements were made one month after treading.

The treatment means and standard errors for each species at each depth together with the results of the analyses of variance are presented in Tables 49 - 52. Further details are shown in Appendices 31 and 32.

TABLE 49

Mean bulk densities. Perennial ryegrass

Treatment \ Depth	0 - 2cms.	2 - 4cms.	4 - 6cms.	6 - 8cms.
UT	1.13	1.14	1.11	1.10
T	1.15 ±0.025	1.29 ±0.023	1.19 ±0.015	1.15 ±0.017
Results of analysis of variance	N.S.	*	*	N.S.

TABLE 50

Mean bulk densities. Timothy

Treatment \ Depth	0 - 2cms.	2 - 4cms.	4 - 6cms.	6 - 8cms.
UT	1.01	1.22	1.15	1.17
T	1.21 ±0.044	1.30 ±0.030	1.21 ±0.051	1.17 ±0.029
Results of analysis of variance	N.S.	N.S.	N.S.	N.S.

TABLE 51

Mean bulk densities. Cocksfoot

Treatment \ Depth	0 - 2cms.	2 - 4cms.	4 - 6cms.	6 - 8cms.
UT	1.04	1.18	1.10	1.10
T	1.21 ±0.041	1.31 ±0.029	1.21 ±0.019	1.19 ±0.037
Results of analysis of variance	N.S.	*	*	N.S.

TABLE 52

Mean bulk densities. Browntop

Treatment \ Depth	0 - 2cms.	2 - 4cms.	4 - 6cms.	6 - 8cms.
UT	0.96	1.19	1.14	1.12
T	1.14 ±0.046	1.30 ±0.009	1.19 ±0.015	1.15 ±0.049
Results of analysis of variance	N.S.	**	N.S.	N.S.

In perennial ryegrass treading caused a significant increase in bulk density in the 2 - 4cms. and 4 - 6cms. depths at the 5% level, and in the 6 - 8cms. depth at the 10% level. The increase in the 0 - 2cms. depth was not significant.

In timothy there was a significant (10% level) increase in the 0-2cms. depth, but no significant effect was detected in the other depths.

In cocksfoot the increase in the 0 -2cms. depth was significant at the 10% level, and in the 2 - 4cms. and 4 - 6cms. depths at the 5% level. The increase in the 6 - 8cms. depth was not significant.

In browntop the increase in the 0 - 2cms. and 4 - 6cms. depths was significant at the 10% level, and in the 2 - 4cms. depth at the 1% level. The increase in the 6 - 8cms. depth was not significant.

PART III

DISCUSSION

This discussion is presented in four sections, as follows:

A. The effect of treatment on the yield of sown species

B. Tiller counts

C. Growing point measurements

D. Soil measurements

A. The effect of treatment on the yield of sown species

The main effect of artificial treading in this experiment was to delay the growth of trodden plots over a period of at least one month.

The faster recovery growth of the T plots, as compared with that in the Autumn trial, was probably due to the relatively favourable conditions for growth that prevailed.

Species differences could not be detected, and this was attributed to deficiencies in the design of the experiment, which were more apparent in the Spring trial where yields were high.

Calculations from the coefficients of variation (Glenday, 1961), suggested that 5 - 6 replications might have been more suitable in this trial.

However, the data obtained confirmed the earlier findings that artificial treading and sheep treading had relatively similar effects on the growth pattern, although in contrast to the Autumn trial, the artificial treading in the Spring appeared to have a more severe effect on yield than sheep treading (10 sheep/acre) (Edmond, 1960).

B. Tiller counts

These results appeared to confirm Edmond's (1958b) observation that the treading effect on tillers was composed of a reduction in tiller number and reduced growth of damaged tillers.

The occurrence of 'abnormal' tillers in this experiment suggested that part of the artificial treading effect was due to direct plant damage.

The changes in tiller numbers over the experimental period were partly explicable in terms of Langer's work (1959a), who noted that tiller numbers declined at a time when conditions were most favourable for active dry weight production. It was suggested that this was probably due to competition among tillers for essential environmental factors, such as light and nutrients.

In this experiment the total rainfall in October was only 0.7in. (Grassland Division, Meteorological Station) and a combination of these conditions with the advent of internode elongation and the flowering in some tillers (Soper, 1958), may have increased the decline in tiller numbers.

In perennial ryegrass the reduction in yield and tillers numbers caused by treading, appeared to predispose these plots to an increase in tillers in the second sampling period, whereas the UT plots showed a decline. This could have been explained by the fact that, in similar pasture, rate of plant growth per unit area increases until all the light energy is intercepted (Brougham, 1956).

At subsequent sampling dates the factors involved in the decline of tiller numbers affected both treatments, although the reduction in the T plots was not so severe. This was probably due to the lower yields and tiller numbers of these plots, and also to the fact that fewer tillers showed internode elongation. However, no differences in flowering were shown.

In timothy and cocksfoot, after the initial decline in tiller numbers due to treading, both UT and T plots showed similar increases in the next sampling period. The fall in tiller numbers of these species started approximately ten days later than for perennial ryegrass, and coincided with the first signs of internode elongation. However, a similar pattern to perennial ryegrass was exhibited, as initially the T plots of timothy showed a slight increase, and the T plots of cocksfoot a slower decrease in tiller numbers.

In both cases there were higher yields, higher tiller numbers, and more tillers showing internode elongation in the UT plots.

In timothy the differential rate of decline was maintained in the final period, but as noted earlier the T plot means may have contained an irregular result.

In cocksfoot, UT and T plots declined at a similar rate, and it was suggested that the higher proportion of tillers showing internode elongation in the T plots, may have offset the effect of lower yields and tiller numbers.

It was concluded that these results provided further evidence for an interaction between the treading effect and environmental factors and/or the physiological state of the plant.

C. Growing point measurements

These measurements showed that it was only at the first sampling date that the tillers of all species were in the vegetative state.

The same difficulties were experienced with timothy as in the Autumn trial; but in browntop considerable stolon development made measurement easier, and this probably affected the results obtained.

In cocksfoot it appeared that treading pushed some of the existing growing points below the soil surface. Alternatively, new tillers that developed after treading were possibly initiated below the soil surface. Similar results obtained for perennial ryegrass in the Autumn trial were not confirmed.

The relationship of these results to the treading effect on the species was not clear. The classification of the growing point position was only an arbitrary one, and it was noted that the differences were small.

It was considered that if the variable reaction of the species to treading (Autumn trial) was to be explained in terms of the position of the growing point, then the differences in this position above and below the soil surface would have to be greater than those observed here. The growing points did not appear to be low enough below the soil surface to be afforded any protection.

Similarly the apparent increase in the percentage of growing points below the soil surface in the T plots of perennial ryegrass and cocksfoot, probably only represented a small change in position. However, the change may be more pronounced in grazed pastures.

The increase in the percentage of growing points above the soil surface coincided with the increase in internode elongation, and it was observed that where the total percentage of growing points above the soil surface was depressed by treading, so too was the percentage of tillers showing internode elongation. This was probably a reflection of the delayed growth of the T plots.

It was possible that differences in the percentage of tillers with flowerheads, in the UT and T plots of perennial ryegrass, developed during the period October 23rd - November 6th. However, the reduction in significance of the treading effect at this time may have led to the similar flowering figures obtained at the final sampling date.

D. Soil measurements

The bulk densities in the UT and T plots were slightly lower than in the Autumn trial. This was probably a reflection of the seasonal conditions, as Zwerman and Ram (1960) stated that bulk density increased in the winter due to a deterioration of soil structure.

The soil moisture content at the time of treading was higher than in the Autumn trial, but the bulk density measurements suggested that compaction of the 0 - 2cms. depth was less. This result may have been due to the increased root growth of the species in this zone, but in view of the severity of the effect of treading on grass growth, and the amount of hoof penetration, it was possible that some puddling of the surface soil had occurred. This may have restricted the diffusion of gases and/or the infiltration of water.

The increase in bulk density in the 2- 4cms. and 4 - 6cms. depths was similar to that obtained in the Autumn trial. The results from the 6 - 8cms. depth agreed with those of Edmond (1958b), who found that, on the Manawatu mottled silt loam, bulk density increases due to sheep treading were reduced in the 6.0 - 7.5cms. depth.

The between species differences in the treading effect on bulk density showed a dissimilar pattern to those obtained in the Autumn trial.

The greater increase in the T plots of browntop may have been due to hoof penetration of the surface 'mat'. The failure of treading to produce significant increases in bulk density in timothy, was considered in terms of excessive puddling, greater root growth and the protective effect of plant cover. However, a comparison with cocksfoot and perennial ryegrass, which showed significant increases in bulk density, failed to reveal the reasons for this difference.

CHAPTER VI

GENERAL DISCUSSION

In order to distinguish between the overall treading effects and those of excretion and defoliation, Edmond (1958b) developed a technique to study treading as a single factor. Although the method was subject to some limitations (p.29) it was considered that the technique permitted the study of treading as the predominant influence on the sward (Edmond *loc.cit.*).

It was considered that the continued elucidation of the treading effect depended on the precise definition of the factors involved in that effect. The initiating point of treading is the hoof, and in this project a study was made of the reaction of four pasture species to a defined force applied by an artificial sheep's hoof.

The results obtained suggested that this treatment (20 p.s.i. - 4 times) produced the main effects of treading.

It was concluded that the most important application of these results was that they essentially agreed with those obtained by Edmond.

CHAPTER VII

SUMMARY

1. A study was made of the reaction of four grass species - perennial ryegrass, timothy, cocksfoot and browntop - to an artificial treading treatment.

2. The treatment (20 p.s.i. - four times) was applied by means of an artificial sheep's hoof in the Autumn and Spring of 1961. A simple comparison was made between untrodden (UT) and trodden (T) areas of each species.

3. In the Autumn trial the plots were sampled at monthly intervals over a period of three months.

4. The yield measurements showed that browntop and cocksfoot were more susceptible to the treatment than perennial ryegrass and timothy.

5. There was no treatment effect on tiller numbers of perennial ryegrass, timothy and cocksfoot.

6. Some evidence was obtained of a differential treatment effect on certain other species present in the sown species plots.

7. The treatment increased the bulk density of the soil in the 0 - 6cms. depth.

8. In the Spring trial the plots were sampled four times at ten day intervals, with a final sampling twenty four days later.

9. The yield of all species was reduced for at least one month following

treatment. A differential species effect was not demonstrated, but this was attributed to deficiencies in the design of the experiment.

10. The tillers numbers of perennial ryegrass, timothy and cocksfoot were reduced by the treatment.

11. The treatment increased the bulk density of the soil in the 0 -6cms. depth.

12. Some difficulties were encountered in the measurement of the position of the growing point in the vegetative state.

13. It was concluded that the use of the artificial hoof had produced the main effectsof treading.

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31. Bulk density measurements at four depths, one month after treading.

32. Analyses of variance of the bulk density data.

APPENDIX 1

The conventional abbreviations used in the text are as follows:

N.S.	result not statistically significant.
*	results statistically significant at the 5% level.
**	results statistically significant at the 1% level.
F.	the variance ratio for specified conditions.
SS	sum of squares.
M.S.	mean square.
d.f.	degrees of freedom.
$\bar{x}$	mean value.
S.E.	standard error of the mean.
v	coefficient of variation.

APPENDIX 2

2.1. Measurements of hoof print size (sq. ins.).
Mean and standard error of 20 values shown.

2.4	2.5
2.5	2.6
2.2	2.5
2.4	2.5
2.6	2.3
2.6	2.4
2.4	2.6
2.6	2.7
2.6	2.4
2.4	2.4
$\bar{x}$ 2.5 ± 0.13	

2.2. Test for the accuracy of the spring balance.
Mean and standard error of 25 values shown.

Weight on scale balance 40 lbs.

Reading on spring balance (lbs.)

40	40
39	41
40	41
39	40
41	39
40	39
39	42
39	41
41	39
38	41
40	38
39	41
40	
$\bar{x}$ 40 ± 0.2	

APPENDIX 3

Dry weight yield at each sampling date (lbs. d.wt./acre)*. Block figure, treatment means and standard errors** shown.

3.1. Perennial ryegrass

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	420	684	1228	764
	T	628	1320	1080	952
2	UT	680	928	708	676
	T	400	540	748	832
3	UT	712	692	864	652
	T	524	788	1112	592
4	UT	200	740	912	788
	T	324	652	856	796
$\bar{x}$	UT	503 ±84	761 ±152	928 ±49	720 ±42
	T	469	825	949	793

3.2. Timothy

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	616	908	1100	756
	T	416	876	1260	652
2	UT	600	552	1020	552
	T	528	860	728	584
3	UT	428	712	928	468
	T	536	628	868	556
4	UT	416	880	1056	472
	T	332	852	664	524
$\bar{x}$	UT	515 ±45	763 ±64	1026 ±87	562 ±30
	T	453	804	880	579

*Conversion factor: gms./6in. square→lb./acre x 383.76

**S.E.'s calculated from analyses of variance (Appendix 4).

APPENDIX 3 (Cont.)

3.3. Cocksfoot

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	336	476	1116	940
	T	392	656	904	584
2	UT	504	876	832	732
	T	616	912	716	700
3	UT	600	772	1084	624
	T	452	744	968	700
4	UT	404	884	636	580
	T	392	504	480	352
$\bar{x}$	UT	461	752	917	719
	T	463 ±40	704 ±84	767 ±40	584 ±68

3.4. Browntop

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	680	1160	2180	1320
	T	952	1052	1360	924
2	UT	788	1888	1564	916
	T	724	1712	1140	772
3	UT	996	1508	1380	1016
	T	988	860	1040	728
4	UT	688	1308	1076	1052
	T	756	1328	952	856
$\bar{x}$	UT	788	1466	1550	1076
	T	855 ±52	1238 ±99	1123 ±155	820 ±39

APPENDIX 4

Analyses of variance of dry weight yield at each sampling date.

Perennial ryegrass

4.1. 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	143920	3	47973	1.72	9.28	N.S.
Treatment	2320	1	2320	<1.00	10.10	N.S.
Error	83872	3	27957			
Total	230112	7				

v = 34.2%

4.2 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	118752	3	39584	<1.00	9.28	N.S.
Treatment	8192	1	8192	<1.00	10.10	N.S.
Error	277808	3	92603			
Total	404752	7				

v = 37.8%

4.3 8.6.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	32352	3	10784	1.12	9.28	N.S.
Treatment	880	1	880	<1.00	10.10	N.S.
Error	28784	3	9595			
Total	62016					

v = 10.4%

4.4 6.7.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	59328	3	19776	2.82	9.28	N.S.
Treatment	10656	1	10656	1.52	10.10	N.S.
Error	21008	3	7003			
Total	90992	7				

v = 10.9%

APPENDIX 4 (Cont.)

Timothy

4.5. 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	39056	3	13019	1.61	9.28	N.S.
Treatment	7696	1	7696	<1.00	10.10	N.S.
Error	24256	3	8085			
Total	71008	7				

v = 18.5%

4.6 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	74944	3	24981	1.55	9.28	N.S.
Treatment	3360	1	3360	<1.00	10.10	N.S.
Error	48496	3	16165			
Total	126800	7				

v = 16.0%

4.7 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	138880	3	46293	1.52	9.28	N.S.
Treatment	42624	1	42624	1.40	10.10	N.S.
Error	91440	3	30480			
Total	272944	7				

v =18.2%

4.8 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	53024	3	17675	5.02	9.28	N.S.
Treatment	576	1	576	<1.00	10.10	N.S.
Error	10560	3	3520			
Total	64160	7				

v = 10.4%

APPENDIX 4 (Cont.)

Cocksfoot

4.9 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	54800	3	18267	2.91	9.28	N.S.
Treatment	16	1	16	<1.00	10.10	N.S.
Error	18848	3	6283			
Total	73664	7				

v = 17.1%

4.10 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	111712	3	37237	1.32	9.28	N.S.
Treatment	4608	1	4608	<1.00	10.10	N.S.
Error	84832	3	28277			
Total	201152	7				

v = 23.0%

4.11 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	278720	3	92907	14.60	9.28	*
Treatment	45008	1	45008	7.07	10.10	N.S.
Error	19088	3	6363			
Total	342816	7				

v = 9.5%

4.12 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	101792	3	33931	1.81	9.28	N.S.
Treatment	36448	1	36448	1.94	10.10	N.S.
Error	56304	3	18768			
Total	194544	7				

v =20.7%

Browntop

4.13 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	86592	3	28864	2.67	9.28	N.S.
Treatment	8976	1	8976	<1.00	10.10	N.S.
Error	32400	3	10800			
Total	127968	7				

v = 12.6%

4.14 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	584512	3	194837	4.95	9.28	N.S.
Treatment	113280	1	113280	2.88	10.10	N.S.
Error	118192	3	39397			
Total	815984	7				

v =14.6%

4.15 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	616352	3	205451	2.15	9.28	N.S.
Treatment	204656	1	204656	2.14	10.10	N.S.
Error	286912	3	95637			
Total	1107920	7				

v =23.0%

4.16 6.7.61

Source	SS.	d.f.	M.S.	F. value	F required	Result
Block	93808	3	31269	5.10	9.28	N.S.
Treatment	131072	1	131072	21.39	10.10 (34.10)	*
Error	18384	3	6128			
Total	243264	7				

v = 8.1%

APPENDIX 5

Analyses of variance of the combined yields of all species at each sampling date.

5.1. 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	169648	3	56549	<1.00	3.86	N.S.
Species	2030000	3	676667	8.45	3.86 (6.99)	**
Error 1	720288	9	80032			
Treatment	16368	1	16368	<1.00	4.75	N.S.
Species X Treatment	96720	3	32240	<1.00	3.49	N.S.
Error 2	545680	12	45473			
Total	3578704	31				

5.2. 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	889040	3	296347	7.55	3.86 (6.99)	**
Species	1143680	3	381227	9.71	3.86 (6.99)	**
Error 2	353264	9	39252			
Treatment	246400	1	246400	11.17	4.75 (9.33)	**
Species X Treatment	206784	3	68928	3.13	3.49	N.S.
Error 2	264624	12	22052			
Total	3103792	31				

5.3 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	192784	3	64261	5.02	3.86 (6.99)	**
Species	638544	3	212848	16.64	3.86 (6.99)	**
Error 1	115152	9	12795			
Treatment	45312	1	45312	5.12	4.75 (9.33)	*
Species X Treatment	133456	3	44485	5.02	3.49 (5.95)	*
Error 2	106256	12	8855			
Total	1231504	31				

APPENDIX 6

Analyses of variance of the combined yields over three sampling dates (11.5.61, 8.5.61, 6.7.61)

6.1. Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	229264	3	76421	4.47	9.28	N.S.
Treatment	73936	1	73936	4.32	10.10	N.S.
Error 1	51296	3	17099			
Dates	147040	2	73520	2.37	3.89	N.S.
Dates X Treatment	12128	2	6064	<1.00	3.89	N.S.
Error 2	371888	12	30991			
Total	885552	23				

6.2. Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	356240	3	118747	3.25	9.28	N.S.
Treatment	565504	1	565504	15.49	10.10 (34.10)	*
Error 1	109552	3	36517			
Dates	827312	2	413656	4.54	3.89 (6.93)	*
Dates X Treatment	43536	2	21768	<1.00	3.89	N.S.
Error 2	1092352	12	91029			
Total	2994496	23				

APPENDIX 7

Tiller counts per 36 sq. ins. for each sampling date. Block figure, treatment means and standard errors shown.

7.1. Perennial ryegrass

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	167	258	278	199
	T	266	324	280	203
2	UT	270	350	220	196
	T	181	188	217	212
3	UT	294	256	207	207
	T	217	261	226	174
4	UT	107	259	267	244
	T	131	220	246	182
$\bar{x}$	UT	210	281	243	212
	T	199 ±31	248 ±34	242 ±6	193 ±13

7.2. Timothy

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	133	188	135	110
	T	132	147	145	98
2	UT	147	135	127	87
	T	124	188	112	130
3	UT	92	117	115	122
	T	117	126	113	70
4	UT	90	124	122	81
	T	74	175	113	88
$\bar{x}$	UT	116	141	125	100
	T	109 ±8	159 ±16	121 ±4	97 ±14

7.3. Cocksfoot

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61
1	UT	116	95	168	117
	T	101	151	128	119
2	UT	138	146	108	121
	T	161	160	143	142
3	UT	166	171	153	113
	T	139	171	144	102
4	UT	84	145	134	105
	T	88	112	75	77
$\bar{x}$	UT	126	139	141	114
	T	122 ±8	149 ±13	123 ±15	110 ±7

APPENDIX 8

Analyses of variance of tiller counts per 36 sq. ins. at each sampling date

Perennial ryegrass

8.1. 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	20992	3	6997	1.77	9.28	N.S.
Treatment	231	1	231	<1.00	10.10	N.S.
Error	11882	3	3961			
Total	33105	7				

v = 30.5%

8.2. 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2767	3	834	<1.00	9.28	N.S.
Treatment	2113	1	2113	<1.00	10.10	N.S.
Error	13960	3	4653			
Total	18840	7				

v = 25.5%

8.3 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	5561	3	1853	13.73	9.28	*
Treatment	1	1	1	<1.00	10.10	N.S.
Error	406	3	135			
Total	5968	7				

v = 4.5%

8.4 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	517	3	172	<1.00	9.28	N.S.
Treatment	703	1	703	1.11	10.10	N.S.
Error	1899	3	633			
Total	3119	7				

v = 12.3%

Timothy

8.5 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	3497	3	1166	5.09	9.28	N.S.
Treatment	78	1	78	<1.00	10.10	N.S.
Error	687	3	229			
Total	4262	7				

v = 13.2%

8.6 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2502	3	834	<1.00	9.28	N.S.
Treatment	648	1	648	<1.00	10.10	N.S.
Error	2938	3	979			
Total	6068	7				

v = 20.7%

8.7 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	824	3	275	4.74	9.28	N.S.
Treatment	32	1	32	<1.00	10.10	N.S.
Error	173	3	58			
Total	1029	7				

v = 6.2%

8.8 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	664	3	221	<1.00	9.28	N.S.
Treatment	24	1	24	<1.00	10.10	N.S.
Error	2349	3	783			
Total	3037	7				

v = 28.0%

APPENDIX 8 (Cont.)

Cocksfoot

8.9 13.4.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	6294	3	2098	8.74	9.28	N.S.
Treatment	28	1	28	<1.00	10.10	N.S.
Error	721	3	240			
Total	7043	7				

v =12.3%

8.10 11.5.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2983	3	994	1.46	9.28	N.S.
Treatment	171	1	171	<1.00	10.10	N.S.
Error	2039	3	680			
Total	5193	7				

v = 17.9%

8.11 8.6.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2653	3	884	1.05	9.28	N.S.
Treatment	666	1	666	<1.00	10.10	N.S.
Error	2527	3	842			
Total	5846	7				

v = 21.8%

8.12 6.7.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	1755	3	585	2.73	9.28	N.S.
Treatment	32	1	32	<1.00	10.10	N.S.
Error	643	3	214			
Total	2430	7				

v = 12.9%

APPENDIX 9

Dry weight of other species at each sample date. Block figure, sown species plot, treatment means and standard errors shown.

9.1 13.4.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	48	20	148	140
	T	60	96	48	184
2	UT	44	224	100	20
	T	28	220	16	32
3	UT	72	200	92	176
	T	56	152	40	160
4	UT	176	32	172	48
	T	136	96	32	40
$\bar{x}$	UT	85	119	128	96
	T	70 ±7	141 ±21	34 ±13	104 ±7

9.2. 11.5.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	184	100	68	96
	T	16	160	–	168
2	UT	148	104	100	164
	T	88	88	40	20
3	UT	104	216	72	32
	T	82	280	16	48
4	UT	160	48	184	40
	T	80	24	–	20
$\bar{x}$	UT	149	117	106	83
	T	67 ±22	138 ±17	14 ±22	64 ±32

APPENDIX 9 (Cont.)

9.3 8.6.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	44	82	144	36
	T	40	52	60	88
2	UT	108	220	108	48
	T	104	184	80	160
3	UT	28	156	16	88
	T	76	68	52	32
4	UT	116	64	188	82
	T	112	8	100	68
$\bar{x}$	UT	79	131	114	64
	T	83 ±9	78 ±9	73 ±21	87 ±26

9.4 6.7.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	52	80	116	48
	T	16	84	24	80
2	UT	64	240	160	20
	T	204	236	144	40
3	UT	28	52	76	144
	T	82	80	84	160
4	UT	64	152	204	48
	T	20	200	88	48
$\bar{x}$	UT	52	131	139	65
	T	81 ±31	150 ±8	85 ±28	82 ±5

APPENDIX 10

Analyses of variance of the yield of other species within each sown species plot.

13.4.61

10.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	17248	3	5749	25.67	9.28 (29.50)	*
Treatment	448	1	448	2.00	10.10	N.S.
Error	672	3	224			
Total	18368	7				

S.E. = ± 7

10.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	40240	3	13413	7.86	9.28	N.S.
Treatment	976	1	976	<1.00	10.10	N.S.
Error	5120	3	1707			
Total	46336	7				

S.E. = ± 21

10.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2960	3	987	1.47	9.28	N.S.
Treatment	17664	1	17664	26.29	10.10 (34.10)	*
Error	2016	3	672			
Total	22640	7				

S.E. = ± 13

10.4 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	34160	3	11387	31.90	9.28 (29.50)	*
Treatment	128	1	128	<1.00	10.10	N.S.
Error	1072	3	357			
Total	35360	7				

S.E. = ± 7

11.5.61

10.5 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	1065	3	355	<1.00	9.28	N.S.
Treatment	13612	1	13612	7.11	10.10	N.S.
Error	5742	3	1914			
Total	20419	7				

S.E. = ± 22

10.6 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	47782	3	15927	14.13	9.28 (29.50)	*
Treatment	882	1	882	<1.00	10.10	N.S.
Error	3382	3	1127			
Total	52046	7				

S.E. = ± 17

10.7 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	4112	3	1371	<1.00	9.28	N.S.
Treatment	16928	1	16928	8.94	10.10	N.S.
Error	5680	3	1893			
Total	26720	7				

S.E. = ± 22

10.8 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	13558	3	4519	1.08	9.28	N.S.
Treatment	722	1	722	<1.00	10.10	N.S.
Error	12566	3	4189			
Total	26846	7				

S.E. = ± 32

8.6.61

10.9 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	8102	3	2700	7.99	9.28	N.S.
Treatment	162	1	162	<1.00	10.10	N.S.
Error	1014	3	338			
Total	9278	7				

S.E. = ± 9

10.10 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	31321	3	10440	30.53	9.28 (29.50)	**
Treatment	5512	1	5512	16.12	10.10 (34.10)	*
Error	1026	3	342			
Total	37859	7				

S.E. = ± 9

10.11 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	12326	3	4109	2.43	9.28	N.S.
Treatment	3362	1	3362	1.99	10.10	N.S.
Error	5078	3	1693			
Total	20766	7				

S.E. = ± 21

10.12 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2469	3	823	<1.00	9.28	N.S.
Treatment	1104	1	1104	<1.00	10.10	N.S.
Error	8186	3	2729			
Total	11759	7				

S.E. = ± 26

6.7.61

10.13 Perennial ryegrass

Source	S.S.	d.f.	M.S.	F value	F required	Result
Block	12689	3	4230	1.13	9.28	N.S.
Treatment	1624	1	1624	<1.00	10.10	N.S.
Error	11250	3	3750			
Total	25563	7				

S.E. = ± 31

10.14 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	39478	3	13159	47.16	9.28 (29.50)	N.S.
Treatment	722	1	722	2.59	10.10	N.S.
Error	838	3	279			
Total	41038	7				

S.E. = ± 8

10.15 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	6838	3	2279	<1.00	9.28	N.S.
Treatment	26982	1	26982	8.49	10.10	N.S.
Error	9538	3	3179			
Total	43358	7				

S.E. = ± 28

10.16 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	17590	3	5863	67.39	9.28 (29.50)	**
Treatment	578	1	578	6.64	10.10	N.S.
Error	262	3	87			
Total	18430	7				

S.E. = ± 5

APPENDIX 11

Total yield of individual weed species at pre- and post-treading dates (derived from yields in perennial ryegrass, timothy amd browntop plots).

11.1 *Sagina procumbens* L.

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61	Total
1	UT	16	-	-	60	60
	T	64	-	12	12	24
2	UT	-	32	16	36	84
	T	48	52	20	-	72
3	UT	24	48	76	-	124
	T	4	12	-	16	28
4	UT	4	-	-	72	72
	T	24	32	-	-	32
$\bar{x}$	UT	11	20	23	41	85
	T	35 ± 11	24	8	7	39 ± 13

11.2 *Trifolium dubium* sibth.

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61	Total
1	UT	64	16	-	24	40
	T	28	20	8	-	28
2	UT	72	20	-	16	36
	T	-	24	20	148	192
3	UT	24	32	8	80	120
	T	-	56	-	52	108
4	UT	44	32	-	24	56
	T	-	-	8	88	96
$\bar{x}$	UT	51	25	2[illegible]	36	63
	T	7 ± 7	25	9	72	106 ± 31

APPENDIX 11 (Cont.)

11.3 Trifolium repens L.

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61	Total
1	UT	-	32	32	-	64
	T	24	68	88	-	156
2	UT	-	-	32	-	32
	T	-	-	112	80	192
3	UT	296	76	-	48	124
	T	280	32	16	68	116
4	UT	48	40	-	120	160
	T	132	16	-	144	160
$\bar{x}$	UT	86	37	16	42	95
	T	109 ±17	19	54	73	146 ±28

11.4 Rumex acetosella agg.

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61	Total
1	UT	52	64	24	24	112
	T	172	8	8	76	92
2	UT	120	120	192	16	328
	T	72	32	64	160	256
3	UT	-	-	4	8	12
	T	-	16	12	48	76
4	UT	20	-	-	-	-
	T	-	40	-	12	52
$\bar{x}$	UT	48	46	54	12	112
	T	61 ±25	24	21	74	119 ±23

11.5 Crepis capillaris (L.) Wallr.

Block	Treatment	13.4.61	11.5.61	8.6.61	6.7.61	Total
1	UT	24	28	20	24	72
	T	40	120	12	16	148
2	UT	16	104	112	204	420
	T	100	204	52	56	312
3	UT	-	24	28	-	52
	T	-	-	4	88	92
4	UT	60	8	24	-	32
	T	48	-	100	8	108
$\bar{X}$	UT	25	39	46	57	142
	T	47 ±15	81	42	20	143 ±31

APPENDIX 12

Dry weight yield of Poa spp within each sown species plot at each sampling date. Total yield, mean and standard error shown.

12.1 11.5.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop	Total
1	UT	20	-	-	56	56
	T	-	-	-	-	-
2	UT	-	28	32	-	60
	T	8	56	24	12	100
3	UT	12	-	-	8	20
	T	24	-	8	20	52
4	UT	40	100	-	16	156
	T	32	-	-	28	60
$\bar{x}$	UT	18	32	8	15	73
	T	16	14	8	15	53 ±23

12.2 8.6.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop	Total
1	UT	24	56	8	32	120
	T	24	20	8	-	52
2	UT	16	52	-	-	68
	T	8	32	32	32	104
3	UT	12	8	-	-	20
	T	20	-	-	8	28
4	UT	20	48	-	40	108
	T	36	44	16	28	84
$\bar{x}$	UT	18	41	2	18	79
	T	22	14	14	17	67 ±16

12.3 16.7.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop	Total
1	UT	8	52	20	20	100
	T	20	88	72	112	292
2	UT	8	64	60	68	200
	T	28	32	-	82	142
3	UT	8	20	-	-	28
	T	-	-	44	32	76
4	UT	40	20	-	16	76
	T	72	-	80	16	168
$\bar{x}$	UT	16	39	20	26	101
	T	30	30	49	61	170 ±37

APPENDIX 13

Percentage of growing points above the soil surface.
Means and standard errors of transformed data shown.
True percentage shown in brackets.

13.1 6.7.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	54 (66)	53 (64)	55 (67)	56 (68)
	T	55 (67)	57 (71)	61 (76)	53 (63)
2	UT	57 (71)	39 (40)	63 (79)	54 (65)
	T	51 (60)	60 (75)	61 (77)	53 (63)
3	UT	56 (68)	53 (63)	71 (89)	50 (59)
	T	53 (63)	56 (68)	56 (69)	36 (34)
4	UT	55 (67)	64 (81)	60 (75)	40 (41)
	T	51 (60)	56 (68)	63 (79)	60 (75)
$\bar{x}$	UT	56 (69)	52 (62)	62 (78)	50 (59)
	T	53 $\pm$1 (64)	57 $\pm$4 (70)	60 $\pm$3 (75)	51 $\pm$5 (60)

APPENDIX 14

Analyses of variance of the transformed percentages.

Individual species

14.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	3	3	1	<1.00	9.28	N.S.
Treatment	18	1	18	4.50	10.10	N.S.
Error	13	3	4			
Total	34	7				

v = 3.6%

14.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	110	3	37	<1.00	9.28	N.S.
Treatment	50	1	50	<1.00	10.10	N.S.
Error	215	3	72			
Total	375	7				

v = 15.4%

14.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	32	3	11	<1.00	9.28	N.S.
Treatment	8	1	8	<1.00	10.10	N.S.
Error	129	3	43			
Total	169	7				

v = 10.9%

14.4 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	162	3	54	<1.00	9.28	N.S.
Treatment	1	1	1	<1.00	10.10	N.S.
Error	302	3	101			
Total	465	7				

v = 19.3%

Combined species

14.5

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	23	3	8	<1.00	3.86	N.S.
Species	502	3	167	5.22	3.86 (6.99)	*
Error 1	285	9	32			
Treatment	1	1	1	<1.00	4.75	N.S.
Species X Treatment	75	3	25	<1.00	3.49	N.S.
Error	660	12	55			
Total	1546					

APPENDIX 15

Soil moisture (% of oven-dried soil) at time of treading (13.4.61). Block figure, species plot, treatment means and standard errors shown.

15.1

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	27.9	24.0	25.4	24.2
	T	26.7	24.8	25.9	25.8
2	UT	24.9	26.3	25.7	26.2
	T	25.3	24.9	24.8	25.8
3	UT	28.2	25.7	25.9	27.0
	T	26.7	26.6	27.1	26.6
4	UT	25.2	26.0	26.6	24.3
	T	25.0	26.4	24.4	24.4
$\bar{x}$	UT	26.6	25.5	25.9	25.4
		$\pm$0.32	$\pm$0.40	$\pm$0.54	$\pm$0.33
	T	25.9	25.7	25.6	25.7

APPENDIX 16

Analyses of variance of soil moisture data

Individual Species

16.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	10.38	3	3.46	8.87	9.28	N.S.
Treatment	0.78	1	0.78	2.00	10.10	N.S.
Error	1.16	3	0.39			
Total	12.32	7				

S.E. = ± 0.32

16.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	4.21	3	1.40	2.19	9.28	N.S.
Treatment	0.06	1	0.06	<1.00	10.10	N.S.
Error	1.72	3	0.64			
Total	5.99	7				

S.E. = ± 0.40

16.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	1.76	3	0.59	<1.00	9.28	N.S.
Treatment	0.24	1	0.24	<1.00	10.10	N.S.
Error	3.43	3	1.14			
Total	5.43	7				

S.E. = ± 0.54

16.4 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	7.00	3	2.33	2.33	9.28	N.S.
Treatment	0.10	1	0.10	<1.00	10.10	N.S.
Error	1.36	3	0.45			
Total	8.46	7				

S.E. = ± 0.33

APPENDIX 17

Bulk density of the soil (gms/cc) at three depths one month after treading. Block figure, species plot, treatment means and standard errors shown.

17.1 0 - 2 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.16	1.04	1.21	1.38
	T	1.39	1.31	1.36	1.35
2	UT	1.23	1.25	1.15	1.12
	T	1.40	1.42	1.41	1.36
3	UT	1.22	1.18	1.13	1.20
	T	1.43	1.39	1.45	1.28
4	UT	1.23	1.21	1.30	1.05
	T	1.38	1.43	1.37	1.15
$\bar{x}$	UT	1.21	1.17	1.20	1.19
	T	1.40 ±0.013	1.39 ±0.014	1.40 ±0.039	1.29 ±0.039

17.2 2 - 4 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.21	1.21	1.17	1.22
	T	1.27	1.34	1.28	1.27
2	UT	1.18	1.29	1.21	1.30
	T	1.29	1.32	1.40	1.32
3	UT	1.12	1.23	1.32	1.21
	T	1.21	1.31	1.30	1.27
4	UT	1.27	1.23	1.25	1.08
	T	1.35	1.32	1.31	1.34
$\bar{x}$	UT	1.20	1.24	1.24	1.20
	T	1.28 ±0.007	1.32 ±0.014	1.32 ±0.031	1.30 ±0.039

17.3 4 - 6 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.18	1.20	1.15	1.17
	T	1.25	1.24	1.18	1.34
2	UT	1.08	1.23	1.19	1.26
	T	1.27	1.22	1.29	1.33
3	UT	1.18	1.08	1.22	1.14
	T	1.21	1.26	1.31	1.15
4	UT	1.20	1.28	1.14	1.14
	T	1.28	1.22	1.30	1.22
$\bar{x}$	UT	1.16	1.20	1.18	1.18
	T	1.25 ±0.024	1.24 ±0.036	1.27 ±0.019	1.26 ±0.024

APPENDIX 18

Analyses of variance of bulk density data

0 - 2 cms.
Individual species

18.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0028	3	0.0009	1.29	9.28	N.S.
Treatment	0.0722	1	0.0722	103.14	10.10 (34.10)	**
Error	0.0020	3	0.0007			
Total	0.0770	7				

v = 2.0%

18.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0314	3	0.0105	13.13	9.28 (29.50)	*
Treatment	0.0946	1	0.0946	118.25	10.10 (34.10)	**
Error	0.0025	3	0.0008			
Total	0.1285	7				

v = 2.2%

18.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0038	3	0.0013	<1.00	9.28	N.S.
Treatment	0.0800	1	0.0800	12.90	10.10 (34.10)	*
Error	0.0187	3	0.0062			
Total	0.1025	7				

v = 5.9%

18.4 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0704	3	0.0235	3.85	9.28	N.S.
Treatment	0.0190	1	0.0190	3.11	10.10	N.S.
Error	0.0184	3	0.0061			
Total	0.1078	7				

v = 6.2%

2 - 4 cms.
Individual species

18.5 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0210	3	0.0070	35.00	9.28 (29.50)	**
Treatment	0.0144	1	0.0144	72.20	10.10 (34.10)	**
Error	0.0007	3	0.0002			
Total	0.0361	7				

v = 1.1%

18.6 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0016	3	0.0005	<1.00	9.28	
Treatment	0.0136	1	0.0136	17.00	10.10 (34.10)	*
Error	0.0025	3	0.0008			
Total	0.0177	7				

v = 2.2%

18.7 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0091	3	0.0030	<1.00	9.28	N.S.
Treatment	0.0145	1	0.0145	3.72	10.10	N.S.
Error	0.0116	3	0.0039			
Total	0.0352	7				

v = 4.8%

18.8 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0107	3	0.0036	<1.00	9.28	N.S.
Treatment	0.0190	1	0.0190	3.17	10.10	N.S.
Error	0.0180	3	0.0060			
Total	0.0477	7				

v = 6.2%

4 -6cms.
Individual species

18.9 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0047	3	0.0016	<1.00	9.28	N.S.
Treatment	0.0171	1	0.0171	7.43	10.10	N.S.
Error	0.0070	3	0.0023			
Total	0.0288	7				

v = 3.9%

18.10 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0068	3	0.0023	<1.00	9.28	N.S.
Treatment	0.0028	1	0.0028	<1.00	10.10	N.S.
Error	0.0160	3	0.0053			
Total	0.0256	7				

v = 5.9%

18.11 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0109	3	0.0036	2.57	9.28	N.S.
Treatment	0.0181	1	0.0181	12.93	10.10 (34.10)	*
Error	0.0042	3	0.0014			
Total	0.0332	7				

v = 3.1%

18.12 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0282	3	0.0094	4.27	9.28	N.S.
Treatment	0.0136	1	0.0136	6.00	10.10	N.S.
Error	0.0065	3	0.0022			
Total	0.0483	7				

v = 3.9%

APPENDIX 19

Dry weight (lbs/acre) at each sampling date. Treatment means and standard errors shown.

19.1 Perennial ryegrass

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	668	1556	2936	4680	5924
	T	696	848	1560	2656	4508
2	UT	716	1324	2232	4301	5736
	T	844	980	2120	3632	5032
3	UT	876	1316	2364	3576	6252
	T	856	848	1284	2716	6788
4	UT	880	1460	2200	3904	5708
	T	1036	948	1740	2864	5112
$\bar{x}$	UT	785	1414	2433	4115	5905
	T	858 ±29	906 ±53	1676 ±203	2967 ±213	5360 ±285

19.2 Timothy

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	752	1228	2032	3668	4932
	T	812	836	1320	2204	4244
2	UT	712	1188	2092	3484	3880
	T	868	1044	1232	2372	3544
3	UT	1052	1468	2128	3372	3876
	T	948	908	1504	2364	5052
4	UT	1244	1388	2544	2384	4004
	T	888	844	808	2208	4588
$\bar{x}$	UT	940	1318	2199	3227	4173
	T	879 ±80	908 ±68	1216 ±184	2287 ±180	4357 ±301

APPENDIX 19 (Cont.)

19.3 Cocksfoot

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	1076	1648	2796	3380	7156
	T	916	1104	1476	2212	4244
2	UT	1024	1256	1636	2860	5728
	T	1112	1008	1564	2272	6892
3	UT	776	1300	3000	5540	7740
	T	680	596	960	2408	5744
4	UT	836	1084	3412	3372	5116
	T	848	752	1164	1204	2984
$\bar{x}$	UT	928	1322	2711	3788	6435
	T	889 ±41	865 ±72	1291 ±348	2024 ±396	4966 ±636

19.4 Browntop

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	1112	2120	2732	3208	3668
	T	1248	1392	1244	1980	3124
2	UT	1004	2344	2596	3016	3396
	T	1188	1620	1496	2304	2424
3	UT	1068	1720	2968	3240	3688
	T	1112	1216	1660	1628	3212
4	UT	1006	1712	2612	3160	3852
	T	1000	972	1312	1932	3620
$\bar{x}$	UT	1048	1974	2727	3156	3651
	T	1146 ±30	1300 ±80	1428 ±56	1961 ±132	3095 ±108

APPENDIX 20

Analyses of variance of the dryweight yield of each species at each sampling date

Perennial ryegrass

20.1 13.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	83584	3	27861	8.11	9.28	N.S.
Treatment	10656	1	10656	3.10	10.10	N.S.
Error	10304	3	3435			
Total	104544	7				

v = 7.0%

20.2 23.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	19696	3	6565	<1.00	9.28	N.S.
Treatment	516128	1	516128	45.20	10.10 (34.10)	**
Error	34256	3	11419			
Total	570080	7				

v = 9.2%

20.3 3.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	224960	3	74987	<1.00	9.28	N.S.
Treatment	1146096	1	1146096	6.93	10.10	N.S.
Error	495856	3	165285			
Total	1866912	7				

v = 19.6%

20.4 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	754864	3	251621	1.38	9.28	N.S.
Treatment	2635808	1	2635808	14.48	10.10 (34.10)	*
Error	546192	3	182064			
Total	3936864	7				

v = 12.0%

20.5 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2144896	3	714965	2.19	9.28	N.S.
Treatment	594176	1	594176	1.82	10.10	N.S.
Error	977424	3	325808			
Total	3716496	7				

v = 10.1%

Timothy

20.6 13.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	126448	3	42149	1.68	9.28	N.S.
Treatment	7440	1	7440	<1.00	10.10	N.S.
Error	75296	3	25099			
Total	209184	7				

v = 17.1%

20.7 23.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	24400	3	8133	<1.00	9.28	N.S.
Treatment	336192	1	336192	18.08	10.10 (34.10)	*
Error	55776	3	18592			
Total	416368	7				

v = 12.0%

20.8 3.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	31664	3	10555	<1.00	9.28	N.S.
Treatment	1932576	1	1932576	14.78	10.10 (34.10)	*
Error	392224	3	130741			
Total	2356464	7				

v = 21.0%

20.9 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	572256	3	190752	1.27	9.28	N.S.
Treatment	1764000	1	1764000	11.78	10.10 (34.10)	*
Error	449440	3	149813			
Total	2785696	7				

v = 14.0%

20.10 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	901408	3	300469	<1.00	9.28	N.S.
Treatment	67712	1	67712	<1.00	10.10	N.S.
Error	1087424	3	362475			
Total	2056544	7				

v = 14.0%

Cocksfoot

20.11 13.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	140208	3	46736	7.28	9.28	N.S.
Treatment	2112	1	2112	<1.00	10.10	N.S.
Error	19232	3	6411			
Total	161552	7				

v = 8.7%

20.12 23.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	266528	3	88843	4.17	9.28	N.S.
Treatment	417696	1	417696	19.60	10.10 (34.10)	*
Error	63936	3	21312			
Total	748160	7				

v = 13.2%

20.13 3.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	523680	3	174560	<1.00	9.28	N.S.
Treatment	4032816	1	4032816	8.35	10.10	N.S.
Error	1448528	3	482843			
Total	6005024	7				

v = 34.4%

20.14 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	3300496	3	1100165	1.75	9.28	N.S.
Treatment	6223392	1	6223392	9.90	10.10	N.S.
Error	1886416	3	628805			
Total	11410304	7				

v = 26.9%

20.15 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	8360720	3	2786907	1.72	9.28	N.S.
Treatment	4315920	1	4315920	2.66	10.10	N.S.
Error	4866128	3	1622043			
Total	17542768	7				

v = 22.1%

Browntop

20.16 13.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	31728	3	10576	2.90	9.28	N.S.
Treatment	16208	1	16208	4.44	10.10	N.S.
Error	10944	3	3648			
Total	58880	7				

v = 5.6%

20.17 23.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	313360	3	104453	4.18	9.28	N.S.
Treatment	1140048	1	1140048	45.68	10.10 (34.10)	**
Error	74896	3	24965			
Total	1528304	7				

v = 9.8%

20.18 3.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	156560	3	52187	4.15	9.28	N.S.
Treatment	3374800	1	3374800	268.59	10.10 (34.10)	**
Error	37696	3	12565			
Total	3569056	7				

v = 5.3%

20.19 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	54448	3	18149	<1.00	9.28	N.S.
Treatment	2856048	1	2856048	41.86	10.10 (34.10)	**
Error	204672	3	68224			
Total	3115168	7				

v = 10.1%

20.20 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	705200	3	235067	4.96	9.28	N.S.
Treatment	618272	1	618272	14.87	10.10 (34.10)	*
Error	142288	3	47429			
Total	1465760	7				

v = 6.4%

APPENDIX 21

Analyses of variance of the combined yields of all species at two sampling dates

21.1 13.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	1087520	3	362507	9.07	3.86 (6.99)	**
Species	4331040	3	1443680	36.15	3.86 (6.99)	**
Error 1	359456	9	39940			
Treatment	12736112	1	12736112	24.19	4.75 (9.33)	**
Species X Treatment	746512	3	248837	<1.00	3.49	N.S.
Error 2	6318480	12	526540			
Total	25579120	31				

21.2 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	3741760	3	1247253	1.34	3.86	N.S.
Species	30507200	3	10169066	10.93	3.86 (6.99)	**
Error 1	8370416	9	930046			
Treatment	2846576	1	2846576	4.83	4.75 (9.33)	*
Species X Treatment	2749424	3	916475	1.55	3.49	N.S.
Error 2	7073328	12	589444			
Total	55288704	31				

APPENDIX 22

Tiller counts per 36 sq.ins. for three species at each sampling date. (Treatment means and standard errors shown).

22.1. Perennial ryegrass

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	279	400	418	430	135
	T	352	273	401	311	162
2	UT	347	438	429	401	165
	T	345	300	348	316	218
3	UT	326	474	455	320	217
	T	329	318	317	324	191
4	UT	381	433	365	351	187
	T	351	307	314	337	197
$\bar{X}$	UT	333	436	417	376	176
	T	344 ± 15	300 ± 5	345 ± 18	322 ± 21	192 ± 12

22.2. Timothy

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	140	157	164	175	115
	T	140	137	149	133	124
2	UT	132	176	168	193	92
	T	136	112	129	169	93
3	UT	139	161	163	175	113
	T	126	102	125	133	153
4	UT	118	151	185	117	74
	T	98	116	96	110	111
$\bar{X}$	UT	132	161	170	165	99
	T	125 ± 4	116 ± 7	125 ± 11	136 ± 6	120 ± 7

APPENDIX 22 (Cont.)

22.3. Cocksfoot

Block	Treatment	13.9.61	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	197	279	308	148	149
	T	205	217	204	127	92
2	UT	290	280	256	169	99
	T	249	235	271	175	113
3	UT	186	165	225	198	131
	T	156	108	124	159	82
4	UT	148	181	233	176	111
	T	172	149	171	96	90
$\bar{X}$	UT	205	226	256	173	123
	T	195 $\pm$ 11	177 $\pm$ 5	192 $\pm$ 20	139 $\pm$ 17	94 $\pm$ 12

APPENDIX 23

Analyses of variance of tiller counts for each species at each sampling date.

Perennial ryegrass

23.1. 13.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	2923	3	974	1.01	9.28	N.S.
Treatment	243	1	243	<1.00	10.10 (34.10)	N.S.
Error	2880	3	960			
Total	6046	7				

V = 9.2%

23.2. 23.9.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	3563	3	1188	12.27	9.28 (29.50)	*
Treatment	37401	1	37401	385.57	10.10 (34.10)	**
Error	291	3	97			
Total	41255	7				

V = 9.2%

23.3. 3.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	5230	3	1743	1.32	9.28	N.S.
Treatment	10296	1	10296	7.80	10.10	N.S.
Error	3953	3	1318			
Total	19479	7				

V = 9.5%

23.4. 13.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	2612	3	872	<1.00	9.28	N.S.
Treatment	5724	1	5724	3.38	10.10	N.S.
Error	5075	3	1692			
Total	13411	7				

V = 11.8%

23.5. 6.11.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	3561	3	1187	2.17	9.28	N.S.
Treatment	512	1	512	<1.00	10.10	N.S.
Error	1645	3	548			
Total	5718	7				

V = 12.6%

Timothy

23.6. 13.9.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	1198	3	399	6.76	9.28	N.S.
Treatment	115	1	115	1.95	10.10	N.S.
Error	177	3	59			
Total	1490	7				

V = 5.9%

23.7. 23.9.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	351	3	127	<1.00	9.28	N.S.
Treatment	3961	1	3961	18.86	10.10 (34.10)	*
Error	640	3	213			
Total	4952	7				

V = 10.4%

23.8. 3.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	287	3	96	<1.00	9.28	N.S.
Treatment	4095	1	4095	8.41	10.10	N.S.
Error	1460	3	487			
Total	5842	7				

V = 14.8%

23.9. 13.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	4648	3	1549	10.99	9.28 (29.50)	*
Treatment	1653	1	1653	11.72	10.10 (34.10)	*
Error	423	3	141			
Total	6724	7				

V = 7.8%

23.10. 6.11.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	2461	3	820	4.25	9.28	N.S.
Treatment	946	1	946	4.90	10.10	N.S.
Error	579	3	193			
Total	3986	7				

V = 12.6%

23.11. Cocksfoot
13.9.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	14544	3	4851	10.41	9.28 (29.50)	*
Treatment	191	1	191	<1.00	10.10	N.S.
Error	1399	3	466			
Total	16134	7				

V = 10.6%

23.12. 23.9.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	21721	3	7240	84.19	9.28 (29.50)	**
Treatment	4802	1	4802	55.84	10.10 (34.10)	**
Error	259	3	86			
Total	26782	7				

V = 4.5%

23.13. 3.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	11027	3	3676	2.39	9.28	N.S.
Treatment	7928	1	7928	5.15	10.10	N.S.
Error	4615	3	1538			
Total	23570	7				

V = 17.4%

23.14. 13.10.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	2009	3	670	<1.00	9.28	N.S.
Treatment	1845	1	1845	1.65	10.10	N.S.
Error	3354	3	1118			
Total	7208	7				

V = 21.3%

23.15. 6.11.61

Source	SS	d.f.	M.S.	F value	F required	Result
Block	437	3	146	<1.00	9.28	N.S.
Treatment	1516	1	1516	2.80	10.10	N.S.
Error	1627	3	542			
Total	3580	7				

V = 21.3%

APPENDIX 24

Counts of "abnormal" tillers per 36 sq. ins. for three species at three sampling dates. Mean percentage occurrence and standard error shown. (Total live tillers shown in Appendix 22).

24.1. 23.9.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot
1	UT	-	-	-
	T	7	9	10
2	UT	-	-	-
	T	6	7	5
3	UT	-	-	-
	T	6	12	4
4	UT	-	-	-
	T	24	6	7
$\bar{X}$ %	UT	-	-	-
	T	3.6 ± 1.1	7.3 ± 2.4	3.7 ± 1.4

24.2. 3.10.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot
1	UT	-	-	-
	T	3	27	12
2	UT	-	-	-
	T	2	18	19
3	UT	-	-	-
	T	-	19	17
4	UT	-	-	-
	T	6	8	11
$\bar{X}$ %	UT	-	-	-
	T	0.8 ± 0.5	14.4 ± 3.1	7.7 ± 1.9

APPENDIX 24 (Cont.)

24.3. 13.10.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot
1	UT	-	-	-
	T	-	5	-
2	UT	-	-	-
	T	-	-	-
3	UT	-	-	-
	T	-	16	-
4	UT	-	-	-
	T	-	9	1
$\bar{X}$ %	UT	-	-	-
	T	-	5.5 ± 1.9	-

APPENDIX 25

Percentage of growing points above the soil surface.
Means and standard errors of transformed data shown.
True percentages shown in brackets.

25.1 13.9.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1.	UT	46 (51)	47 (54)	49 (57)	62 (78)
	T	53 (63)	40 (42)	51 (60)	63 (79)
2.	UT	60 (75)	42 (44)	43 (47)	61 (76)
	T	60 (75)	46 (51)	52 (62)	44 (49)
3.	UT	39 (40)	34 (32)	63 (79)	56 (69)
	T	51 (61)	40 (42)	51 (60)	37 (36)
4.	UT	48 (56)	47 (54)	51 (60)	51 (60)
	T	46 (52)	40 (41)	53 (63)	60 (75)
$\bar{x}$	UT	48 (56)	43 (46)	52 (61)	58 (71)
	T	$53^{\pm 2}$ (63)	$42^{\pm 4}$ (44)	$52^{\pm 3}$ (61)	$51^{\pm 5}$ (60)

25.2 23.9.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1.	UT	65 (82)	51 (61)	61 (77)	62 (78)
	T	51 (60)	33 (29)	51 (60)	64 (81)
2.	UT	51 (61)	48 (56)	57 (71)	59 (74)
	T	57 (71)	58 (72)	58 (72)	48 (56)
3.	UT	47 (53)	36 (35)	76 (94)	53 (64)
	T	47 (54)	41 (43)	34 (32)	56 (68)
4.	UT	61 (77)	53 (63)	48 (55)	55 (67)
	T	51 (61)	48 (55)	43 (46)	48 (56)
$\bar{x}$	UT	56 (68)	47 (54)	61 (74)	57 (71)
	T	$52^{\pm 3}$ (62)	$45^{\pm 4}$ (50)	$47^{\pm 7}$ (53)	$54^{\pm 2}$ (65)

APPENDIX 25 (Continued)

25.3 3.10.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1.	UT	57 (71)	46 (52)	53 (64)	58 (72)
	T	50 (59)	39 (40)	51 (61)	57 (70)
2.	UT	66 (84)	39 (40)	63 (79)	46 (52)
	T	46 (52)	50 (59)	47 (54)	66 (84)
3.	UT	51 (60)	47 (54)	61 (77)	73 (92)
	T	60 (75)	49 (57)	55 (67)	75 (93)
4.	UT	59 (74)	50 (59)	61 (77)	65 (82)
	T	54 (66)	50 (59)	53 (64)	61 (77)
$\bar{X}$	UT	58 (72)	46 (51)	60 (74)	61 (75)
	T	$53^{\pm 4}$ (63)	$47^{\pm 3}$ (54)	$52^{\pm 2}$ (62)	$65^{\pm 4}$ (81)

25.4 13.10.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1.	UT	59 (74)	45 (50)	60 (75)	62 (78)
	T	56 (69)	44 (48)	47 (54)	72 (91)
2.	UT	71 (89)	47 (54)	82 (98)	71 (89)
	T	70 (88)	53 (64)	51 (60)	65 (82)
3.	UT	65 (82)	75 (93)	65 (82)	76 (94)
	T	61 (77)	59 (74)	54 (66)	65 (82)
4.	UT	56 (69)	61 (77)	74 (93)	74 (92)
	T	50 (59)	66 (84)	46 (52)	67 (85)
$\bar{X}$	UT	63 (79)	57 (69)	70 (87)	71 (88)
	T	$59^{\pm 1}$ (73)	$56^{\pm 4}$ (68)	$50^{\pm 4}$ (58)	$67^{\pm 3}$ (85)

APPENDIX 25 (Continued)

25.5 6.11.61

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1.	UT	78 (96)	66 (84)	64 (81)	77 (95)
	T	69 (87)	69 (87)	66 (84)	90 (100)
2.	UT	80 (97)	59 (74)	72 (91)	90 (100)
	T	80 (97)	69 (87)	73 (92)	80 (97)
3.	UT	71 (89)	78 (96)	74 (92)	90 (100)
	T	75 (93)	70 (88)	77 (95)	82 (98)
4.	UT	90 (100)	72 (91)	72 (91)	90 (100)
	T	90 (100)	78 (96)	90 (100)	75 (93)
$\bar{X}$	UT	80 (96)	69 (86)	71 (89)	87 (99)
	T	$79^{\pm 2}$ (94)	$72^{\pm 3}$ (90)	$77^{\pm 1}$ (93)	$82^{\pm 2}$ (97)

APPENDIX 26

Analyses of variance of the transformed percentages (growing points)

13.9.61

26.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	268	3	89	4.24	9.28	N.S.
Treatment	36	1	36	1.71		
Error	62	3	21			
Total	366	7				

26.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	67	3	22	<1.00	9.28	N.S.
Treatment	2	1	2	<1.00	10.10	N.S.
Error	73	3	24			
Total	142	7				

26.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	98	3	33	<1.00	9.28	N.S.
Treatment	1	1	1	<1.00	10.10	N.S.
Error	116	3	39			
Total	215	7				

26.4 Browntop.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	265	3	88	<1.00	9.28	N.S.
Treatment	84	1	84	<1.00	10.10	N.S.
Error	282	3	94			
Total	631	7				

26.5 Combined species

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	124	3	41	<1.00	3.86	N.S.
Species	673	3	224	3.50	3.86 (6.99)	N.S.
Error 1	573	9	64			
Treatment	4	1	4	<1.00	4.75	N.S.
Species x Treatment	119	3	40	<1.00	3.49	N.S.
Error 2	533	12	44			
Total	2026	31				

23.9.61

26.6 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	137	3	46	1.10	9.28	N.S.
Treatment	40	1	40	<1.00	10.10	N.S.
Error	126	3	42			
Total	303	7				

26.7 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	283	3	94	1.24	9.28	N.S.
Treatment	8	1	8	<1.00	10.10	N.S.
Error	229	3	76			
Total	520	7				

APPENDIX 26 (Continued)

26.8 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	177	3	59	<1.00	9.28	N.S.
Treatment	392	1	392	2.13	10.10	N.S.
Error	553	3	184			
Total	1122	7				

26.9 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	155	3	52	2.26	9.28	N.S.
Treatment	21	1	2	<1.00	10.10	N.S.
Error	70	3	23			
Total	246	7				

26.10 Combined species.

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	203	3	68	1.11	3.86	N.S.
Species	434	3	145	2.38	3.86	N.S.
Error 1	548	9	61			
Treatment	282	1	282	3.43	4.75	N.S.
Species x Treatment	179	3	60	<1.00	3.49	N.S.
Error 2	979	12	82			
Total	2625	31				

APPENDIX 26 (Continued)

3.10.61

26.11 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	11	3	4	<1.00	9.28	N.S.
Treatment	66	1	66	<1.00	10.10	N.S.
Error	211	3	70			
Total	288	7				

26.12 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	68	3	23	<1.00	9.28	N.S.
Treatment	4	1	4	<1.00	10.10	N.S.
Error	83	3	28			
Total	155	7				

26.13 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	42	3	14	<1.00	9.28	N.S.
Treatment	128	1	128	7.53	10.10	N.S.
Error	52	3	17			
Total	222	7				

26.14 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	400	3	133	2.29	9.28	N.S.
Treatment	36	1	36	<1.00	10.10	N.S.
Error	174	3	58			
Total	610	7				

26.15 Combined species

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	283	3	94	3.62	3.86	N.S.
Species	1081	3	360	13.85	3.86 (6.99)	* *
Error 1	237	9	26			
Treatment	32	1	32	<1.00	4.75	N.S.
Species x Treatment	203	3	68	1.56	3.49	N.S.
Error 2	520	12	43			
Total	2356	31				

13.10.61

26.16 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	341	3	114	57.00	9.28(29.50)	* *
Treatment	24	1	24	12.00	10.10(34.10)	*
Error	5	3	2			
Total	372	7				

26.17 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	690	3	230	4.42	9.28	N.S.
Treatment	4	1	4	<1.00	10.10	N.S.
Error	155	3	52			
Total	849	7				

26.18 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	170	3	57	1.09	9.28	N.S.
Treatment	861	1	861	16.56	10.10 (34.10)	*
Error	156	3	52			

26.19 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	19	3	6	<1.00	9.28	N.S.
Treatment	25	1	25	<1.00	10.10	N.S.
Error	128	3	43			
Total	172	7				

26.20 Combined species

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	415	3	138	1.52	3.86	N.S.
Species	684	3	228	2.51	3.86	N.S.
Error 1	815	9	91			
Treatment	428	1	428	11.89	4.75 (9.33)	* *
Species X Treatment	496	3	165	4.58	3.49 (5.95)	*
Error 2	436	12	36			
Total	3274	31				

6.11.61

26.21 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	115	3	38	2.53	9.28	N.S.
Treatment	3	1	3	<1.00	10.10	N.S.
Error	45	3	15			
Total	163	7				

26.22 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	226	3	75	1.83	9.28	N.S.
Treatment	32	1	32	<1.00	10.10	N.S.
Error	124	3	41			
Total	382	7				

26.23 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	187	3	62	7.75	9.28	N.S.
Treatment	36	1	36	4.50	10.10	N.S.
Error	23	3	8			
Total	246	7				

26.24 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	8	3	3	<1.00	9.28	N.S.
Treatment	6	1	6	<1.00	10.10	N.S.
Error	37	3	12			
Total	51	7				

26.25 Combined species

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	401	3	134	2.97	3.86	N.S.
Species	931	3	310	6.89	3.86 (6.99)	*
Error 1	423	9	45			
Treatment	3	1	3	<1.00	4.75	N.S.
Species × Treatment	136	3	45	1.15	3.49	N.S.
Error 2	462	12	39			
Total	2356	31				

APPENDIX 27

Percentage of tillers showing internode elongation and flowering. Treatment means and standard errors of transformed data shown.

27.1 Perennial ryegrass

Internode elongation

Block	Treatment	23.9.61	3.10.61	13.10.61	6.11.61
1	UT	6 (1)	18 (10)	23 (15)	54 (65)
	T	10 (3)	10 (3)	31 (26)	40 (42)
2	UT	12 (4)	18 (10)	28 (22)	41 (43)
	T	14 (6)	18 (10)	35 (33)	50 (58)
3	UT	8 (2)	14 (6)	36 (34)	46 (51)
	T	8 (2)	19 (11)	20 (12)	48 (56)
4	UT	8 (2)	22 (14)	38 (38)	59 (73)
	T	8 (2)	23 (15)	25 (18)	56 (69)
$\bar{X}$	UT	9 (2)	18 (10)	32 (28)	50 (59)
	T	10 ±1 (3)	18 ±4 (10)	28 ±9 (22)	48 ±7 (55)

27.2 Perennial ryegrass

Flowering

Block	Treatment	6.11.61
1	UT	31 (26)
	T	31 (26)
2	UT	31 (27)
	T	24 (16)
3	UT	27 (20)
	T	24 (16)
4	UT	24 (16)
	T	30 (25)
$\bar{X}$	UT	28 (22)
	T	27 (21)

APPENDIX 27 (Cont.)

27.3 Timothy

Internode elongation

Block	Treatment	13.10.61	6.11.61
1	UT	16 (8)	57 (70)
	T	- (-)	34 (34)
2	UT	24 (17)	46 (46)
	T	- (-)	33 (33)
3	UT	18 (10)	42 (42)
	T	20 (12)	42 (42)
4	UT	13 (5)	44 (44)
	T	- (-)	53 (53)
$\bar{X}$	UT	18 (10)	47 (51)
	T	5 $\pm$4 (3)	41 $\pm$5 (41)

27.4 Cocksfoot

Internode elongation

Block	Treatment	13.10.61	6.11.61
1	UT	10 (3)	30 (25)
	T	13 (5)	63 (79)
2	UT	8 (2)	43 (46)
	T	- (-)	51 (61)
3	UT	31 (27)	40 (42)
	T	8 (2)	50 (59)
4	UT	17 (9)	38 (38)
	T	- (-)	46 (52)
$\bar{X}$	UT	17 (10)	38 (38)
	T	5 $\pm$4 (2)	53 $\pm$7 (63)

3 flowering tillers were noted in UT plots.

APPENDIX 27 (Cont)

27.5 Browntop

Internode elongation

Block	Treatment	3.10.61		13.10.61		6.11.61	
1	UT	33	(30)	30	(25)	47	(54)
	T	-	(-)	16	(8)	59	(74)
2	UT	14	(6)	31	(27)	67	(84)
	T	-	(-)	31	(27)	51	(60)
3	UT	-	(-)	34	(31)	64	(81)
	T	18	(10)	29	(24)	48	(55)
4	UT	-	(-)	33	(30)	72	(91)
	T	-	(-)	27	(21)	43	(47)
$\bar{X}$	UT	12	(9)	32	(28)	63	(78)
	T	$5^{\pm 8}$	(3)	$26^{\pm 2}$	(20)	$50^{\pm 6}$	(59)

APPENDIX 28.

Analyses of variance of the transformed percentages (internode elongation).

Timothy

28.1 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	188	3	63	1.07	9.28	N.S.
Treatment	325	1	325	5.51	10.10	N.S.
Error	177	3	59			
Total	690	7				

28.2 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	94	3	31	<1.00	9.28	N.S.
Treatment	91	1	91	<1.00	10.10	N.S.
Error	298	3	99			
Total	483	7				

Cocksfoot

28.3 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	256	3	85	1.33	9.28	N.S.
Treatment	253	1	253	3.95	10.10	N.S.
Error	192	3	64			
Total	701	7				

28.4 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	82	3	27	<1.00	9.28	N.S.
Treatment	1250	1	1250	6.65	10.10	N.S.
Error	563	3	188			
Total	1895	7				

APPENDIX 28. (Continued)

Browntop

28.5 13.10.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	95	3	32	1.88	9.28	N.S.
Treatment	78	1	78	4.59	10.10	N.S.
Error	50	3	17			
Total	223	7				

28.6 6.11.61

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	40	3	13	<1.00	9.28	N.S.
Treatment	300	1	300	2.01	10.10	N.S.
Error	448	3	149			
Total	788	7				

APPENDIX 29.

Soil moisture (% of oven-dried soil) at time of treading (13.9.61). Block figure, species plot, treatment means and standard errors shown.

29.1

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	35.0	26.6	31.7	34.1
	T	32.6	31.1	33.5	30.6
2	UT	33.1	28.9	32.4	30.3
	T	27.3	31.6	34.4	33.1
3	UT	36.0	32.4	34.8	32.8
	T	34.1	32.1	34.8	32.5
4	UT	34.7	30.7	33.1	31.0
	T	32.0	32.8	33.0	34.7
$\bar{x}$	UT	34.7 $\pm$ 0.62	29.7 $\pm$ 0.70	33.0 $\pm$ 0.40	32.1 $\pm$ 1.14
	T	31.5	31.9	33.9	32.7

Overall Mean = 32.4%

APPENDIX 30.

Analyses of variance of soil moisture data.

30.1 Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	25.53	3	8.51	5.46	9.28	N.S.
Treatment	20.48	1	20.48	13.13	10.10 (34.10)	*
Error	4.67	3	1.56			
Total	50.68	7				

30.2 Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	14.21	3	4.74	2.41	9.28	N.S.
Treatment	10.12	1	10.12	5.14	10.10	N.S.
Error	5.90	3	1.97			
Total	30.23	7				

30.3 Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	5.42	3	1.81	2.83	9.28	N.S.
Treatment	1.71	1	1.71	2.67	10.10	N.S.
Error	1.91	3	0.64			
Total	9.04	7				

30.4 Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	1.52	3	0.51	<1.00	9.28	N.S.
Treatment	0.91	1	0.91	<1.00	10.10	N.S.
Error	16.02	3	5.34			
Total	18.45	7				

APPENDIX 31

Bulk density of the soil (gms/c.c.) at four depths one month after treading (11.10.61). Block figure, species plot, treatment means and standard errors shown.

31.1 0-2 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.16	1.05	0.93	1.02
	T	1.22	1.22	1.23	1.15
2	UT	1.12	1.06	1.05	1.15
	T	1.19	1.18	1.15	1.17
3	UT	1.06	0.98	0.97	0.83
	T	0.98	1.09	1.21	1.06
4	UT	1.16	0.96	1.20	0.83
	T	1.21	1.34	1.25	1.15
$\bar{x}$	UT	1.13 ± 0.025	1.01 ± 0.044	1.04 ± 0.041	0.96 ± 0.046
	T	1.15	1.21	1.21	1.14

31.2 2-4 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.23	1.19	1.31	1.21
	T	1.31	1.33	1.35	1.32
2	UT	1.13	1.29	1.05	1.20
	T	1.34	1.44	1.29	1.34
3	UT	1.08	1.30	1.13	1.16
	T	1.27	1.27	1.24	1.25
4	UT	1.12	1.11	1.21	1.20
	T	1.22	1.17	1.35	1.29
$\bar{x}$	UT	1.14 ± 0.023	1.22 ± 0.030	1.18 ± 0.029	1.19 ± 0.009
	T	1.29	1.30	1.31	1.30

APPENDIX 31 (Continued)

31.3 4-6 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.16	1.17	1.15	1.16
	T	1.19	1.18	1.21	1.19
2	UT	1.16	1.23	1.00	1.12
	T	1.25	1.15	1.19	1.24
3	UT	1.04	1.12	1.09	1.11
	T	1.18	1.17	1.16	1.16
4	UT	1.06	1.06	1.16	1.16
	T	1.15	1.32	1.27	1.18
$\bar{x}$	UT	1.11 ± 0.015	1.15 ± 0.051	1.10 ± 0.019	1.14 ± 0.015
	T	1.19	1.21	1.21	1.19

31.4 6-8 cms.

Block	Treatment	Perennial ryegrass	Timothy	Cocksfoot	Browntop
1	UT	1.09	1.24	1.06	1.20
	T	1.13	1.20	1.13	1.05
2	UT	1.11	1.20	1.20	1.20
	T	1.13	1.12	1.21	1.24
3	UT	1.11	1.11	1.12	1.14
	T	1.13	1.13	1.15	1.16
4	UT	1.09	1.12	1.01	0.95
	T	1.21	1.23	1.25	1.14
$\bar{x}$	UT	1.10 ± 0.017	1.17 ± 0.029	1.10 ± 0.037	1.12 ± 0.049
	T	1.15	1.17	1.19	1.15

APPENDIX 32

Analyses of variance of bulk density data

0-2 cms

32.1. Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0382	3	0.0127	5.08	9.28	N.S.
Treatment	0.0012	1	0.0012	<1.00	10.10	N.S.
Error	0.0075	3	0.0025			
Total	0.0469	7				

V = 4.5%

32.2. Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0159	3	0.0053	<1.00	9.28	N.S.
Treatment	0.0761	1	0.0761	9.63	10.10	N.S.
Error	0.0238	3	0.0079			
Total	0.1158	7				

V = 7.8%

32.3. Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0278	3	0.0093	1.37	9.28	N.S.
Treatment	0.0595	1	0.0595	8.75	10.10	N.S.
Error	0.0205	3	0.0068			
Total	0.1078	7				

V = 7.3%

32.4. Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0557	3	0.0186	2.24	9.28	N.S.
Treatment	0.0613	1	0.0613	7.39	10.10	N.S.
Error	0.0250	3	0.0083			
Total	0.1420	7				

V = 8.7%

2-4 cms

32.5. Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0140	3	0.0047	2.24	9.28	N.S.
Treatment	0.0420	1	0.0420	20.00	10.10 (34.10)	*
Error	0.0063	3	0.0021			
Total	0.0623	7				

V = 3.6%

32.6. Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0520	3	0.0173	4.94	9.28	N.S.
Treatment	0.0128	1	0.0128	3.66	10.10	N.S.
Error	0.0105	3	0.0035			
Total	0.0753	7				

V = 4.2%

32.7. Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0353	3	0.0117	3.44	9.28	N.S.
Treatment	0.0351	1	0.0351	10.32	10.10	*
Error	0.0103	3	0.0034			
Total	0.0807	7				

V = 4.5%

32.8. Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0053	3	0.0018	6.00	9.28	N.S.
Treatment	0.0231	1	0.0231	77.00	10.10 (34.10)	**
Error	0.0008	3	0.0003			
Total	0.0292	7				

V = 1.4%

4-6 cms

32.9. Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0146	3	0.0049	4.90	9.28	N.S.
Treatment	0.0153	1	0.0153	15.30	10.10 (34.10)	*
Error	0.0030	3	0.0010			
Total	0.0329	7				

V = 2.8%

32.10. Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0027	3	0.0009	<1.00	9.28	N.S.
Treatment	0.0072	1	0.0072	<1.00	10.10	N.S.
Error	0.0311	3	0.0104			
Total	0.0410	7				

V = 8.7%

32.11. Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0175	3	0.0025	1.79	9.28	N.S.
Treatment	0.0231	1	0.0231	16.50	10.10 (34.10)	*
Error	0.0052	3	0.0014			
Total	0.0458	7				

V = 3.1%

APPENDIX 32 (Cont.)

32.12. Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0025	3	0.0008	<1.00	9.28	N.S.
Treatment	0.0061	1	0.0061	6.10	10.10	N.S.
Error	0.0030	3	0.0010			
Total	0.0116	7				

V = 2.8%

6-8 cms

32.13. Perennial ryegrass

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0018	3	0.0006	<1.00	9.28	N.S.
Treatment	0.0050	1	0.0050	4.55	10.10	N.S.
Error	0.0034	3	0.0011			
Total	0.0102	7				

V = 2.8%

32.14. Timothy

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0103	3	0.0034	1.00	9.28	N.S.
Treatment	0.0001	1	0.0001	<1.00	10.10	N.S.
Error	0.0101	3	0.0034			
Total	0.0205	7				

V = 5.0%

32.15. Cocksfoot

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0128	3	0.043	<1.00	9.28	N.S.
Treatment	0.0153	1	0.0153	2.78	10.10	N.S.
Error	0.0164	3	0.0055			
Total	0.0445	7				

V = 6.4%

32.16. Browntop

Source	SS.	d.f.	M.S.	F value	F required	Result
Block	0.0313	3	0.0104	1.07	9.28	N.S.
Treatment	0.0013	1	0.0013	<1.00	10.10	N.S.
Error	0.0290	3	0.0097			
Total	0.0616	7				

V = 8.7%