SOME EFFECTS OF TREADING BY SHEEP ON PASTURES IN A MEDITERRANEAN ENVIRONMENT OF SOUTH AUSTRALIA

A thesis presented in partial fulfilment of the
requirements for
the Degree of Master of Agricultural Science
Faculty of Agricultural Science
University of Adelaide

by

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March 1973

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SUMMARY

Two field experiments were undertaken at the Waite Agricultural Research Institute, near Adelaide, to study the influence of intensity and frequency of treading by sheep on pasture density and tillering, pasture growth, seed production, pasture regeneration, and on the soil. The technique described by Edmond at Palmerston North, New Zealand, was used to study the effects of treading *per se* on plant and soil. The studies were of short duration (two to three months of treading) to fit into the rainfall pattern of the environment.

Studies were made during three main phases - the treading phase, the recovery phase and the pasture regeneration phase. During the treading phase the direct effects of treading on the plant-soil interface were studied, while the residual effects of treading were assessed during the recovery phase and the regeneration phase.

In Experiment 1, the effect of intensity and frequency of treading was studied using three densities of a mixed pasture of subterranean clover and annual ryegrass. The low density pasture suffered most treading damage. The influence of treading on the pasture was shown by decreased pasture density and tiller number, depressed pasture yield and poorer pasture regeneration the following year. Treading intensity had a greater effect than

treading frequency on all these variables. Greater treading intensity and more frequent treading caused the greatest damage to the pasture.

In Experiment 2, the effect of intensity and frequency of treading was studied with five pasture swards (subterranean clover, annual ryegrass, a mixture of these two species, cluster clover and perennial ryegrass) with and without defoliation. An increased treading intensity had the greatest influence on the swards: there was a decrease in plant density, pasture yield and in the plant number at pasture regeneration. Of the swards perennial ryegrass showed the greatest tolerance to treading. In general the grass species were more tolerant of treading than the legumes. Cluster clover was more tolerant of treading than subterranean clover. Defoliated pasture was more sensitive to treading damage than the undefoliated trodden sward.

In both experiments the residual influence of treading persisted during the recovery phase, and during the pasture regeneration phase in the following season. The effects on the pasture were more pronounced than the effects on the soil.

Investigation into the effects of treading on the soil were concentrated on the estimation of soil compaction. Soil bulk density, total porosity, penetrability and soil moisture percentage were determined to assess the degree of soil compaction. There was evidence of soil compaction as shown by the increase in the penetrability values, which appeared to be a more sensitive index of soil compaction in this study than the bulk density, total porosity or the soil moisture values.

Despite the time limits of these experiments and the limitation set by the climatic conditions, it is concluded that the effects of treading on the pasture are far greater than the effects on the soil. Finally, the overall influences of treading on the annual pastures in this Mediterranean environment appear to be similar to those observed on perennial pastures in temperate climatic zones.

STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and, to the best of my knowledge and belief, contains no material previously published or written by another person, except when due reference is made in the text.

T. Sivalingam

1.0.0 INTRODUCTION

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In grazed pasture ecosystems the grazing animal has an important influence on the pasture through defoliation, distribution of nutrients and seeds, and by treading (Carter 1969). The term 'grazing' includes all these activities, which are either complementary, destructive or both. While a good deal is known of the effects of defoliation by the grazing animals, probably least is known of the general and specific effects of treading.

Treading is the effect of hooves on the soil-plant interface. Depending on the treading intensity and the physical condition of the soil, the effect of hooves has differing terminology. Trampling, treading, pugging and puddling, qualify the effects of hooves on plant and soil in their ascending order of magnitude, under different physical conditions of the soil. Hoof cultivation has a long history; the paddy tracts of most of the Asian countries employ the animal hoof for puddling the paddy soils and for destruction of weeds. In southern England sheep folding was long practised for the consolidation of light soils (Frame 1971). In New Zealand Packard (1957) observed improved moisture relations for plant growth when coarse pumice soils were consolidated by sheep treading. The combined effects of defoliation, treading and excretion have been particularly valuable in reclamation work by surface-sowing techniques such as the 'Muirfad' system (Harkess 1965). Here, grazing helped to depress competition from existing pasture; treading broke off bog myrtle, bracken and blaeberry shoots, cultivated the seed bed, buried the seed and firmed the seedlings so simulating the action of cultivator, harrow, drill and roller.

Although the general effects of treading have been appreciated in the past, generally these have been neglected in pasture management studies. However, with the shift in emphasis from per-animal to per-acre (or per-hectare) as a basis for assessing animal production, the importance of treading damage is likely to increase. McMeekan (1956) reported that high efficiency of pasture utilization was determined by the greater number of mouths harvesting the pasture. Freer (1959) noted that higher stocking rates were accompanied by greater grazing times. Thus higher stocking rates, involving greater grazing times, lead to the increased importance of treading as a factor in pasture production and utilization. This implies that increased treading effects are the certain consequence of increased in situ pasture utilization. Mitchell (1960) and Edmond (1960) contended that, with the tendency to increase stocking rate, treading damage to the pasture could be a dominant factor in placing a ceiling on herbage yield and animal production.

Treading studies so far have been mainly confined to perennial pastures (e.g. Klecka 1937; Edmond 1958a, 1963, 1964, 1966, 1970; Pieters 1961; Brown 1968, 1971), and little attempt has been made to examine the influence of treading on annual pasture species. A better understanding of the effects of treading on vegetation and soil, and the mechanism of treading, will further assist our understanding of management of both perennial and annual pastures.

The Project

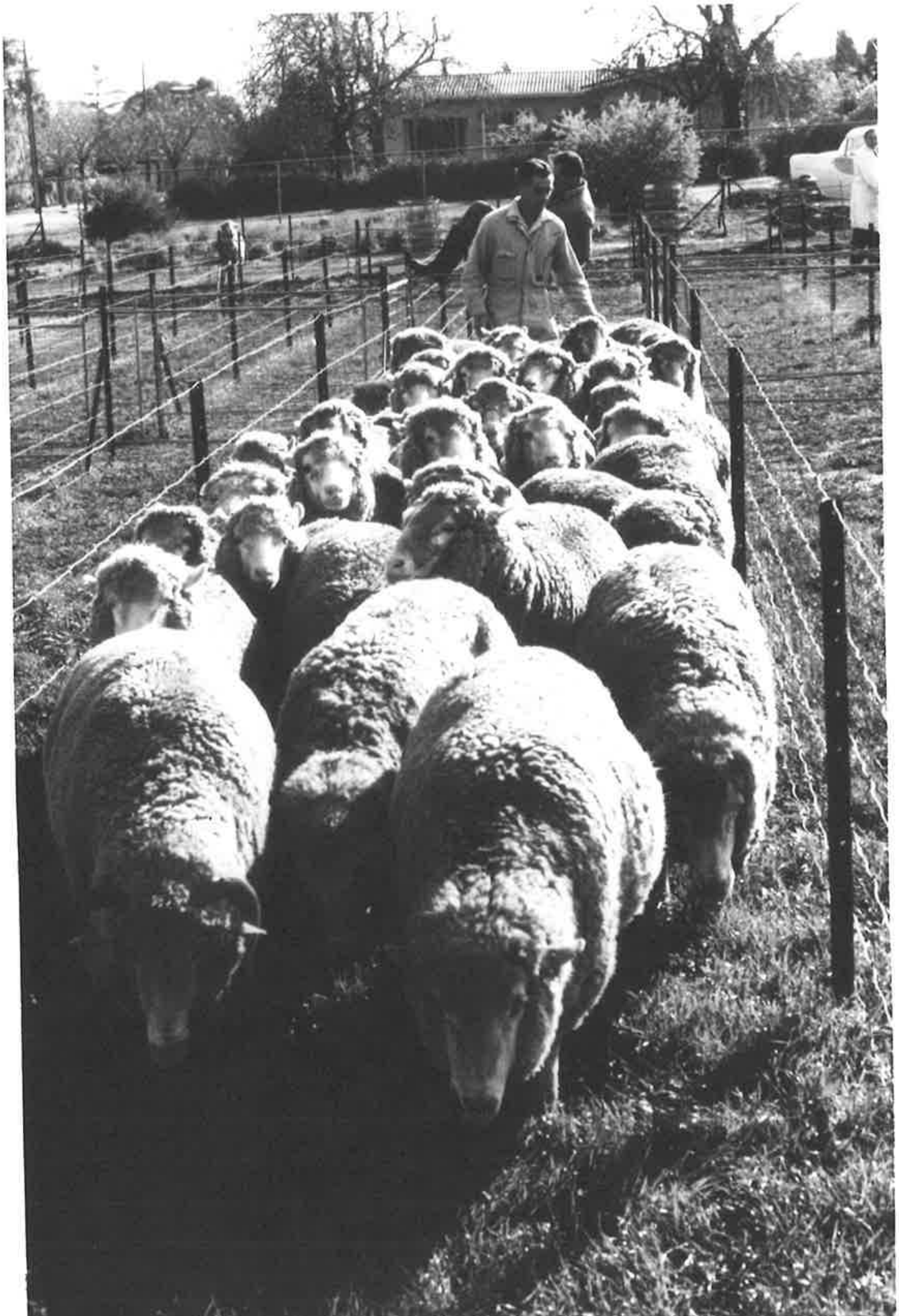
The studies reported in this thesis were undertaken to evaluate the effects of treading on the pasture-soil interface under several pastures at the Waite Agricultural Research Institute. Two field experiments were undertaken in 1971 as follows:

Experiment 1 - A study on the effect of different intensity and frequency of treading by sheep on a mixed pasture of subterranean clover and annual ryegrass, established with three sowing densities.

Experiment 2 - A study on the effect of different intensity and frequency of treading by sheep on five pasture swards with and without mowing.

Plate 1

General view of the treading procedure involving a small flock of 35 Merino wethers.



2.0.0 REVIEW OF LITERATURE

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The review of literature is divided into four parts, as follows:

1. The treading animal.
2. The effects of treading on vegetation.
3. The effects of treading on soil.
4. Some beneficial effects of treading.

2.1.0 The Treading Animal

While the effects of treading on pasture and soil have been noted for a long time it is only recently, with the widespread use of high stocking rates, that the impact of treading on animal production is being appreciated. With the goal of greater animal production, pastures carry more animals per unit area than before. Pastures provide feed as well as the basic physical support for body weight of the grazing animals. Pastures of greater carrying capacity imply greater production of herbage and involve heavier animal loads per unit area. The fact that grazing animals do not remain stationary for long periods, their movements being conditioned by many environmental factors, increases the complexity and magnitude of treading damage.

The activities of grazing animals on pasture may be grouped into three main categories, viz. grazing, idling and resting. The body weight of the animal while grazing and idling is supported on three or four legs and the pressure is exerted on the ground through their hooves. The time involved in treading is the total time spent in grazing and idling.

2.1.1 Animal locomotion

Locomotion is described as the act or power of moving from place to place - continuous progression from a state of rest. When an animal is carrying itself forward by any system of regular motion, its limbs in relation to the body have alternatively a progressive and a retrogressive action (Ottaway 1955). Quadrupeds employ all four feet for the purpose of support and propulsion. The duration of contact of the foot with the ground varies with different animals under different systems of movements. Muybridge (1899) by photographic analysis demonstrated that quadrupeds employ eight different regular systems of progressive motion as follows:

(1) The walk.
(2) The amble.
(3) The trot.
(4) The rack (or pace).
(5) The canter.
(6) The transverse-gallop.
(7) The rotatory-gallop.
(8) The ricochet.

During normal stride, quadrupeds use all four limbs as support and their movements consist of four steps. These steps may occur singly, and at approximately regular periods of time, as in the walk; singly and at irregular periods, as in the amble, the canter or the gallop; or in pairs, as in the trot or in the rack (Brown 1957).

2.1.2 The hoof load

The body weight of the animal is taken on the hooves during standing and during locomotion. Environmental factors condition the effect of hooves on pasture. Lull (1959) calculated the static ground pressure exerted by cattle and sheep and reported that sheep with an average weight of 120 pounds (54.5 kg) exerted a ground pressure of 9.2 pounds per square inch (0.65 kg/cm^2) and cattle with the average weight of 1,350 pounds (612.9 kg) exerted a ground pressure of 23.9 pounds per square inch (1.68 kg/cm^2). Therefore, it is not surprising that cattle cause more severe poaching of pasture than do sheep.

2.1.3 The hoof manoeuvreability

The hoof exerts a vertical compression and a distinct horizontal rotatory twist when it leaves the ground (Davies 1938). Considering these actions, the treading force of a hoof can be of four components:

(1) Compression

(2) Shear

(3) Twist

(4) Kick

The intensity of these components varies with the condition of the pasture and the animal activity; when the animal is running or galloping, the kicking component is greater than when the animal is walking. Running on firm soil results in little soil disturbance but plant damage may be high.

2.1.4 Placement of the hoof

Placement of the hoof on pastures becomes an important consideration in pasture variability. Under intensive grazing management systems such as strip grazing, the placement of the hoof could be more uniform on the pasture than in the case of set stocking. Intensive hoof traffic was observed near desired objectives like water points, salt licks and shade under normal conditions (Bates 1950; Lange 1969). Other aspects such as steepness of the slope, roughness of the terrain, are all important in determining the intensity and distribution of animal traffic. Mueggler (1965) observed that on a 10% slope the cattle were within 810 yards of the foot of the slope and on a 60% slope, 75% of use was within only 35 yards of the foot of the slope. Skerman (1956) stated that the wind direction also determined the grazing pressure in the grass tussock country of Queensland.

2.1.5 Animal behaviour

The behaviour of the grazing animals may influence the treading pattern on the pasture. Environmental factors, such as the area available, the quality and quantity of the feed offered, and the individual preference of the animals, determine the general grazing behaviour. Tribe (1955) reported that the grazing time and distance travelled varied with the quantity and quality of the pasture on offer, and with the area available for grazing. When larger areas were offered, the distance travelled in grazing was increased. England (1954) observed an increase in the distance travelled where the offered pasture was of a poor quality. Grazing behaviour studies give an indication of the treading time in pastures. On average the amount of time spent lying down is found to be between 8 to 9 hours in temperate pastures (Freer 1959) and 9 to 10 hours in tropical pastures (Fernando and Sivalingam 1961). It should be noted from these grazing-behaviour studies that about a third of the time is spent lying down, and the rest of the time is spent standing (the animals either grazing or idling) where the body weight is distributed over a small area on the soil surface.

Selective grazing by the animal is another factor influencing grazing movements. Since the forage selected by the grazing animal is generally higher in quality than the average on offer, a greater amount of movement and time are involved in this selection of quality herbage. Arnold (1964) listed the animal factors influencing herbage selection and stated that the plant material available to, and selected by, grazing animals may be determined as much by the animal as by climate and soil fertility and need not in any way be related to the total dry matter per unit area on offer.

The increase in nutritional requirement is another factor influencing grazing time. Cresswell (1960) observed an increase in grazing time with pregnancy or lactation. In general it implies more grazing and idling time, and a consequent increase in the effects of treading on pasture and soil.

2.2.0 The Effects of Treading on Vegetation

The effects of treading on vegetation became evident with the studies of Bates (1935). He studied the vegetation in gateways, field or farm tracks, and water- or feeding-trough areas, and commented on the structural adaptation of certain plant species to survive treading damage. Davies (1938) studied the vegetation of grass verges and other extensively-trodden habitats and attributed the persistence of certain plants to species adaptation. In Aberystwyth he observed persistence of certain vegetation under conditions of persistent grazing. The ingress and destruction of certain types of weeds in an over-grazed pasture in New Zealand has been attributed to the effects of treading (Edmond 1966). The encouragement of certain pasture species and the destruction of others by grazing and treading, emphasizes the effects on vegetation and the inherent ability of certain pasture species to survive by their adaptation to such conditions. Edmond (1964) studied the effects of sheep treading on the growth of ten pasture species and ranked them in order of the most-tolerant to the least-tolerant to treading. Ellenberg (1952) studied the treading tolerance of pasture species and listed the plant characters connected with their tolerance as follows:

(1) Annual species with flexible stem and narrow or lanceolate leaves.

(2) Rosette plants with flat leaves but with tough vascular bundles.

(3) Fast-growing bottom grasses with good regeneration and tillering ability.

(4) Shallow rooted turf plants with creeping rhizomes or stolons.

In addition he stated that the 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.

Discussion on the subject of the treading tolerance of pasture species could be divided into those factors related to the morphological and physiological attributes as follows:

2.2.1 Morphology

The position of the growing points, the growth habit and the protective tissues are the main points of consideration under the morphological adaptation of the vegetation to withstand treading damage. Bates (1935) drew attention to the nature of the footpath vegetation and attributed the persistence of Poa pratensis L. and Lolium perenne L. to their morphological adaptation by the possession of a conduplicate stem and folded leaf section, with the cryptophylic habit of the growing points. Edmond (1964) further stressed the morphological adaptation when there was a highly significant treading X species interaction ($P < 0.01$) in his experiment, with different pasture species. Using 4, 8, 16 and 32 sheep equivalents per acre he demonstrated the importance of the morphological features of different species to tolerate treading damage. He traced the treading tolerance of Poa pratensis L. and Poa trivialis L. to their basal growth characteristics. The rhizomatous growth of the former and the stoloniferous growth of the latter have been the main features associated with the treading tolerance of these species.

The sensitivity to treading of cocksfoot (Dactylis glomerata L.) has been attributed to the elevation of the growing points above the soil, while the treading tolerance of Timothy (Phleum pratense L.) is ascribed to the protection of the apex by a thick pad of tissue. Tall-growing stemmy plants, climbing plants and plants with high basal leaves are reported to be most susceptible to treading damage (Ellenberg 1952). Donald (1946) commented on the lack of structural adaptation of the hay species to treading damage and the disappearance of such species under grazing.

(a) Plant Tillers

The vulnerability of plant tillers and nodes to treading damage is an important factor involved in the reduction of yield. Tiller number and vigour and the ability to recover quickly from damage are important considerations in assessing the effects of treading. Edmond (1964) recorded a decrease in tiller numbers with all ten pasture species in his study. Lancashire (1961) noted a reduction in tiller number and vigour and observed abnormality in the tillers under artificial treading treatments. Brown (1971) reported a reduction in tiller numbers in perennial ryegrass and browntop (*Agrostis tenuis* Sibth.), and a similar reduction in the number of basal nodes of white clover.

(b) Plant Form

Treading treatments have been reported to have changed the plant form. Edmond (1958a) noted a change from the round, tufted and erect plants of short rotation ryegrass to ones of prostrate and elliptical form. In his later trials he noted that the grass plants became tufted under heavy treading treatments (Edmond 1963, 1964). The change of plant form and character could be attributed to the direct injury to the foliage and plant parts and their mode of tolerance to such damage.

2.2.2 Physiology

Edmond (1964) reported that the treading tolerance of certain pasture species was related to their period of active growth. He observed a highly significant interaction between the harvest time and treading treatments. Perennial ryegrass and short-rotation ryegrass (*Lolium perenne* L. X *Lolium multiflorum* L.) were found to be more tolerant of treading in winter than in summer whereas white clover (*Trifolium repens* L.) exhibited more tolerance in summer. Slow-growing pasture species with limited regenerative ability were found to be more susceptible to damage by treading. Lack of vigour of the root system, during the period of slow growth, is one of the factors responsible for the slow recovery of such species (Ellenberg 1952). Evans (1967) referred to physical strength of perennial ryegrass, associated with the high proportion of sclerenchyma tissue, to withstand the wear and tear of the hoof.

Bates (1935) stressed the importance of biotic factors rather than edaphic and climatic factors involved in treading tolerance, and attributed treading tolerance both to morphology and physiology of the pasture species.

2.2.3 Yield components

(a) Dry matter yield

Pasture yield is the product of plant number and plant growth. Edmond (1964) observed a retrogressive decrease in plant number with treading intensities, at the early growth phase. Synnot (1969) reported a decrease in plant numbers in Wimmera ryegrass (*Lolium rigidum* Gaud.) and subterranean clover (*Trifolium subterraneum* L.) cv. Yarloop with different intensities of treading.

In almost all studies of treading by grazing animals it has been reported that dry matter production has been depressed. In the annual pasture of the Mediterranean environment of southern Australia, Underwood (1956) referred to the destruction of the vegetation by tearing off the brittle leaves by treading animals. O'Connor (1957) reported a 30% reduction in the herbage production in cocksfoot by treading. Rossiter (1958) reported a reduction in the dry matter yield of 22% due to trampling and losses through summer rains, in an annual pasture of the Mediterranean environment. Trampling by livestock has been reported to reduce the yield of lucerne/smooth brome grass/Ladino clover mixtures by 20% (Tanner and Mamaril 1959). Edmond (1964) observed that the heaviest treading treatments caused the greatest reduction in the dry matter yield of various pasture species. Muller (1965) obtained a loss of 5 to 10% of the plant yield by treading, in West Germany.

Brown (1971) observed a decrease in herbage yield of 61% at a treading rate of 48.0 sheep equivalents per acre (118.6/ha.) in a pasture of browntop and white clover. Dry matter yield is found to be affected by direct damage and by indirect environmental factors such as soil condition and moisture regime, influenced by treading effects.

(b) Seed yield

Another factor which has been reported to be influenced by treading is the seed yield and seed-head number. Edmond (1958b) reported a greater number of ryegrass seed heads on heavily trodden plots than on lightly trodden areas while Brown (1968) observed an increase in seed-head number and seed yield in perennial ryegrass and Timothy following treading. Browntop showed a decrease in seed yield while seed-head count and seed yield of cocksfoot was unaffected by the treading treatments (Brown *loc. cit.*).

2.3.0 The Effects of Treading on Soil

Pasture is influenced both directly and indirectly by the treading of grazing animals. Direct effects on pasture are attributed to physical damage of the growing point and other plant parts. Indirect effects are brought about by the effect of treading on the soil supporting the pasture. Conditions influencing the physical properties of soils are found to influence the vegetation it supports and the effects vary with the soil type.

2.3.1 Soil types

Treading is found to have different effects on different soil types. Light-textured, sandy soil with low organic matter is generally improved by compaction brought about by treading. Soil compaction helps to create a firm seed bed and improve the water holding capacity of these soils. Keen and Cashen (1932) studied the effects of sheep folding on sandy soil and reported compaction of the soil to a depth of 10 cm. The greatest compaction was observed at 3 to 4 cm depth. They also noted an increase in crumb size and believed that treading benefited these soils. Packard (1957) reported that compaction by treading improved the moisture availability on the light pumice soils of New Zealand. Frame (1971) mentioned the benefit of moderate treading on light dry soils and the practice of sheep folding for better conditioning of these soils in southern England.

Heavier soils are known to offer resistance to treading and this may impair their structure. Gradwell (1966) observed deep hoof penetration on wet alluvial soil under pasture and reported the incidence of "pugged" pastures.

2.3.2 Soil compaction

One of the main effects of treading by livestock is soil compaction. Lull (1959) defines soil compaction as "the packing together of soil particles by instantaneous forces exerted at the soil surface resulting in an increase in soil density through a decrease in pore space". Soil compaction is usually harmful for crop growth, except in certain light-textured soils where there may be some benefit in treading, as mentioned in the last section.

Soil compaction becomes a problem when the stocking rate or stocking density on the pastures is increased. Compaction depends upon the load and stress per unit area. Sears (1956) reported the pressure exerted by the hoof of a Jersey cow to be about 45 lb per square inch (3.16 kg/cm^2) and the pressure exerted by sheep to be about 30 lbs per square inch (2.11 kg/cm^2). He calculated that each year a dairy pasture producing 12,000 lb of dry matter could receive approximately 8 complete hoof compactions of 45 lb/in^2. Lull (1959) calculated from the average bearing area of sheep and cattle, the ground pressure (static load) exerted as follows:

Animal	Average bearing area in^2	Average bearing area cm^2	Average weight lb	Average weight kg	Ground pressure lb/in^2	Ground pressure kg/cm^2
Sheep	13.0	83.9	120	54	9.2	0.64
Cattle	56.4	363.8	1,350	613	23.9	1.68

During movement, pressures would be greater as body weight is distributed over smaller bearing surfaces.

Edaphic factors influencing compaction

Soil texture and soil structure, soil density, moisture content and organic content are some of the common site factors that affect the rate and degree of soil compaction.

(a) Soil Texture and Structure

It is generally known that the coarser the soil, the lower its density and the more liable it is to compaction. Huberty (1944) observed that the soils with a wide range of particle size compact to much greater densities than the soils of uniform particle size. Light soils are known to benefit from compaction, but in the case of heavy soils compaction may be damaging. Medium-textured soils, i.e. loams, sandy loams, and silt loams, are found to form hardpans, due to compaction (Raney et al. 1955).

Soil structure also affects the degree to which a soil can be compacted. Well aggregated soils are known to have low bulk densities, which, in turn, may influence compaction. Lull (1959) contends that under compactive forces, the aggregates are crushed, particles fill the inter-aggregate spaces and permeability is reduced. He attributes the destruction of aggregates, normally associated with grass cover, to trampling. Alderfer and Merkle (1941) observed that the land under bluegrass or other sod-producing grasses, if not subjected to compaction may develop a degree of granulation equal to or better than that found in forest land.

(b) Soil Density

Under equal stress, compaction will be a function of the initial density, all other factors being the same. The less the density the greater the compaction. There was a 37 percent decrease in compaction with a 5 percent increase in bulk density, and a 13 percent increase in bulk density reduced compaction 65 percent (Lull 1959).

(c) Soil Moisture

Bruce (1955) observed an optimal relationship between compactability and soil moisture content. Greatest compaction can be achieved when the soil is at a moisture content slightly less than the plastic limit (Markwick 1945). O'Connor (1957) contended that compaction was most severe at some intermediate moisture content and aggregate destruction may be most serious under very wet or very dry conditions. Compaction has been observed to be severe when the soil is plastic after rains. Maximum compaction is associated with an optimum soil moisture content (Li 1956).

(d) Organic Matter

The amount of organic matter in the soil influences the degree of compaction possible and also determines the moisture content at which maximum compaction occurs. The greater the content of organic matter, the smaller is the maximum compaction and the greater the moisture content required for maximum compaction (Lull 1959). O'Connor (1956) stated that where organic matter forms a surface mat, it may impart considerable bearing strength to the soil, even up to relatively high moisture contents. The cushioning effect of forest humus and litter is supposed to offer some protection for the underlying soil (Lull *loc. cit.*).

2.3.3 Effects of Compaction on Soils and Plants

Soil compaction is known to increase the bulk density and reduce porosity, water holding capacity, water infiltration rates, and soil aeration. Compacted soils affect the infiltration capacity and encourage runoff. Alderfer and Robinson (1947) reported that the compacting effect of cattle trampling appears to be most pronounced in the first inch of the surface soil. From the stand-point of infiltration and runoff, it is this layer in the profile of well drained soils that is important in determining their absorptive capacity for rainfall.

Physical condition of the soil is known to influence the crop productivity and pasture growth. Wittsell and Hobbs (1965) reported that the yield of wheat, sorghum, Sudan grass and tomato, was reduced by compacting a silt loam to a bulk density of 1.6 g/cc. Flocker *et al.* (1958) observed a 62% reduction in the yield of legume crops and 24% reduction in the yield of other crops tested, when a fine sandy loam was compacted to a bulk density of 1.58 g/cc. Adams et al. (1960), working on silt loam and silty clay, reported that increasing surface bulk density from 1.07 to 1.19 g/cc lowered yields of potatoes by 54%, sugar beet by 13%, wheat by 13% and corn by 7.5%. Compacted soils offered mechanical resistance to root growth and limited their development (Wiersum 1957).

2.3.4 The Effects of Compaction on the Physical Properties of Soil

Changes in total porosity and pore size distribution are the basic changes in the soil properties resulting from compaction. Accompanying these are changes in moisture-retention properties, infiltration properties, aeration and soil strength.

(a) Soil Porosity

Soil porosity may be defined as that percentage of the soil volume which is not occupied by solid particles (Baver 1956). Compaction, either by treading or any other means exerted at the soil surface, results in an increase in soil density through a decrease in pore space. During compaction the soil particles are brought together and fine grains are forced into the voids between coarse grains which were earlier occupied by air or water, thus reducing the total porosity. Gradwell (1956) stated that the compaction of moist soils under treading may be expected to occur mainly through the closing of air voids, i.e. a reduction in soil porosity. He observed reduced porosity in wet alluvial soils under pasture on three grazing occasions. However, Vomocil and Flocker (1961) considered that changes in pore size distribution were of greater significance than changes in total porosity. Baver (1956) stated that an ideal soil should have the pore space about equally divided between large and small pores. Such a distribution will encourage both moisture and air passage through the soil. Perhaps the most important change caused by compaction is the reduction in the total volume occupied by macropores and an increase in that occupied by micropores. Alderfer and Robinson (1947) reported that the high rate of runoff from a heavily-grazed pasture was associated with a lack of soil cover together with high volume weights and low values for non-capillary and total porosity in the 0 to 1 inch surface soil layer.

(b) Moisture-Retention Properties

The moisture-retention properties vary with compaction. Gradwell (1966) observed an increase in density of the puddled top soil associated with a decrease in porosity, and the increased density was accompanied by a reduction in the volume of water, extractable at low suctions, which the surface soil had the capacity to store. The tensions at which the soil moisture was held in the field was found to be higher in the puddled plots on all occasions. The unpuddled soils stored more water in the available suction range than puddled soils. Packard (1957) reported that a change in pore-size distribution by compaction on pumice soils of New Zealand resulted in a large increase in the moisture-storage capacity of the soil.

(c) Infiltration

Compaction of the soil by treading or other means is known to have an effect on the infiltration capacity of soils. Treading by grazing animals was found to reduce the infiltration 91 percent and 67 percent in two different forest soils in North Carolina (Johnson 1952). The compacting ability of cattle trampling was more pronounced in the first inch of surface soil and, from the standpoint of infiltration and runoff, it is this layer in the profile of well-drained soils that is important in determining their absorptive capacity for rainfall (Alderfer and Robinson 1947). In their later work Robinson and Alderfer (1952) concluded that the low infiltration capacity and high runoff losses on many permanent pastures are attributed to soil compaction by grazing animals. They recorded 80% of runoff on a heavily grazed area compared to no runoff on an ungrazed area. Thomas (1960) considered that poor water penetration on trodden areas was due to compaction. It is well known that in compacted soils the poor infiltration properties give rise to soil erosion by runoff water.

(d) Aeration

An increase in apparent density of soils through compaction reduces aeration by decreasing porosity (mainly non-capillary porosity). Total porosity in soils could be partitioned into the "capillary porosity" which is associated with water retention and the "non-capillary porosity" which stores and conducts gases (Vomocil and Flocker 1961). Since compaction is known to reduce or disarrange the porosity from the non-capillary to smaller size capillary pores and, as soil aeration is associated more with the former than the latter, the immediate effect of compaction could be reduced soil aeration. Millington (1959) attributed the reduction in seedling establishment on the red-brown earth at the Waite Institute, South Australia, to poor aeration brought about by the high apparent density of the surface soil due to high rainfall. Edmond (1963) observed gleying in the top 1-2 inch layer of the soils under heavy treading, which was a clear indication of poor aeration brought about by treading treatments.

(e) Soil Strength

This is a measure of the resistance of the soil to penetration. It is commonly measured by a penetrometer. Tanner and Mamaril (1959) contended that measurements made on bulk density and porosity were relatively insensitive to compaction. From a series of measurements made over a period of four years they found air permeability and penetrability to be more sensitive to changes in soil compaction than bulk density and porosity measurements.

Mechanical resistance of soil to root development and growth is understood as a limiting factor in growth physiology. Barley _et al._ (1965) reported that the penetration and growth of roots were controlled chiefly by the strength of the soil. They observed that soil strength as influenced by compaction limited the elongation of the roots. Phillips and Kirkham (1962) noted a decrease in root elongation of corn seedlings as the needle penetration into Colo clay decreased. The depth of the root zone of corn seedlings was found to be related linearly to the depth of penetrometer needle penetration. Meredith and Patrick (1961) have also reported a retardation in root growth due to compaction in three soil types in Louisiana. Edmond (1958b) reported that, though there was apparent tolerance of perennial ryegrass and short-rotation ryegrass seedlings to compaction, their root distribution was affected. Flocker _et al._ (1959) reported delayed seedling emergence and blossoming due to soil compaction.

Soil strength is reported to have affected the burr burial in subterranean clover (Barley and England 1970). They observed that beyond a critical value of soil strength the burr burial of cultivar Dwalganup could be affected. This occurred when the red-brown loam of Parafield was compressed to a bulk density of 1.52 g/cc.

The workability during cultivation of compacted soil is well known to influence the load, work time and greater wear and tear of the implements. Thus compaction by any means has a definite influence on crop cultivation and productivity.

2.3.5 Rehabilitation of Compacted Soils

Compacted soils are known to regenerate in time by the operation of natural climatic, edaphic, and biotic factors (Thomas 1960). Swelling of soil colloids or heaving in winter, and the activity of earthworms and other soil fauna, under high soil fertility conditions are reported to be the natural means of restoring the structure of compacted soil under temperate climatic condition (Frame 1971). Harkess (1965) is of the opinion that frost and winter heaving of soil can ameliorate the effects of summer treading, provided that the field is rested from stock in winter. In the tropics, the treading effects are bound to persist longer, owing to the absence of winter reconditioning where frosts are absent, and irrigation not feasible (Thomas 1960).

The activities of earthworms in soil restoration in the red-brown earth of Adelaide has been reported by Barley (1959). Even though their effects are quite slow earthworms are found to make a positive contribution towards restoration of soil structure. Edmond (1958a) contended that the earthworm activity, the drying of the soil and the plant growth, appear to contribute in part to the amelioration of the effects of treading.

2.3.6 Soiling of the Herbage

Soiling of the vegetation by mud splashing and transfer during treading is known to be a factor influencing palatability to the grazing animal. Soiling makes the vegetation unattractive and reduces the availability for grazing (Arnold 1964). Teeth wear and soil intake are closely related (Ludwig *et al.* 1966). In general, soiling of the leaves will have an effect on the plant availability and palatability, thus affecting intake by the grazing animal.

2.4.0 Some Beneficial Effects of Animal Treading

The effects of treading are usually associated with its destructive role in pastures. Though the overall destructive features are of more concern than the beneficial effects, the benefits may be exploited for better management of pastures (Donald 1946).

The benefit of treading light soils is exploited in the

"Muirfad" system of sowing to get a compacted seed bed (Harkess 1965). Moderate treading was found to benefit the dry soils of southern England and hence sheep-folding has been a long-accepted practice in pasture establishment and renovation (Frame 1971). Treading has been reported to open up pastures to light penetration by preventing mat formation in ryegrass and white clover pastures of New Zealand (Levy 1951; Sears 1953). The suppression of the vigorous growing Poa trivialis by treading has been reported to reduce the plant competition in clover and ryegrass mixed pastures (Sears 1956). The encouragement of the desirable pasture species and the suppression of the undesirables by treading is referred to as a fortunate step in the selection for proved persistence (Edmond 1964). Brougham et al. (1960) contended that, owing to the effects of treading, hardy plant species persisted in pastures by a process of natural selection. Packard (1957) reported that consolidation by treading of the soil aggregates on the light pumice soils of New Zealand improved the moisture retention ability.

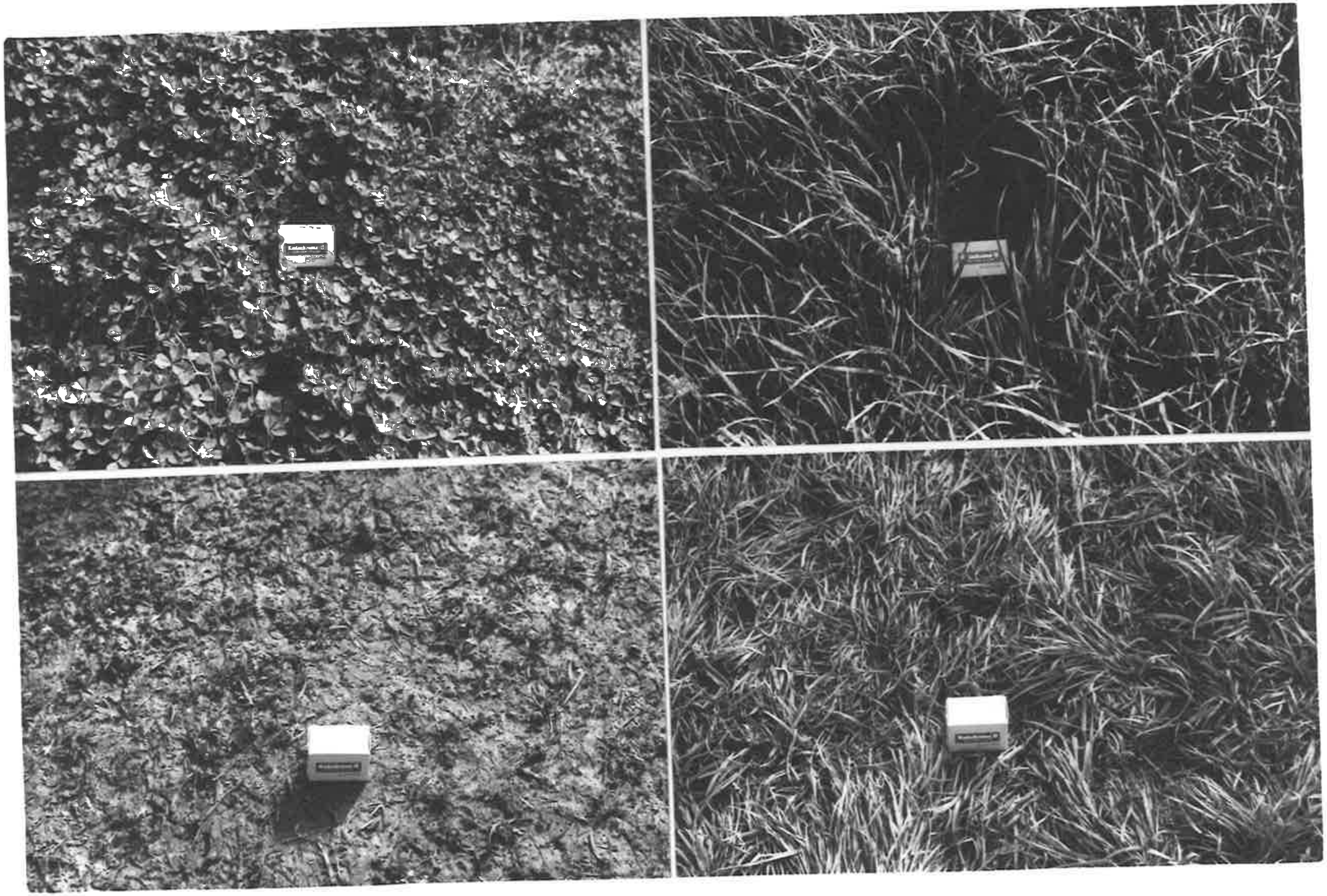
The ready availability of certain plant nutrients is reported to be associated with treading effects. Bromfield (1961) stated that the phosphate present in the dung became more readily available to the root zone through the action of the hooves of the grazing animals, incorporating the dung into the soil.

Plate 2.

Preliminary experiment conducted at the Waite Agricultural Research Institute in 1969, showing the severe effects of treading on subterranean clover and less severe effects on annual ryegrass.

Above Before treading.

Below After treading.



3.0.0 SITE OF EXPERIMENTS

3.0.0 SITE OF EXPERIMENTS

The two field experiments were carried out at the Waite Agricultural Research Institute (Lat. 34° 58'S., Long. 138° 38'E., Alt. 122.5 m) at Glen Osmond, near Adelaide, South Australia.

The soil of the experiment site is a red-brown earth of the Urrbrae series (Litchfield 1951). He described it as a "Red brown earth usually with ten inches or more of top soil of fine sandy loam texture, a prismatic structured clay subsoil and a calcareous deep subsoil; transition from topsoil to subsoil marked but rather diffuse; free from gravel or stone".

The climate of the site is described as mild Mediterranean type of the warm temperate zone. Seasonal rains usually commence in March - June and conclude in September - December, most of the rainfall being borne by south-west winds. January is regarded as the driest month and July as the wettest month of the year (Litchfield 1951). In 1971, the year of the experiments, the total rainfall received was 34.53 inches (877 mm), and April was the wettest month with 7.46 inches (189.5 mm). The total rainfall during the year was about 10 inches (254 mm) above average. Some climatic data for the site is summarized in Table 1.

Until the mid-1920's the experiment site was covered by degraded native pasture dominated by *Danthonia* spp. Since then the area has been under various crops and sown pastures; just prior to these treading experiments the site had been under uniform treatment. The site sloped gently to the west, the fall varying from 1-2 percent.

TABLE 1

CLIMATIC DATA FOR WAITE AGRICULTURAL RESEARCH INSTITUTE*

Lat. 34° 58'S, Long. 138° 38'E, Alt. 122.5 m (Daily readings at 0900 hr)

Month	Rainfall (mm)			Evaporation (mm)≠			Air temperature‡ (°C)		
	Mean 1925-1971	1971	1972	Mean 1960-1971	1971	1972	Mean 1925-1971	1971	1972
January	22.4	17.0	36.1	242.1	234.7	207.3	21.9	21.3	21.2
February	26.9	0.3	29.0	201.7	214.9	223.3	21.8	23.7	23.1
March	20.8	35.8	0.3	174.8	194.3	194.8	20.5	23.0	19.2
April	56.4	189.5	53.1	109.2	129.5	135.6	17.2	19.5	18.7
May	83.1	129.0	18.0	59.7	59.7	88.4	14.1	13.8	15.6
June	75.2	85.9	30.0	45.7	39.9	71.9	11.8	11.7	12.5
July	83.3	54.1	166.3	45.5	53.1	52.3	10.8	11.1	11.4
August	73.9	116.8	88.4	63.0	70.9	64.8	11.5	11.4	11.9
September	60.2	102.4	42.2	95.5	93.2	130.6	13.3	13.3	14.7
October	51.3	37.8	39.4	149.6	141.5	155.7	15.5	14.7	16.1
November	39.9	69.8	21.8	179.6	150.4	203.2	17.9	16.2	18.1
December	30.7	38.6	31.5	214.1	204.7	255.0	20.0	18.9	21.1
Total	624.1	877.0	556.1	1580.5	1586.8	1782.9	-	-	-

* Source: Meteorological Records, Waite Agricultural Research Institute.

≠ A Class Pan (New Standard). ‡ Mean Daily.

4.0.0 EXPERIMENTAL

4.0.0 EXPERIMENTAL

4.1.0 The Treading Technique

To study the effect of treading as a single factor free from the other concomitant effects of the grazing animal, the treading technique described by Edmond (1958a) was used.

Edmond assumed that a sheep walked 1.7 miles (2.74 km) per day while grazing under normal conditions. An area 1.7 miles long and 4 feet 10 inches (147.3 cm) wide is an acre (0.4047 ha). The daily passage of one sheep through a fenced plot with an effective treading width of 147.3 cm is assumed to simulate the treading rate of one sheep per acre per day. Any stocking rate and treading frequency may be simulated by passing 'n' sheep through the area every 'd' days. For example, to simulate a treading intensity of 5 sheep/acre at 7 day frequency, 35 sheep may be used to tread the area once every 7 days. To limit the flocks to a manageable size, smaller numbers of sheep may be driven in both directions to get the desired effect, e.g. the treading intensity of the 140 sheep rate may be effected by walking 70 sheep in both directions. It is essential that the treading procedure be completed as quickly as practicable to prevent defoliation and defaecation by the treading flock.

Though this technique is not without weakness it seems to be the most practicable method of studying treading, per se in isolation from other animal activities. The walking or driving of sheep may give different results from those of set-stocked sheep, and unless good care is taken the middle portion of the race is trodden more than the outer areas.

In both experiments the same technique was used for the manipulation of the intensity and frequency of treading, and the format is given in Table 3 and Table 19 for Experiments 1 and 2 separately.

4.2.0 Site Preparation and Fencing

Prior to hand sowing the experiments the areas were well prepared and levelled, then fenced with six-line Cyclone "Ring-lock"* sheep fencing and a top plain wire using Y steel droppers with creosoted pine posts for extra rigidity where required. Individual races (for main-plots and sub-plots) were fenced with end droppers at 5' 6" (167.6 cm) centres to ensure that the actual trodden width was 4' 10" (147.3 cm), and with a light gate at both ends which could swing across the end-of-block race to divert the moving flock of sheep along the relevant treatment race. Details of the layout of the two experiments are shown in Figure 1 and Figure 4.

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* Registered trade name of the Cyclone Co. of Australia.

4.3.0 The Sheep Used and the Treading Procedure

Mature South Australian strong wool Merino wethers of mean body weight 44.9 kg and mean hoof area per sheep of 67.15 sq. cm were used for treading. As far as possible the same flock was used on the various treading occasions and at the different frequencies to ensure the advantages of prior experience by the sheep and consequent improvement in uniformity of treading.

The flock (varying in size from 35 to 140) was driven at slow to normal walking pace along the fenced races (Plates 1, 3-5). One person walked ahead of the flock (and as near as practicable to the fence on the area outside the sampling sites) to restrain the movement of the sheep to normal walking pace. A second person with trained sheepdog walked behind the flock to ensure that a compact flock moved through the race and that full-width treading occurred in the races.

Sheep were fasted overnight prior to this treading procedure which was undertaken between 8 a.m. and 10 a.m. This prevented defaecation by the sheep on the experiment. Though the leading sheep did have a tendency occasionally to take a mouthful of pasture along the fence while plots were being newly trodden, it was an insignificant occurrence and was outside the sampling area.

Plate 3.

A general view of the treading procedure, using 140 sheep on Experiment 1. The leading sheep are moving off the experiment having passed through Block I, the inter-block race and Block II.

Plate 4.

Views of the treading procedure using 140 sheep on Experiment 2. When large numbers (i.e. a long line) of sheep were used, a third or fourth person was often required to ensure that the sheep walked at a steady pace and did not stop to nibble.



Plate 5.

Views of the treading procedure using 140 sheep on Experiment 2. By the end of the weekly treading activity the fasted sheep were tiring and showed a tendency to nibble through the fence. However such defoliation was outside the randomised harvest sites and did not influence data collection.

4.4.0 EXPERIMENT 1

4.4.0 Experiment 1 - The Effects of Treading by Sheep at Various Intensities and Frequencies on an Annual Pasture Mixture Sown at Three Densities

This experiment was designed to assess the importance of intensity and frequency of treading and the possible interaction of these two main effects. The three density treatments were included to simulate typical newly-sown pasture (low density) and typical self-sown pasture (medium and high density). The influence of treading was assessed in terms of its effects on plants (plant numbers, tiller numbers, seed yield and pasture production) and soil (soil moisture content, bulk density, porosity and penetrability).

4.4.1 Materials and Methods

(a) General Plan

The experiment was designed as an incomplete factorial with superimposed split-plot design (for the three sowing densities) together with a control. There were two blocks. The main-plot and sub-plot treatments are summarized in Figure 1 and Table 2.

(b) The Pasture

Experiment 1 was conducted on the same area as a previous treading experiment (Synott 1969). All fences and gates were intact but it was necessary to remove naturally regenerating annual sown and volunteer species. The desiccant herbicides Reglone* ($\frac{1}{2}$ pint/acre) and Gramoxone* ($1\frac{1}{2}$ pints/acre) were used to kill newly-emerged seedlings; the fenced races were then cleared of pasture residue from the 1970 growing season, tilled to c. 5 cm depth with Howard Rotovator, then hand-raked to prepare a fine seedbed.

Subterranean clover (Trifolium subterraneum L.) cv. Yarloop and annual ryegrass (Lolium rigidum Gaud.) cv. Wimmera seeds were weighed out separately for each sub-plot and sown by hand, along with the basal fertilizer mixture comprising, per hectare, 300 kg superphosphate (with Lindane), 50 kg urea and 50 kg muriate of potash. Fertilizer, damp sand and seeds were mixed by rotary motion in a large jar and the mixture broadcast by hand, care being exercised to avoid contamination of contiguous sub-plots or main plots and ensure uniformity of sowing. After separate sowing of the three sub-plots the main plot was raked to ensure seed coverage. After all plots had been sown the end-of-block and between-block races and adjacent holding areas were sown to a uniform high-density mixture of Yarloop subterranean clover and Wimmera ryegrass to avoid unnecessary poaching and soil pugging through excessive concentration of sheep.

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* I.C.I. Products.

(c) The Timetable of the Experiment

There were three phases of the experiment, viz. the treading phase and the recovery phase in 1971, and the regeneration phase in 1972. During the treading phase the immediate effects of treading on pasture and soil were studied. The schedule of treading is summarized in Table 3. During the recovery phase (which followed the treading phase) the residual effects of treading on pasture and soil were assessed and these studies continued until the end of the growing season. During the regeneration phase in autumn 1972, the re-establishment of the subterranean clover and annual ryegrass (sown in 1971) was assessed, together with the residual effects on soil.

(d) Collection of Data

(i) Pasture Data - The initial establishment of the sown species and the subsequent changes in plant population were assessed by taking duplicate core samples in each sub-plot. Core samples (c. 11 cm diameter) were taken using the Coile sampler without the insert tin. Cores were transferred to individual cartons, placed in a polythene bag fastened with rubber bands, and held in cold storage (2^{o}C) awaiting hand-separation. The core samples were used to determine the density of sown subterranean clover and annual ryegrass, and the dry matter yield of these sown species. Hence, botanical composition (percentage contribution to dry matter of the sown species) was determined. Samples were dried at 85^{o}C in a forced-draught dehydrator.

Pasture production during the recovery phase was determined by harvesting random sites of 100 X 25 cm to ground level with motorised sheep shearing handpieces. These samples were dried in a forced-draught dehydrator at 85°C for 12 hours before weighing.

Tiller counts for both the clover and ryegrass were made on the occasion of the fourth recovery harvest following the treading phase. For this purpose, four plants of clover and of ryegrass were selected at random from core samples within the harvest areas to determine the mean tiller count for these species on the particular sampling occasion.

The seed yield of subterranean clover was determined in two portions - an above-ground and a below-ground component from sampling sites of 100 X 25 cm by the method described by Carter (1971). The above-ground seed was derived from the dry herbage while the below-ground seed was derived from the same site by excavating soil plus clover burr, soaking in water, washing through a 1.00 mm sieve, then drying at 50°C, and finally cleaning with "Genklene"* (trichloroethane of S.G. 1.31).

The annual ryegrass seed was likewise harvested from sampling sites of 100 x 25 cm and comprised an above-ground component only, together with surface sweepings. The technique

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* Registered trade name I.C.I. product.

used for deriving clean seed of both ryegrass and subterranean clover was the same as described by Carter (1971).

(ii) Soil Data - At each harvest, two samples were taken at random from each sub-plot on the borders adjacent to herbage harvest sites for soil moisture and bulk densities (Figure 1). The surface soil was sampled to a depth of 6 cm using a Coile sampler (Coile 1936), the soil samples being collected in thin-walled metal cans which are inserted in the sampling cylinder. The cylindrical soil samples thus obtained were trimmed to ensure uniformity of volume then closed with a close-fitting lid to prevent loss of moisture.

The soil samples were weighed then dried at 105°C for 24 hr and the dry weights recorded. Hence the soil moisture content at time of sampling and the soil bulk density (g/cc) were derived.

The total porosity of the soil samples was determined from the bulk density values (Vomocil 1965). The particle density of the soil was 2.65 g/cc (Emerson, unpublished data).

$$\text{Total porosity} = (St) = 100[(\rho p - Db)/\rho p].$$

ρp = particle density

Db = bulk density

The resistance of the soil to penetration was measured by a 'Soil test Model CL-700' Pocket Penetrometer. Ten readings were taken at random for each sub-plot at each harvest. The piston needle was pushed into the soil up to the calibration groove, and the resistance was read directly on the scale as described by Davidson (1965). When the soil surface was too hard to allow reasonable penetration of the needle, a modified attachment was made reducing the length and the diameter of the tip by half. The readings from the scale were multiplied four times for the actual reading (Barley, personal communication).

(iii) Animal Data - The body weight and hoof area of 35 sheep selected at random from the 140 sheep used for the treading process were determined to allow a better understanding of the treading pressures involved in this experiment. Sequential body weight measurements were taken during the treading phase. These showed an overall mean body weight of 44.9 kg per sheep during this period.

Hoof area was estimated from hoof impressions made in polythene-covered plasticine sheets. These showed an overall mean of 67.2 sq. cm per sheep.

(e) Statistical Analyses

The plant and soil data were processed through the 6400 computer using the Statscript programme. Natural (i.e. untransformed) data were used throughout.

As the three density treatments formed the sub-plots within each of the fenced races (main plots) split-plot analyses were used. Furthermore, because of the incomplete factorial design, not all of the treatments could be used to analyse the effects of intensity and frequency of treading and their possible interaction. In Experiment 1, the plant data was statistically analysed in the following categories: clover, grass, total, for the plant density, dry matter yield, seed yield and for the plant count at pasture regeneration. In Experiment 2, the plant data was statistically analysed as pasture swards for plant density and for the yield estimation.

The seed yield of subterranean clover was estimated and analysed as the above-ground, below-ground and the total seed in pure and mixed plots.

Figure 1.

Experiment 1 - Plan showing general layout and details of main-plot and sub-plot treatments. The enlarged sub-plot shows the harvest sites for plant data and the sampling sites for soil/plant data.

PLAN OF EXPERIMENT I

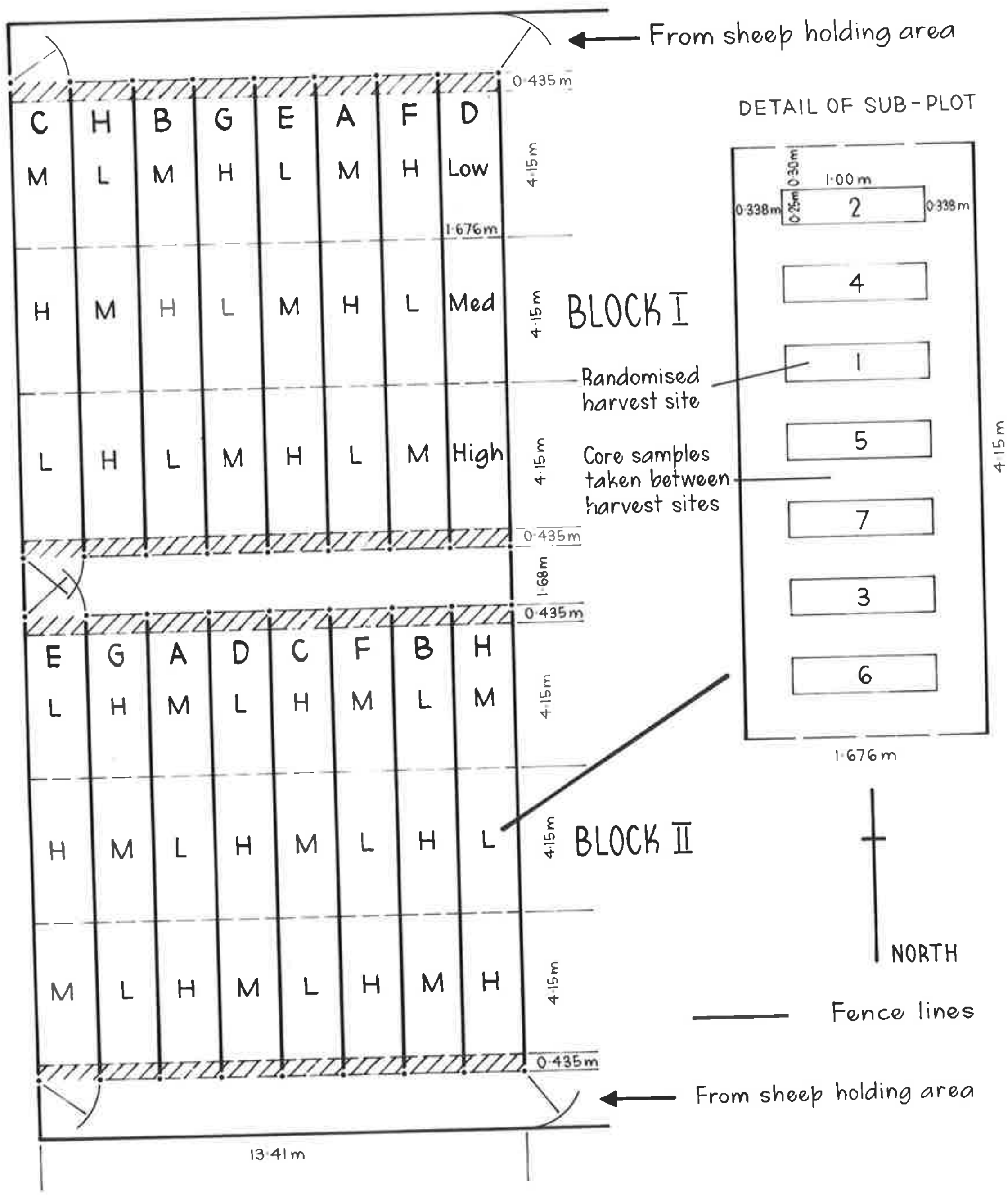


TABLE 2

EXPERIMENT 1 - MAIN-PLOT AND SUB-PLOT TREATMENTS

Main-plot Treatments	Treading Intensity (sheep/acre)	Treading Frequency (days)
A	0	0
B	5	7
C	5	14
D	10	14
E	20	14
F	5	28
G	10	28
H	20	28

Sub-plot Treatments	Sowing Rate (kg/ha*)	
	Yarloop subterranean clover	Wimmera annual ryegrass
Low density	20	10
Medium density	100	50
High density	500	250

* Sowing rates based on pure germinating seed.

TABLE 3

EXPERIMENT 1 - INTENSITY AND FREQUENCY OF TREADING

	Dates of Treading and Sheep Numbers Required							
	May 25	June 1	June 8	June 15	June 22	June 29	July 6	July 13
Treatment								
A control	-	-	-	-	-	-	-	-
B 5/7 day	35/1*	35/1**	35/1*	35/1**	35/1*	35/1**	35/1*	35/1**
C 5/14 day	-	70/1*	-	70/1**	-	70/1*	-	70/1**
D 10/14 day	-	70/2	-	70/2	-	70/2	-	70/2
E 20/14 day	-	70/4***	-	70/4***	-	70/4***	-	70/4***
F 5/28 day	-	-	-	70/2≁	-	-	-	70/2≁
G 10/28 day	-	-	-	70/4***	-	-	-	70/4***
H 20/28 day	-	-	-	140/4	-	-	-	140/4

Note: 5/7 day = 5/acre trodden every 7 days, etc.
35/1 = 35 sheep one way, etc.
* = South to north direction of treading
** = North to south direction of treading
*** = Alternatively 140/2
≁ = Alternatively 140/1

4.4.2 Results

(a) Pasture Data

(i) Plant Populations

Seedlings of subterranean clover were observed to be emerging from the third to sixth day after sowing (plots sown May 12, 1971) and there was a good emergence of both species within a week of sowing. Because of inadequate rain, three spray irrigations with reservoir water were given to ensure a satisfactory establishment of both of the species.

Core samples were taken for plant counts at all of the eight harvests during the treading phase and up to the fifth harvest during the recovery phase in 1971. Re-establishment of sown species was examined in the regeneration phase in 1972 by counting the plants within a 10 X 10 cm quadrat in the field. Separate series of data on changes in density of subterranean clover, annual ryegrass and the total of these two sown species were collected during the recovery phase and these are summarized in Figure 2. The pasture growth at the first recovery harvest for the treading treatments with the three sown densities is depicted on Plate 6.

The plant population during the treading phase was not influenced by the treading treatments. The treatment effects on the plant population were significant during the recovery phase. The effects of the various treatments on the population of clover, grass and total sown species during the recovery phase are shown in Figure 2. Tables 4 and 5 show the effect of treading treatments during the first recovery harvest. These data reflect the residual influence of the treading at various intensities and frequencies during the eight-week treading phase. Table 5 shows clearly the interaction of treading intensity and treading frequency with sowing density. Figure 2 also shows the decline in plant numbers with the advance of the growing season - presumably through plant competition.

(ii) Tiller Counts

Although treading treatments had no significant effect on the tiller count of the subterranean clover, increased treading intensity reduced the number of tillers in the annual ryegrass. In both species tillering was also reduced at higher sowing densities. These results are summarized in Table 6.

(iii) Pasture Production

During the treading phase, pasture production was related mainly to pasture density which reflected the three sowing rates. There was a marked depression in yield of clover at the highest treading intensity (Table 7), but there was no significant effect of treading treatment on ryegrass. Both intensity and frequency of treading depressed yield during the treading phase but it was not until all treading treatments had been completed that a clear indication of the importance of intensity and frequency of treading became obvious.

TABLE 4

EXPERIMENT 1 - RESIDUAL PLANT DENSITIES AT THE TIME OF THE FIRST POST-TREADING HARVEST

(Plots sampled on 12.8.71. Data in plants/m^2)

Treatment	Clover			Grass			Total		
	Low*	Medium*	High*	Low	Medium	High	Low	Medium	High
A	956	3038	3714	1969	4333	6190	2925	7371	9904
B	478	2447	3151	1069	2701	4361	1547	5148	7512
C	253	675	2841	787	1631	3742	1040	2306	6583
D	393	1209	2363	731	1716	3826	1124	2925	6189
E	253	1434	1463	647	1729	2335	900	3163	3798
F	450	1097	1800	1069	1941	2082	1519	3038	3882
G	478	928	1181	844	1378	2053	1322	2306	3234
H	281	1294	1266	506	844	2110	787	2138	3376
LSD (5%)≁		724			1060			1575	
CV (%)		24.5			21.2			18.9	

* These headings refer to sowing densities.

≁ LSD for treatment X sowing density.

TABLE 5

EXPERIMENT 1 - INTERACTION OF TREADING INTENSITY, TREADING FREQUENCY AND SOWING DENSITY ON PLANT POPULATION

(Plots sampled on 12.8.71. Data in plants/m^2)

Treatment: Treading Intensity	Treatment: Treading Frequency	Clover Low*	Clover Medium*	Clover High*	Grass Low	Grass Medium	Grass High	Total Low	Total Medium	Total High
5	14	253	675	2841	787	1631	3742	1040	2306	6583
	28	450	1097	1800	1069	1941	2082	1519	3038	3882
10	14	393	1209	2363	731	1716	3826	1124	2925	6189
	28	478	928	1181	844	1378	2053	1322	2306	3234
20	14	253	1434	1463	647	1729	2335	900	3163	3798
	28	281	1294	1266	506	844	2110	787	2138	3376
LSD (5%)≠		NS			701			514		
CV (%)		24.5			21.2			18.9		

* These headings refer to sowing densities.

≠ LSD for intensity X frequency X sowing density.

TABLE 6

EXPERIMENT 1 - THE EFFECTS OF TREADING INTENSITY AND SOWING DENSITY ON TILLER NUMBER IN SUBTERRANEAN CLOVER AND ANNUAL RYEGRASS

(Tillers per plant on 3.11.71)

Treading Intensity	Subterranean Clover	Annual Ryegrass
0	4.33	5.67
5	2.75	3.46
10	2.75	2.96
20	2.33	2.58
LSD (5%)	NS	0.36
CV (%)	11.4	10.2

Sowing Density	Subterranean Clover	Annual Ryegrass
Low	3.75	4.63
Medium	3.09	3.66
High	1.69	1.81
LSD (5%)	0.22	0.32
CV (%)	11.4	10.2

Figure 2.

Experiment 1 - The effects of intensity and frequency of treading on the density of subterranean clover, annual ryegrass and the total of these two species, at different harvests.

EXPT. I. RESIDUAL EFFECTS OF TREADING ON PASTURE DENSITY

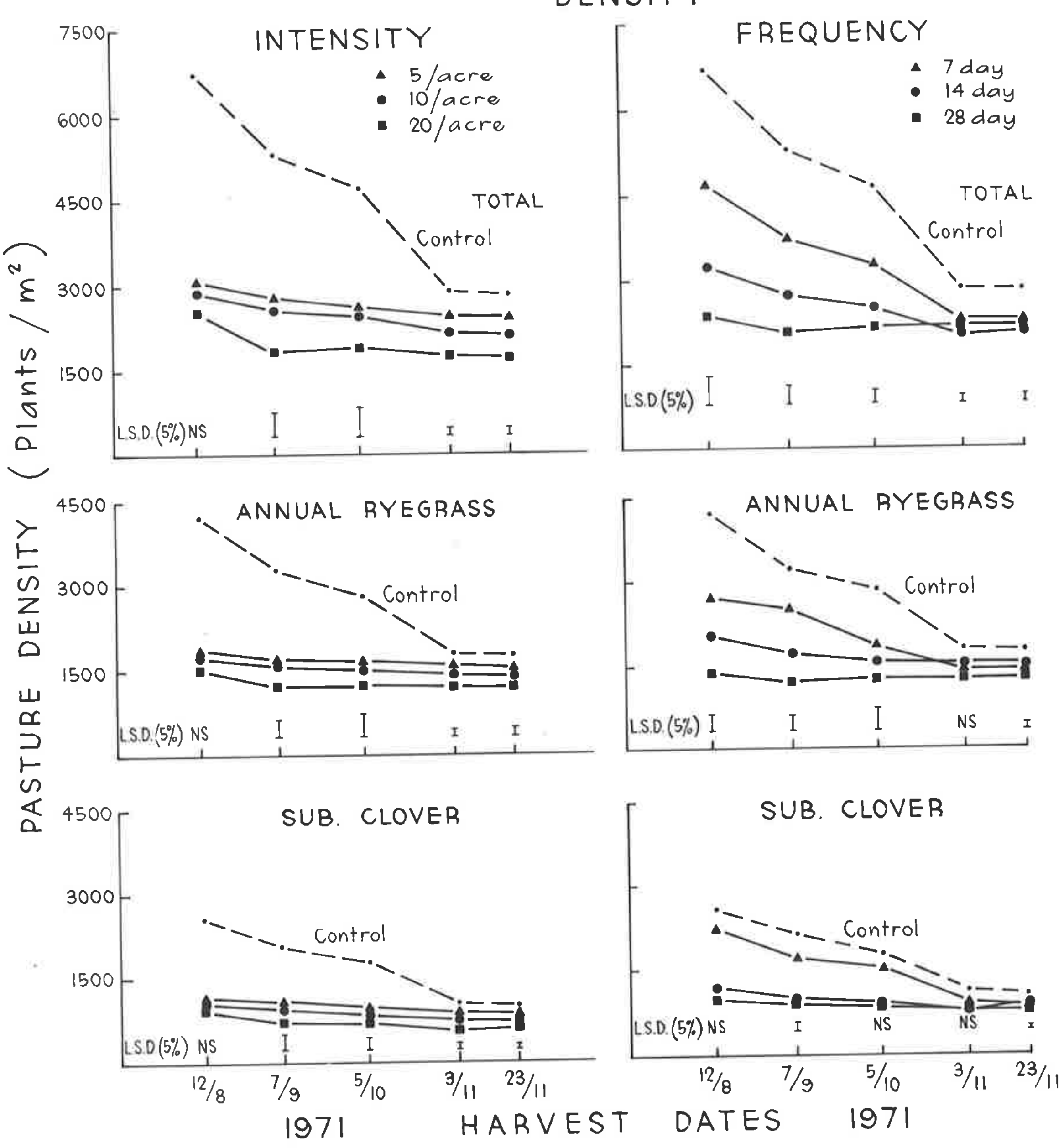


TABLE 7

EXPERIMENT 1 - THE EFFECT OF TREADING INTENSITY ON YIELD OF CLOVER AT HARVESTS 4 AND 8 DURING THE TREADING PHASE
(Data in g/m^2 D.M.)

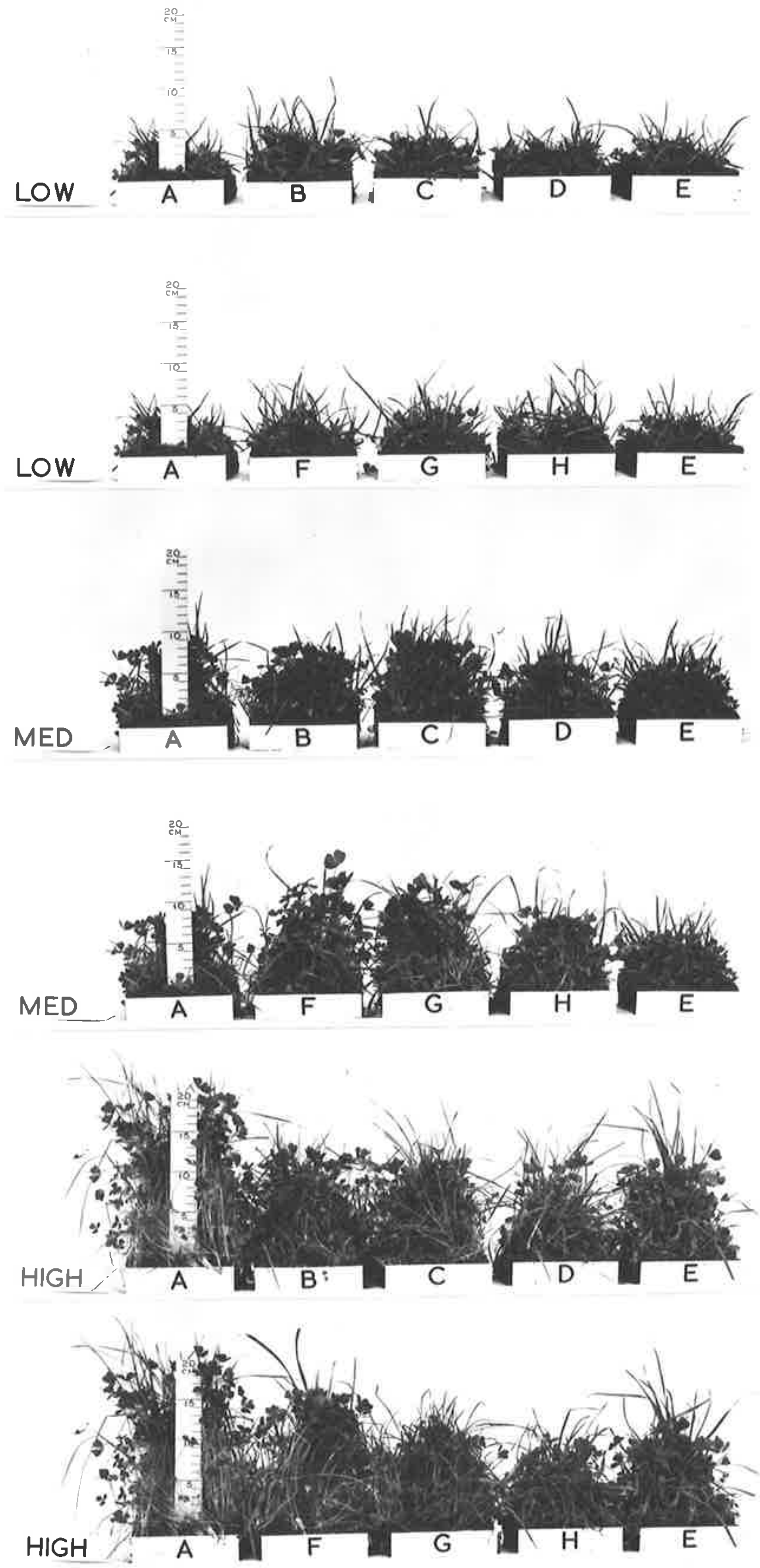
	Treading Intensity 0	5	10	20	LSD (5%)	CV (%)
Harvest 4	26.2	18.5	20.6	20.1	2.9	35.6
Harvest 8	69.0	70.5	71.8	47.3	21.0	23.9

During the recovery phase of the experiment the residual influence of treading became obvious; growth curves of subterranean clover, annual ryegrass and total sown species are shown in Figure 3, while Table 8 summarizes data at the last recovery harvest.

During the recovery phase there was a marked residual effect of the earlier treading. From the time of the second to the fifth harvest during the recovery phase (Figure 3) the yield of clover was influenced by the previous treading intensity and treading frequency. There was a highly significant interaction between treading intensity and frequency, between treading intensity and pasture density, between treading frequency and pasture density, 57.

Plate 6.

Experiment 1 - Residual influence of treading on pasture growth at the three sowing densities (Low, Medium and High) for the eight treading treatments (A to H). Samples taken on 12.8.71.


LOW A B C D E
LOW A F G H E
MED A B C D E
MED A F G H E
HIGH A B C D E
HIGH A F G H E

58.

Figure 3.

Experiment 1 - The effects of intensity and frequency of treading on the growth of subterranean clover, annual ryegrass and the total of these two species, at different harvests.

EXPT. I. RESIDUAL EFFECTS OF TREADING ON PASTURE GROWTH

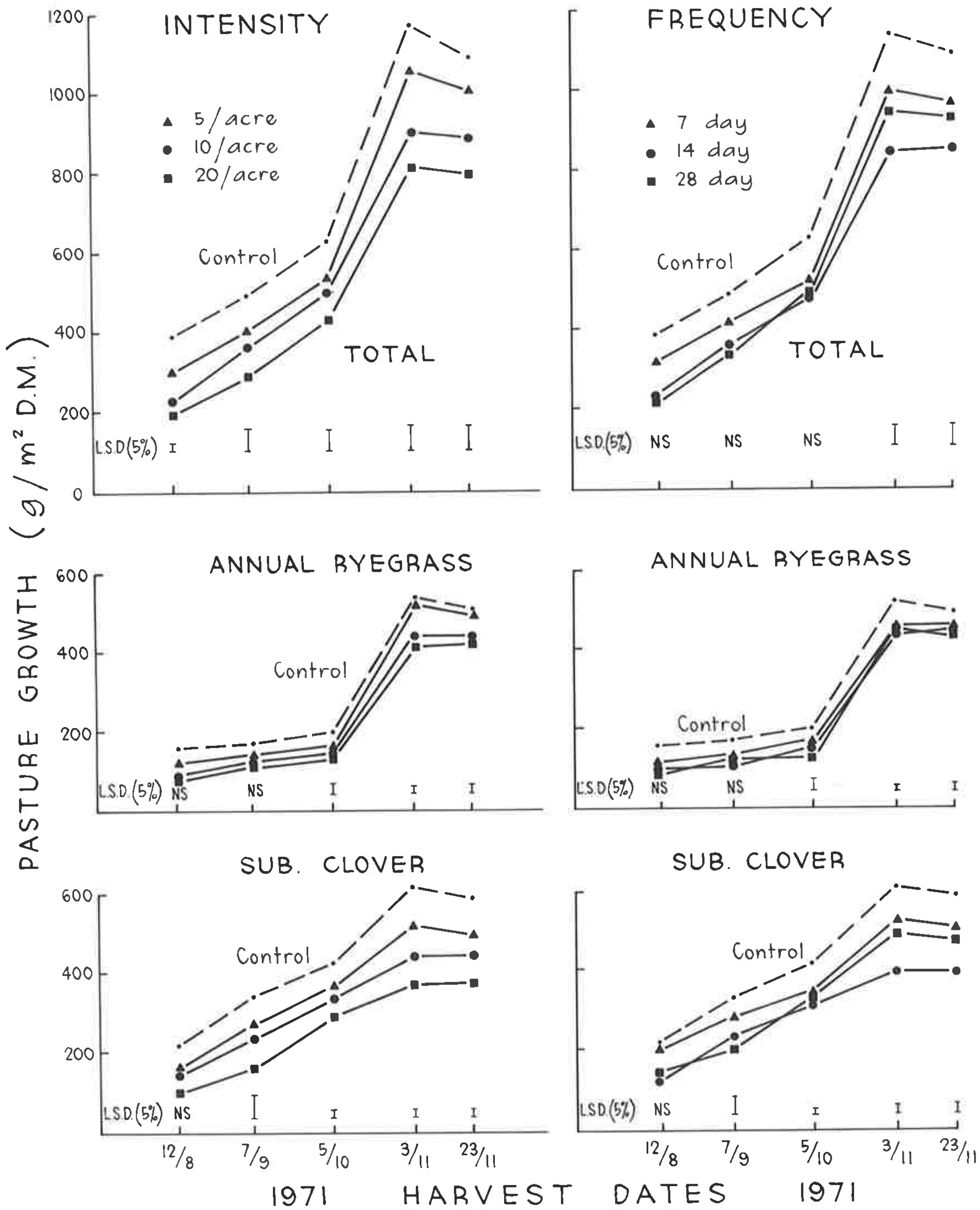


TABLE 8

EXPERIMENT 1 - YIELD OF CLOVER, GRASS AND TOTAL HERBAGE DURING THE RECOVERY PHASE

(Plots sampled on 23.11.71. Data in g/m^2 D.M.)

Treatment	Clover Low*	Clover Medium*	Clover High*	Grass Low	Grass Medium	Grass High	Total Low	Total Medium	Total High
A	496	600	646	359	455	669	855	1055	1315
B	452	468	544	344	461	600	796	929	1144
C	400	391	559	358	476	619	758	867	1178
D	269	425	454	315	361	563	584	786	1017
E	218	396	428	310	331	564	528	727	992
F	430	567	586	356	505	660	786	1072	1246
G	399	532	557	383	387	616	782	919	1173
H	278	436	497	384	378	534	662	814	1031
Mean (Density effect)	368	477	534	351	419	603	719	896	1137

	Clover Density	Clover Density X Treatment	Grass Density	Grass Density X Treatment	Total Density	Total Density X Treatment
LSD (5%)≠	84	41	101	92	43	NS
CV (%)	29.7		17.5		23.9	

* These headings refer to sowing densities.

≠ LSD for treatment X sowing density.

TABLE 9a

EXPERIMENT 1 - INTERACTION OF TREADING INTENSITY, TREADING FREQUENCY AND PASTURE DENSITY IN TERMS OF YIELD OF SUBTERRANEAN CLOVER AT RECOVERY HARVEST 5

(Plots sampled on 23.11.71. Data in g/m^2 D.M.)

Treading Intensity	Treading Frequency	Pasture Density Low	Medium	High
5	14	400	391	559
	28	430	567	586
10	14	269	425	454
	28	399	532	557
20	14	218	396	428
	28	278	436	497
LSD (5%) Interaction			43	
CV (%)			29.7	

TABLE 9b

EXPERIMENT 1 - INTERACTION OF TREADING INTENSITY, TREADING FREQUENCY AND PASTURE DENSITY IN TERMS OF YIELD OF ANNUAL RYEGRASS AT RECOVERY HARVEST 5

(Plots sampled on 23.11.71. Data in g/m^2 D.M.)

Treading Intensity	Treading Frequency	Pasture Density Low	Medium	High
5	14	358	476	619
	28	356	505	660
10	14	315	361	563
	28	383	387	616
20	14	310	331	564
	28	384	378	534
LSD (5%) Interaction			94	
CV (%)			17.5	

and between treading intensity, treading frequency and pasture density at the last recovery harvest (Appendix IIa). This second order interaction is illustrated by the data summarized in Table 9a.

The patterns of accumulation of dry matter yields of annual ryegrass during the recovery phase were similar to those for subterranean clover. The second order interaction is illustrated by the data summarized in Table 9b.

It is logical that total pasture yield on the various occasions during the recovery phase should simply reflect the responses of the two components (subterranean clover and annual ryegrass). This was generally the case.

(iv) Seed Yields

Table 10 summarizes seed yield data for Experiment 1. Though treading treatments had no significant effect on the yield of clover seed (above-ground and below-ground seed considered separately) there was a significant effect of treading intensity on the yield of annual ryegrass seed, as follows:

Treading Intensity	0	5	10	20	LSD	CV (%)
Seed Yield (g/m^2)	76.6	71.4	59.6	51.4	15.9	21.1

The exceptionally high ratios (7.9 to 10.0 (NS*) for treading intensity and 9.0 to 11.6 (NS*) for treading frequency) of above-ground to below-ground seeds of subterranean clover are indicative of the hard surface of the soil at the time of seed-set. This could have contributed to the rather low seed-yield (per m^2) of subterranean clover.

(v) Pasture Regeneration in Autumn 1972

Pasture establishment counts taken following natural regeneration during May 1972 showed residual effects of treading from the 1971 season. There were significant differences due to treading intensity, treading frequency and their interactions. These data are summarized in Tables 11a, b, c; 12a, b, c; 13a, b, c.

(i) Clover - There was a significant decrease in plant number with increased treading intensity and with 14 day frequency. The significant interaction between treading intensity and frequency emphasized the reduction in the plant number with frequent treading and high treading intensity. Frequent treading on the pasture reduced the density of the regenerating clover (Table 11b). The reduction in plant count at high treading intensity, with 14 day frequency of treading and with the low pasture density resulted in the significant interaction between intensity and frequency of treading and pasture density (Table 11c).

(ii) Grass - The number of ryegrass plants was significantly influenced by the intensity and frequency of treading and by the interaction of intensity and density (Table 12b) and by frequency and density (Table 12c). Greater treading intensity significantly reduced the stand of the ryegrass. More frequent treading (14 day frequency) gave greater reduction in the plant count. There was greater reduction in plant number where the original pasture was sown at lower density and where the pasture was trodden more frequently.

(iii) Total Plant Count - Both treading intensity and frequency affected the total plant count at regeneration. There was a decrease in the total plant count with the increase in treading intensity (Table 13b). There was an interaction of treading intensity and treading frequency which gave a significant reduction in the plant number at the 14 day frequency and at the highest treading intensity (Table 13b). Treading intensity was found to interact with the pasture density, which gave higher reduction in plant number with low pasture density (Table 13c).

TABLE 10

EXPERIMENT 1 - YIELD OF CLOVER SEED, GRASS SEED AND TOTAL SEED
(Plots sampled on 14.12.71. Data in g/m^2)

Treatment	Clover			Grass			Total		
	Low*	Medium*	High*	Low*	Medium	High	Low	Medium	High
A	104.2	118.9	133.2	67.1	70.7	92.0	171.3	189.6	225.2
B	86.4	132.9	109.9	48.0	70.5	88.3	134.4	203.4	198.2
C	83.7	83.5	104.5	54.4	60.0	67.7	138.1	143.5	172.2
D	82.0	101.8	128.2	43.6	58.2	87.3	125.6	160.0	215.5
E	66.4	100.2	122.7	33.5	52.4	79.5	99.9	152.7	202.3
F	82.4	128.2	136.1	57.4	69.8	87.2	139.9	198.0	223.3
G	67.4	76.3	97.2	28.6	43.6	47.2	95.9	119.9	144.4
H	83.4	122.1	155.2	39.6	66.1	86.5	123.0	188.2	241.7
Mean (Density effect)	81.9	107.9	123.3	46.5	61.4	79.4	128.5	169.4	202.8
	Density		Density X Treatment	Density		Density X Treatment	Density		Density X Treatment
LSD (5%)	13.5		NS	10.5		NS	21.7		NS
CV (%)	16.0			21.1			15.3		

* These headings refer to sowing densities.

TABLE 11a

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING TREATMENT AND SOWING DENSITY IN 1971, ON THE REGENERATION OF SUBTERRANEAN CLOVER IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treatment	Sowing Density Low	Medium	High	Mean
A	1825	3900	6625	4117
B	1400	2775	5575	3250
C	1725	3575	5975	3758
D	1125	3100	4725	2983
E	850	1725	3075	1883
F	1775	3600	6350	3908
G	1425	3650	5025	3367
H	975	2200	4650	2608
Mean	1387	3066	5250	3234
	Treatment	Density	Treatment X Density	
LSD (5%)	169	142	400	
CV (%)	15.6			

TABLE 11b

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING FREQUENCY AND SOWING DENSITY IN 1971, ON THE REGENERATION OF SUBTERRANEAN CLOVER IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Frequency	Sowing Density Low	Medium	High	Mean
14	1233	2800	4592	2875
28	1392	3150	5342	3294
	Frequency		Frequency X Density	
LSD (5%)	98		226	
CV (%)	15.6			

TABLE 11c

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY, TREADING FREQUENCY AND SOWING DENSITY IN 1971, ON THE REGENERATION OF SUBTERRANEAN CLOVER IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Intensity	Treading Frequency	Sowing Density Low	Medium	High	Mean
5	14	1725	3575	5975	3758
	28	1775	3600	6350	3908
10	14	1125	3100	4725	2983
	28	1425	3650	5025	3367
20	14	850	1725	3075	1883
	28	975	2200	4650	2608
		Intensity	Frequency	Intensity X Frequency X Density	
LSD (5%)		120	98	276	
CV (%)		15.6			

TABLE 12a

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING TREATMENT AND SOWING DENSITY IN 1971, ON THE REGENERATION OF ANNUAL RYEGRASS IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treatment	Sowing Density Low	Sowing Density Medium	Sowing Density High	Mean
A	3625	6875	11925	7475
B	3425	5875	6700	5333
C	3325	6100	9100	6175
D	2550	4675	7800	5008
E	1975	3925	5850	3917
F	3675	6650	10700	7008
G	2925	4975	8700	5533
H	2875	4125	7350	4783
Mean	3047	5400	8516	5654

	Treatment	Density	Treatment X Density
LSD (5%)	353	311	484
CV (%)	14.2		

TABLE 12b

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY AND SOWING DENSITY IN 1971, ON THE REGENERATION OF ANNUAL RYEGRASS IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Intensity	Sowing Density Low	Medium	High	Mean
5	3500	6375	9900	6591
10	2737	4825	8250	5270
20	2425	4025	6600	4350
Mean	2887	5075	8250	
	Intensity	Density	Intensity X Density	
LSD (5%)	304	312	365	
CV (%)	14.2			

TABLE 12c

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING FREQUENCY AND SOWING DENSITY IN 1971, ON THE REGENERATION OF ANNUAL RYEGRASS IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Frequency	Sowing Density Low	Medium	High	Mean
14	2617	4900	7583	5033
28	3158	5250	8917	5775
	Frequency		Frequency X Density	
LSD (5%)	248		296	
CV (%)	14.2			

TABLE 13a

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING TREATMENT AND SOWING DENSITY IN 1971, ON THE REGENERATION OF THE TOTAL PLANT POPULATION IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treatment	Sowing Density Low	Sowing Density Medium	Sowing Density High	Mean
A	5450	10775	18550	11592
B	4825	8650	12275	8583
C	5050	9675	15075	9933
D	3675	7775	12525	7992
E	2825	5650	8925	5800
F	5450	10250	17050	10917
G	4350	8625	13725	8900
H	3850	6325	12000	7392
Mean	4434	8466	13766	8889

	Treatment	Density	Treatment X Density
LSD (5%)	448	271	766
CV (%)	14.1		

TABLE 13b

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY AND TREADING FREQUENCY ON THE REGENERATION OF THE TOTAL PLANT POPULATION IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Intensity	Treading Frequency 14	Treading Frequency 28	Mean
5	9933	10917	10425
10	7992	8900	8446
20	5800	7392	6596
Mean	7908	9069	8489
	Intensity	Frequency	Intensity X Frequency
LSD (5%)	361	295	533
CV (%)	14.1		

TABLE 13c

EXPERIMENT 1 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY AND SOWING DENSITY IN 1971, ON THE REGENERATION OF THE TOTAL PLANT POPULATION IN 1972

(Plots sampled May 1972. Data in plants/m^2)

Treading Intensity	Sowing Density Low	Sowing Density Medium	Sowing Density High	Mean
5	5250	9962	16062	10425
10	4012	8200	13125	8446
20	3337	5987	10462	6596
	Intensity	Intensity X Density		
LSD (5%)	361	533		
CV (%)	14.1			

(b) Soil Data

(i) Soil Moisture

The data on soil moisture content of the 0-6 cm samples collected on various occasions is summarized in Table 14. It is clear that during the treading phase and the recovery phase in 1971, and on the sampling occasion during the period of pasture regeneration during 1972, there were no marked differences in soil moisture.

There was no significant effect of treading intensity while on one occasion there was a significant effect of treading frequency. However, this could well have been a chance result.

(ii) Soil Bulk Density and Porosity

The data on soil bulk density for the 0-6 cm soil are summarized in Table 15. Here again, the data for bulk density are fairly uniform except for the occasion of the final treading at the eighth week of the experiment: the highest treading intensity increased the bulk density. On this occasion, the significant increase in bulk density may have been a transitory occurrence, as there was no further indication of any significant increase at subsequent harvest occasions.

As the values for soil porosity were derived from data on bulk density it is not surprising that total soil porosity was significant for treading intensity only at harvest 8, during the treading phase, as was the case with soil bulk density. These data are summarized in Table 16.

(iii) Soil Penetrability

Data on the penetrometer readings are summarized in Table 17. Treading intensity treatments appear to have affected the penetrability only during the recovery harvest. There was a proportional increase in the resistance to penetration with increase in the treading intensity and the relationship was linear (mean soil moisture 17.6%). The linear regression equation of penetrability (Y) on treading intensity (x) was

$$Y = 0.304x + 5.075 \ (r = 0.957^{***}, \ n = 48).$$

During the treading phase and the recovery phase, there was a significant interaction between treading intensity and pasture density: low pasture density and high treading intensity resulted in greater resistance to penetration by the surface soil.

TABLE 14

EXPERIMENT 1 - SOIL MOISTURE CONTENT DURING THE TREADING PHASE, RECOVERY PHASE AND AT THE TIME OF PASTURE REGENERATION

(Data in percentages by weight)

Harvest No. and date	H_4* (15.6.71)	H_8 (13.7.71)	RH_1* (7.8.71)	RH_2 (5.10.71)	PRH_1* (5.5.72)
Treatments					
A	22.9	20.1	24.8	16.8	20.9
B	23.8	19.2	24.7	17.3	21.5
C	21.7	20.0	25.2	17.3	21.5
D	22.7	19.1	23.3	17.1	21.7
E	22.3	19.3	25.1	18.3	21.3
F	23.8	19.4	24.4	18.4	21.9
G	22.6	20.7	24.7	17.8	22.2
H	23.3	20.1	24.1	17.4	21.4
LSD (5%)	NS	NS	NS	NS	NS
CV (%)	5.0	6.2	6.1	13.9	5.6

* H = Harvest during treading phase

RH = Harvest during recovery phase

PRH = Harvest during pasture regeneration phase

TABLE 15

EXPERIMENT 1 - DRY BULK DENSITY VALUES DURING THE TREADING PHASE, RECOVERY PHASE AND AT THE TIME OF PASTURE REGENERATION

(Data in g/cc)

Harvest No. and date	H_4* (15.6.71)	H_8 (13.7.71)	RH_1* (7.8.71)	RH_2 (5.10.71)	PRH_1* (5.5.72)
Treatments					
A	1.39	1.32	1.42	1.35	1.46
B	1.34	1.36	1.41	1.35	1.40
C	1.35	1.30	1.41	1.35	1.41
D	1.29	1.38	1.44	1.38	1.43
E	1.35	1.43	1.39	1.34	1.40
F	1.32	1.37	1.43	1.34	1.37
G	1.31	1.31	1.40	1.35	1.39
H	1.34	1.39	1.46	1.32	1.45
LSD (5%)	NS	NS	NS	NS	NS
CV (%)	5.6	6.7	8.7	6.6	5.4

* H = Harvests during treading phase

RH = Harvest during recovery phase

PRH = Harvest during pasture regeneration phase

TABLE 16

EXPERIMENT 1 - TOTAL POROSITY VALUES DURING THE TREADING PHASE, THE RECOVERY PHASE AND AT THE TIME OF PASTURE REGENERATION

(Data in cc/cc)

Treatments	Treading Phase (7.8.71)	Recovery Phase (5.10.71)	Pasture Regeneration (5.5.72)
A	50.30	46.47	44.76
B	48.65	46.78	47.05
C	50.83	46.81	46.84
D	47.78	45.81	46.08
E	45.97	47.71	47.03
F	49.19	46.23	48.22
G	50.51	46.99	47.27
H	47.53	44.92	45.21
LSD (5%)	NS	NS	NS
CV (%)	8.9	9.1	8.1

TABLE 17

EXPERIMENT 1 - PENETROMETER RESISTANCE DURING THE TREADING PHASE, THE RECOVERY PHASE AND AT THE PASTURE REGENERATION

(Data in kg/cm^2)

Treatments	Treading Phase (7.8.71)	Recovery Phase (5.10.71)	Pasture Regeneration (5.5.72)
A	1.03	5.67	3.08
B	1.79	7.22	3.13
C	2.19	6.63	2.96
D	1.65	7.43	3.00
E	2.25	9.62	3.04
F	1.53	6.22	3.04
G	1.89	7.18	2.96
H	2.31	9.42	3.04
LSD (5%)	0.60	0.95	NS
CV (%)	28.9	27.6	8.1

4.4.3 Discussion

(a) Plant Data

During the treading phase treatment differences were not significant in the case of plant numbers. Neither treading intensity nor treading frequency had much influence on the plant population. This might be due to the treading phase coinciding with the active growth period of these pasture species, thus allowing rapid recovery from damage by treading as suggested by Edmond (1964).

During the recovery phase both treading intensity and treading frequency affected the plant numbers of subterranean clover and annual ryegrass. A reduction of about 55% in the total plant population was recorded at the highest intensity of treading. At the 5/ac and 10/ac treading intensities the reduction in the total plant population was around 40% and 45% respectively (Figure 2). At different frequencies of treading the total plant numbers were reduced to about 50%, as against the control. At 14 day frequency of treading the reduction in the total plant population was around 44% (Figure 2). However, it should be noted that there was a general decline in plant numbers through treading phase and recovery phase and this decline is ascribed to plant competition (Donald 1963).

Treading had a far greater impact on subterranean clover than on annual ryegrass as had been shown previously by Synnot (1969) and Carter (unpublished data) - see Plate 2.

The decline in the number of tillers with the treading intensity treatments would indicate that tillering is either suppressed or discouraged by the effects of treading. Edmond (1963, 1964) reported a reduction in tiller number in both white clover and perennial ryegrass (perennial species of the same genera as used in this experiment) while Lancashire (1961) noted a reduction in tiller number as well as abnormality in tiller production in four grasses subjected to an artificial treading treatment.

At the high pasture density the production of tillers was the lowest, it being 1.69 for clover and 1.81 for grass for the individual plant (Table 6). This decrease in tiller production with increased density is a common phenomenon in crops and pastures (e.g. Donald 1954, 1963) and this is ascribed to greater inter-plant and intra-plant competition for light and nutrients.

The fact that treading intensity decreased the number of tillers in Wimmera annual ryegrass, and that treading decreased the total dry matter production could mean that the reduction of the number of tillers also contributed to the reduction in dry matter (Silsbury 1966; King 1971).

The dry matter yield during the treading phase was reduced only at the highest intensity of treading and the reduction was more pronounced on clover than on grass. During the treading phase the pasture was in an active growth period conditioned by the climate. Active growth of the pasture could reduce the intensity of the treading effect (Edmond 1964). The poor response of the pasture during the treading phase to treatment effects could be due to the compensatory effect of the active growth in reducing the treading damage.

The sensitivity of clover to treading damage is evident from the decrease in the dry matter yield at the highest treading intensity (20 sheep/ac). Similar results have been reported by Synnot (1969).

During the recovery phase the total dry matter yield decreased with increased treading intensity at all harvests. A reduction of 30.4%, 20.9% and 11.6% was recorded at 20, 10 and 5 sheep treading intensity, as against the control. The trend observed in the decrease of the dry matter yield with the increase in the treading intensity is in close agreement with the results reported by Edmond (1964) and Brown (1968).

The treading frequency of 14 days gave a greater reduction in dry matter yield than did 28 days (19.4% and 12.9% reduction respectively), hence frequent treading appears to cause the greatest decline in dry matter yield at a given treading intensity

The dry matter yields of the pasture components (clover and grass) were found to be influenced by the treading treatments in much the same way as was total yield of dry matter. Though there was no significant reduction in the tiller numbers of the clover, a reduction of plant numbers was caused by both treading intensity and treading frequency (Figure 2).

The dry matter yield of the annual ryegrass was affected only at the last three recovery harvests by the treading intensity treatments (Figure 3, Appendix IIb). The 10/ac and 20/ac sheep treading intensities caused a significant and a proportional reduction in the dry matter yield. At a 5/ac sheep treading intensity there was no significant difference between the control and the treading intensity and this could be due to the ability of the grass to withstand treading damage at low treading intensity. The grass appears to be more tolerant to treading damage than the clover as evidenced by the small reduction in the plant number and dry matter yield.

Treading treatments did not significantly affect the production of seeds by the subterranean clover, either above or below ground. Resistance of the soil to burr burial is considered the main factor limiting the underground production of seed by subterranean clover (Barley and England 1970). Under treading, soil compaction could induce resistance. However, as there was no significant compaction evident in this experiment it is not surprising that there was no difference between the seed production under the different treading treatments.

There was a significant reduction in the yield of grass seeds at the 10/ac and 20/ac sheep treading intensities compared with the control and 5/ac sheep treading intensity. This could be due to the reduction in plant number and tiller number affecting seed production rather than through the direct effects of treading.

Pasture Regeneration in 1972

There was about a three-fold increase in the total plant density following natural regeneration in 1972, compared with the establishment count taken at the treading phase in 1971. The decrease in the plant number with increasing treading intensity and the decrease at the 14-day treading frequency suggest a marked residual influence of the earlier treatments. As there was no effect by the treading treatments on the physical properties of the soil, the persistance of the treading influence is ascribed to the carry over effects on total plant number, tiller number and the total dry matter yield, which could have influenced the number and/or quality of seeds available for regeneration.

The effect of treading intensity and treading frequency interacted, giving a reduction in the plant number at high treading intensity and at frequent treading (Table 11c, 12b, 13b). The interaction between the treading intensity and pasture density gave a significant reduction in the plant number at low pasture density and high treading intensity. These effects could be the residual influence of treading persisting through with the plant number and the dry matter yield observed during the recovery period.

The residual influence of treading on the populations of subterranean clover and annual ryegrass was similar in trend to that on total plant numbers; grass seedling numbers were greater than for the clover.

(b) Soil Data

The retention and availability of soil moisture is generally conditioned by the physical properties of the soil (Baver 1956). Measurements made on the bulk density, total porosity and penetrability did not indicate any marked trends in the physical property of the soil. Thus there was no indication of the treading treatments causing a change in the soil moisture percentage.

Treading treatments have not affected the bulk density values. The increase of the bulk density at the 20 sheep intensity at harvest 8 during the treading phase was significant at the 5% level, which must have been transitory as there was no further indication of any increase at subsequent harvests.

As in the case of bulk density, there was a significant reduction in the total porosity at the 20 sheep treading intensity during the treading phase. The change appears to be transitory similar to the bulk density values. There was no significant difference at any other harvests.

Though there was no clear indication of soil compaction from the bulk density or total porosity values during the recovery phase, the resistance of the soil to penetration at higher treading intensities was evident. Tanner and Mamaril (1959) reported that penetrability was more sensitive to changes in soil compaction than the bulk density or the total porosity values. Therefore, it could be that the measurements made on bulk density and total porosity during the recovery phase could not distinguish differences in soil compaction.

Differences in the penetrability of soil did not persist to the time of pasture regeneration in May 1972. However, at this time, soil moisture was high (21.5%) and this could have reduced potential differences in resistance to soil penetration (Bryant et al. 1972). Natural reconditioning of the soil following the early autumn rains might have been another factor responsible for the lack of statistical significance between the treatments during the regeneration phase (Frame 1971).

4.5.0 EXPERIMENT 2

4.5.0 Experiment 2 - The Effects of Treading by Sheep at Various Intensities and Frequencies on Four Pasture Species and a Mixture, With and Without Defoliation

This experiment was designed to assess the importance of intensity and frequency of treading, and the possible interaction of these two main effects on three Mediterranean annual pasture species, and a mixture, together with a Mediterranean perennial grass. The influence of treading was assessed in terms of its effects on pasture plant numbers and pasture production, soil-moisture content, bulk density, porosity and penetrability.

4.5.1 Materials and Methods

(a) General Plan

The experiment was a factorial with a super-imposed split-plot design for the five pasture sub-plots. There were three blocks. The main-plot and sub-plot treatments are summarized in Figure 4 and Table 18.

(b) The Pasture

Experiment 2 was conducted on a freshly tilled area which had been under crop in 1970. The plots were fenced as per plan (Figure 4), then re-worked with Howard Rotovator to c. 5 cm before hand-raking to prepare a fine seed bed. The seeds of the pasture species were weighed separately (Table 18) and individual sub-plots were hand-sown along with basal fertilizer mixture as in the case of Experiment 1.

Figure 4.

Experiment 2 - Plan showing general layout and details of main-plot and sub-plot treatments. The enlarged sub-plot shows harvest sites for plant data and the sampling sites for soil/plant data.

PLAN OF EXPERIMENT 2.

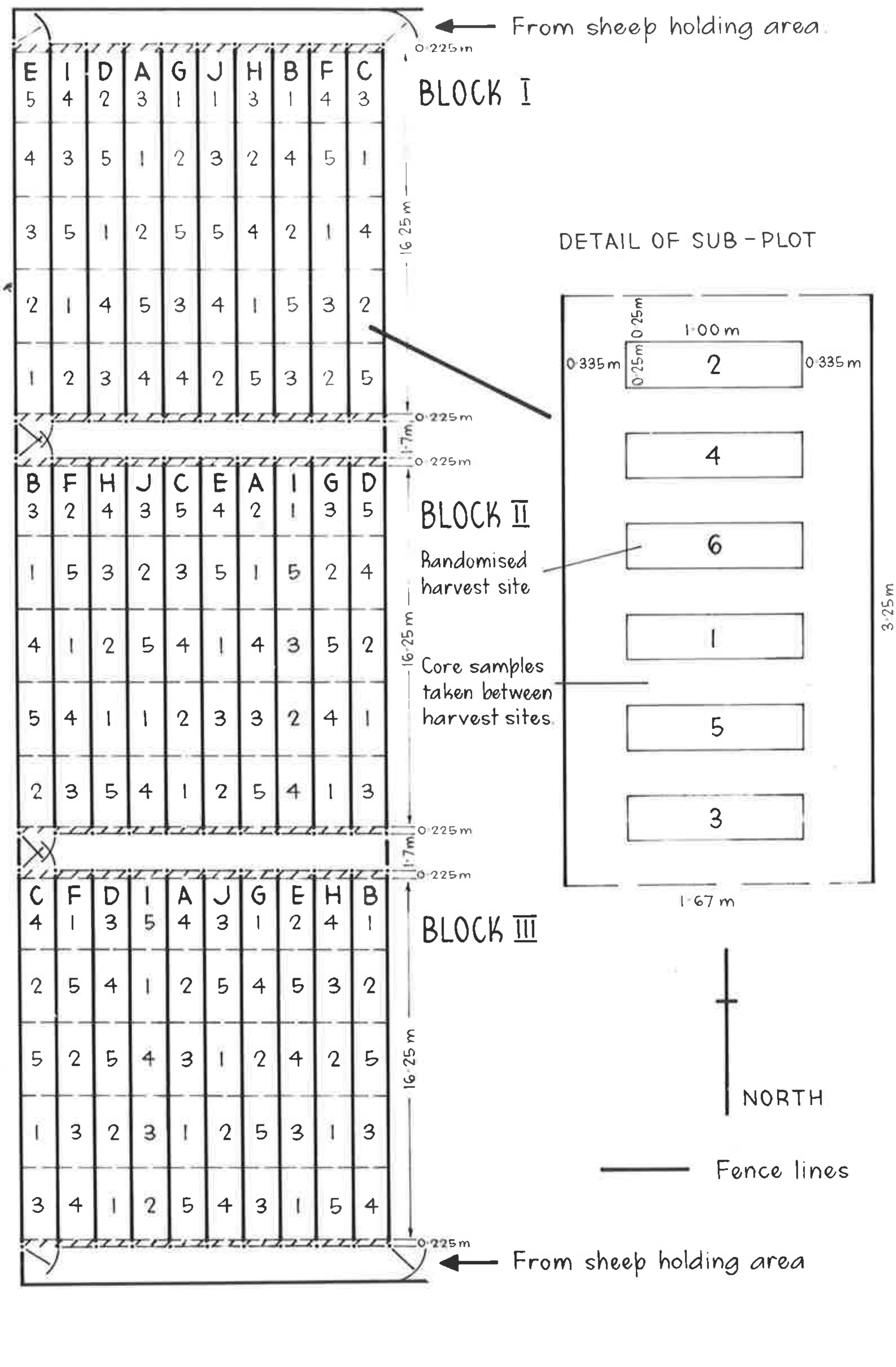


TABLE 18

EXPERIMENT 2 - MAIN-PLOT AND SUB-PLOT TREATMENTS

Main-Plot Treatments	Treading Intensity (sheep/acre)	Treading Frequency (days)	Defoliation
A	0	0	Unmown
B	0	0	Mown
C	5	14	Unmown
D	5	14	Mown
E	20	14	Unmown
F	20	14	Mown
G	5	28	Unmown
H	5	28	Mown
I	20	28	Unmown
J	20	28	Mown

Sub-Plot Treatments - Five swards as follows:

(1) *Trifolium subterraneum* L. (Subterranean clover) cv. Yarloop

(2) *Lolium rigidum* Gaud. (Annual ryegrass) cv. Wimmera

(3) *Trifolium glomeratum* L. (Cluster clover)

(4) *Lolium perenne* L. (Perennial ryegrass) cv. Medea

(5) Mixture of subterranean clover (cv. Yarloop) and annual ryegrass (cv. Wimmera)

The Sowing Rates used in Experiment 2 were as follows:

		(kg/ha*)
(1)	Subterranean clover	200
(2)	Annual ryegrass	100
(3)	Cluster clover	200
(4)	Perennial ryegrass	100
(5)	Mixture - Subterranean clover and Annual ryegrass	100)) 50)

Defoliation. The relevant main-plots were first mown prior to treading on the fourth week of the treading phase (August 3, 1971), when the pasture had attained an overall height exceeding 5 cm which was the height of mowing. Plots were mown with a rotary lawn mower (fitted with a catcher) each week from the fourth to the eighth harvest (September 28, 1971), immediately preceding the treading treatment. Herbage samples were taken before and after mowing to determine the pasture yield.

(c) The Timetable of the Experiment

The schedule of treading is summarized in Table 19. The other details were similar to those for Experiment 1.

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* Sowing rates based on pure germinating seed.

TABLE 19

EXPERIMENT 2 - INTENSITY AND FREQUENCY OF TREADING

Treatment		Dates of treading and sheep numbers required							
		June 22	July 6	July 20	Aug. 3	Aug. 17	Aug. 31	Sept. 14	Sept. 28
A Control	Unmown	-	-	-	-	-	-	-	-
B Control	Mown	-	-	-	-	-	-	-	-
C 5/14 day	Unmown	70/1*	70/1**	70/1*	70/1**	70/1*	70/1**	70/1*	70/1**
D 5/14 day	Mown	70/1**	70/1*	70/1**	70/1*	70/1**	70/1*	70/1**	70/1*
E 28/14 day	Unmown	70/4	140/2	70/4	140/2	70/4	140/2	70/4	140/2
F 20/14 day	Mown	70/4	140/2	70/4	140/2	70/4	140/2	70/4	140/2
G 5/28 day	Unmown	-	140/1*	-	140/1**	-	140/1*	-	140/1**
H 5/28 day	Mown	-	140/1**	-	140/1*	-	140/1**	-	140/1*
I 20/28 day	Unmown	-	140/4	-	140/4	-	140/4	-	140/4
J 20/28 day	Mown	-	140/4	-	140/4	-	140/4	-	140/4

Note: 5/14 day = 5/acre trodden every 14 days, etc.

70/1 = 70 sheep one way, etc.

* = South to North direction of treading

** = North to South direction of treading.

(d) Collection of Data

(i) Pasture Data - The details of the pasture data collection were similar to that for Experiment 1, excepting that no tiller counts were taken in Experiment 2.

The seed yield of pure subterranean clover and the subterranean clover mixed plots were determined in two portions, viz. above-ground and below-ground seeds. The other details were the same as for Experiment 1.

(ii) Soil Data - The procedure and the sampling details were the same as for Experiment 1.

(e) Statistical Analysis

The details of the statistical analysis and of processing the data through the computer are similar to that described under Experiment 1.

4.5.2 Results

(a) Pasture Data

(i) Plant Populations

Table 20 summarizes the data on plant densities for treading intensity at various times during the experiment, while the total plant density at different harvests for the treading intensities and frequencies are shown in Figure 5.

Plant numbers differed significantly with treading intensity; there was a proportionate decrease in plant number with the increase in treading intensity. The interaction between treading intensity and pasture swards was significant during both the treading and the recovery phase (Table 21 and 22, Appendix IIIa). The population of Medea ryegrass was reduced by 38% at the 20 sheep treading intensity, whereas the other pasture species were reduced by over 50% as compared to the control (Table 21). The residual influence of treatment on plant numbers during the recovery phase was similar to that obtained during the treading phase (Table 22).

There was a significant reduction in plant number due to treading frequency only at the last two harvests during the recovery phase, when the 14-day treading frequency gave the greatest reduction (Table 23). The differences due to treading frequency at the other harvests were not significant (Figure 5).

(ii) Pasture Production

Pasture growth data for treading intensity are summarized in Table 24. The effect of different treading intensities and treading frequencies on pasture growth is shown in Figure 6.

At all harvests pasture growth was affected significantly by treading intensity. There was a significant decrease in the available dry matter with increase in treading intensity (Table 24 and Figure 6).

At recovery harvest 1, there was an interaction between treading intensity and defoliation. The 20 sheep treading intensity gave the lowest available dry matter yield with the defoliated pasture. Even at the lower treading intensity of 5 sheep per acre there was a significant decrease in pasture production following defoliation and treading (Table 25).

At the last two recovery harvests there was a significant interaction between treading intensity and sward (Tables 26, 27). There was greater treading damage at the highest treading intensity. In both harvests the order of reduction in the available dry matter was lowest in perennial ryegrass and highest in cluster clover. The data on the influence of treading intensity and the percentage pasture availability is given in Tables 26 and 27.

Frequent treading significantly decreased pasture yield (Table 28). The difference in reduction between the yields at treading frequencies of 14 and 28 days were not as great as the differences observed with the treading intensities (Figure 6).

Table 29 summarizes the interaction of treading intensity, pasture swards and defoliation. At the treading intensity simulating 5 sheep per acre, mown pasture gave a significant reduction in the available dry matter in all species except in cluster clover. At the 20 sheep per acre treading intensity there was no significant difference between the yield of the mown and the unmown plots in all species except in the case of the annual ryegrass.

(iii) Seed Yields

Above-ground Seed - The yield of seeds was significantly reduced with the increase in the treading intensity, where 20 sheep treading intensity gave the greatest decrease. There was an interaction between the pasture sward and treading intensity as regards seed production. Except for cluster clover, all pasture species showed a significant reduction at the 20 sheep treading intensity (Table 30). The seed yield of cluster clover was not influenced by the intensity of treading. The table shows the percentage of the yield of seed compared to the control under treading intensity treatments. At low treading intensity Medea perennial ryegrass gave the greatest percentage reduction while at high treading intensity subterranean clover showed the greatest percentage reduction

Below-ground Seed - Table 31a summarizes data on the below-ground seed yield of subterranean clover in the subterranean clover and mixed plots, at different treading intensities. In both cases treading intensity affected the below-ground seed yield. With subterranean clover there was a 36.6% reduction at 5 sheep per acre treading intensity and 55.5% reduction at 20 sheep per acre treading intensity from the control. In the grass-clover mixture the underground seed yield of clover was depressed by 33.3% and 59.9% respectively at 5 and 20 sheep treading intensity (Table 31a).

There was an interaction between treading intensity and treading frequency. At the 14 days treading frequency the difference between the 5 and 20 sheep treading intensity was significant, whereas at the 28 day frequency of treading there was no significant difference between the yield at the different treading intensities (Table 31b).

(iv) Pasture Regeneration in the Autumn of 1972

Treading intensity was found to influence the pasture regeneration in May 1972: there was a decrease in the total plant number with increasing treading intensity (Table 32). Furthermore, there was an interaction between treading intensity and frequency. At 5 sheep treading intensity there was no significant difference between the 14 and 28 day frequency. At the 20 sheep treading intensity the 14 day frequency of treading gave a significantly lower plant density (Table 32).

(b) Soil Data

(i) Soil Moisture

The effects of treading intensity and treading frequency on percentage soil moisture are shown in Tables 33a and 33b.

During the treading phase, there was an inconsistent variation of soil moisture between harvests (Table 33a). At harvest 4 (3/8*) and at harvest 6 (31/8*), there was a significant decrease in soil moisture with increase in the treading intensity. During the recovery phase (9/11*) there was a similar trend in the reduction of soil moisture with increase in treading intensity. There was no significant difference in soil moisture between the treading intensity treatments at pasture regeneration in May 1972 (Table 33a).

There was no significant difference between the frequency treatments at the different harvests, except at harvest 4 (3/8*) when the 14 day frequency resulted in a significant reduction in the soil moisture percentage (Table 33b).

(ii) <u>Soil Bulk Density and Porosity</u>

The effects of treading intensity and treading frequency on soil bulk density are shown in Tables 34a and 34b.

Except in harvest 4 (3/8*) during the treading phase, there was no significant difference between treading intensities. At harvest 4, the treading intensity of 20 sheep per acre gave a significant increase in bulk density. There was no significant difference between treading intensity treatments either during the recovery phase or at regeneration in 1972.

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* Harvest dates.

The effects of treading intensity and treading frequency on the total porosity are shown in Tables 35a and 35b. On no occasion were there significant differences due to treatment. This is in agreement with the data on bulk density.

(iii) Soil Penetrability

Data on the penetrometer readings are summarized in Tables 36a, 36b. Treading intensity appears to have affected the penetrability during both the treading and the recovery phases. There was a proportional increase in the resistance to penetration with increase in the treading intensity and the relationship was linear during the treading phase and during the recovery phase. The linear regression equations of penetrability (Y) on treading intensity (x) were as follows:

For the treading phase

$$Y = 2.218x + 3.960 \quad (r = 0.968^{***}, n = 30)$$

For the recovery phase

$$Y = 2.091x + 7.032 \quad (r = 0.948^{***}, n = 30)$$

The mean soil moisture percentage was 22.0% and 15.1%, at the treading phase and at the recovery phase respectively, at the time of recording the penetrometer resistance.

The treading frequency did not affect the resistance of the soil to penetration during the treading phase, but during the recovery phase, the 14 day frequency of treading resulted in increased resistance of the soil to penetration (Table 36b).

Figure 5.

Experiment 2 - The effects of intensity and frequency of treading on pasture density and the overall trends in density of subterranean clover, annual ryegrass, mixture (subterranean clover + A.R.G.), cluster clover and perennial ryegrass, at different harvests.

EXPT. 2. EFFECTS OF TREADING ON PASTURE DENSITY

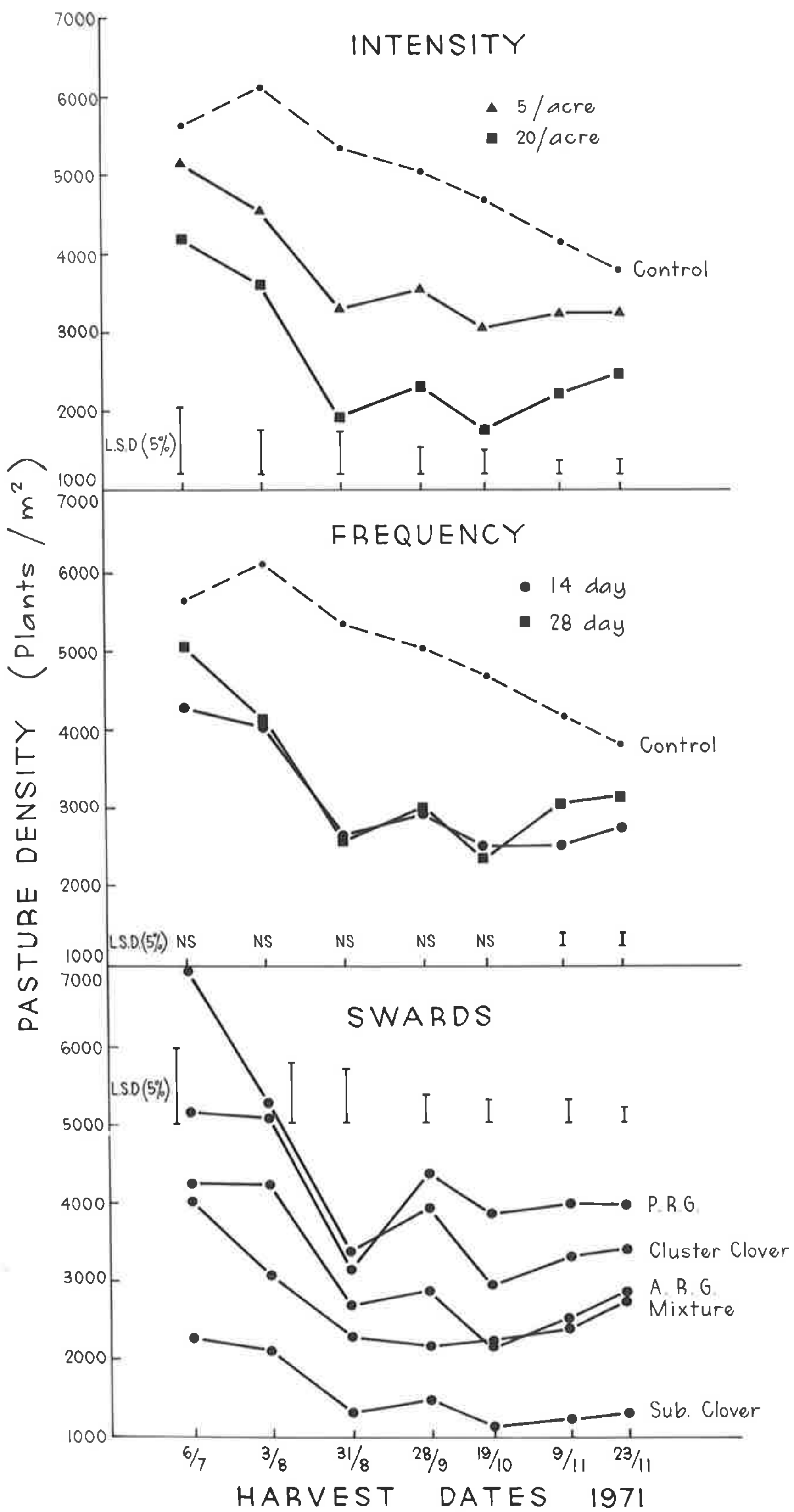

Figure 6.

Experiment 2 - The effects of intensity and frequency of treading on pasture growth and the overall trends in growth of subterranean clover, annual ryegrass, mixture (subterranean clover + A.R.G.), cluster clover and perennial ryegrass at different harvests.

EXPT. 2. EFFECTS OF TREADING ON PASTURE GROWTH

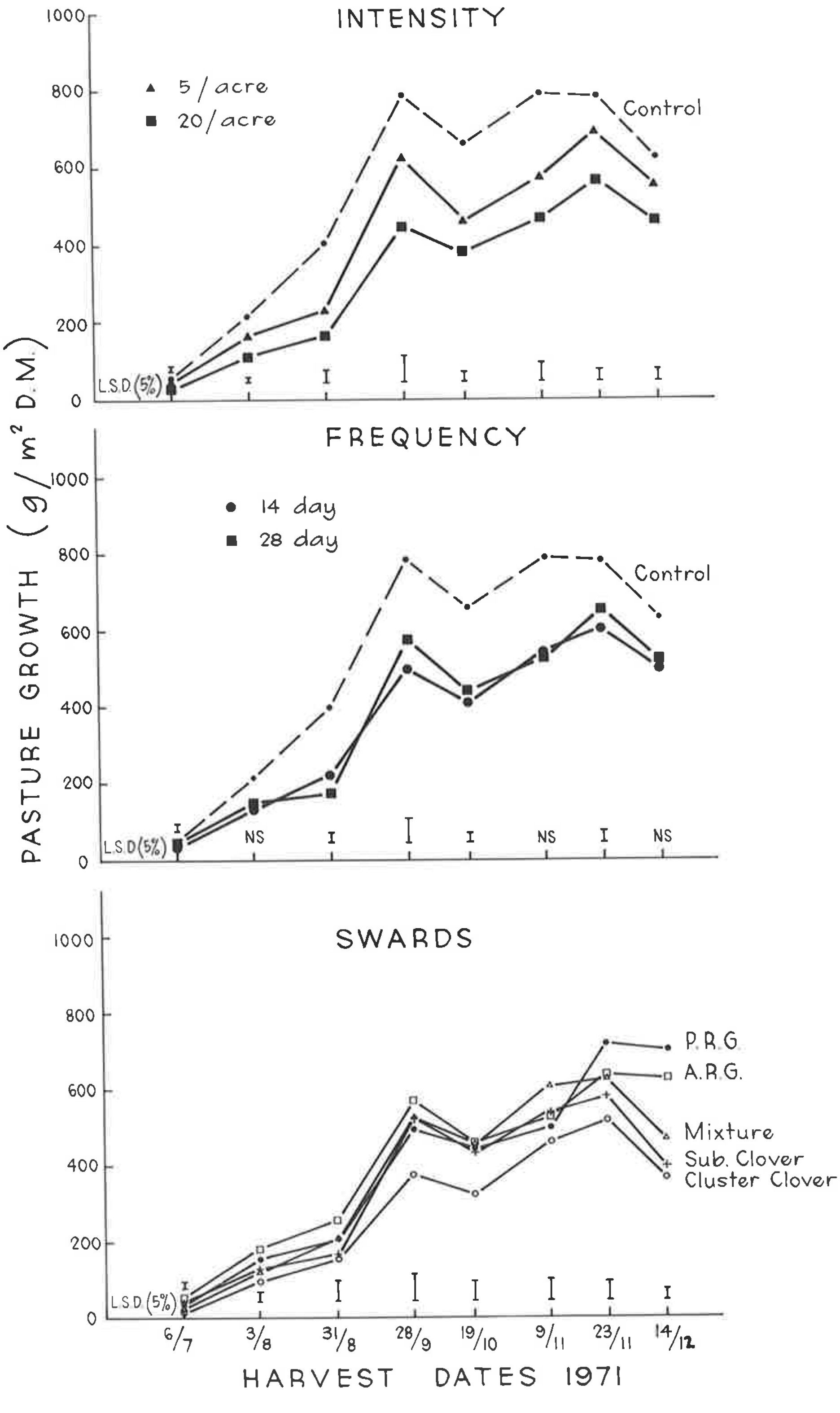

Plate 7.

Experiment 2 - Views of the five pasture swards on the most heavily trodden treatments after the final treading on 28.9.71.

No. 32: Annual ryegrass.

No. 33: Mixture of subterranean clover and annual ryegrass.

No. 34: Cluster clover.

No. 35: Subterranean clover.

No. 36: Perennial ryegrass.

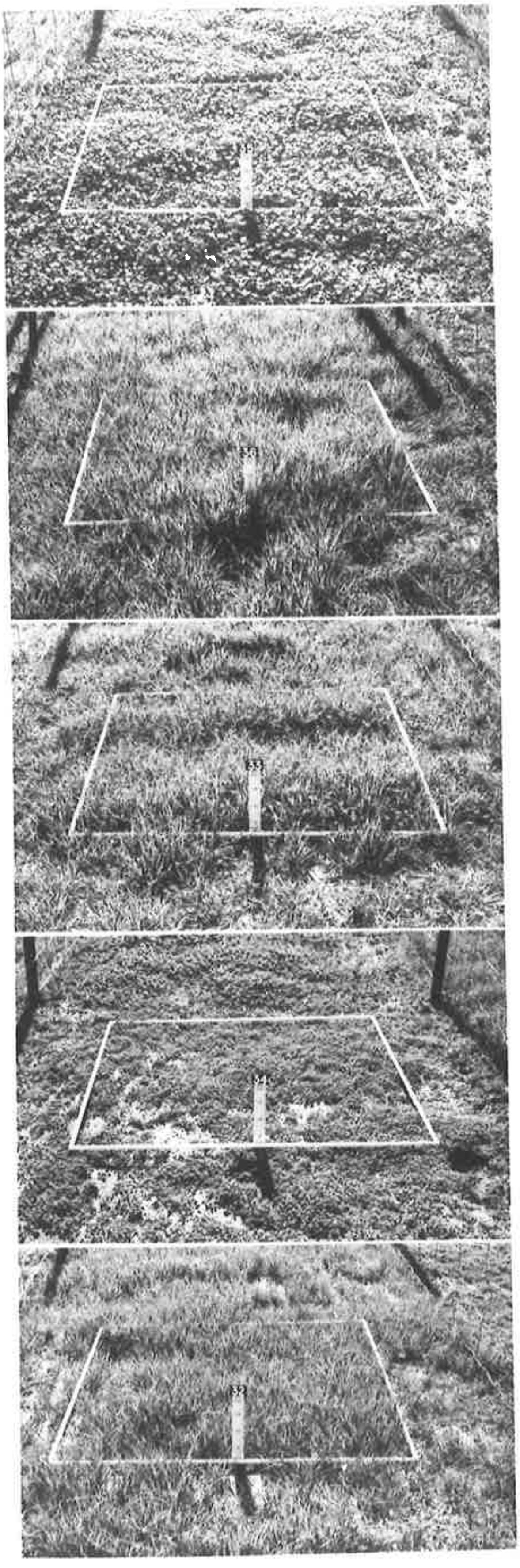

TABLE 20

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON PLANT DENSITY AT DIFFERENT HARVESTS

(Data in plants/m^2)

Harvest Date	Control	Treading Intensity			
		5	20	LSD*(5%)	CV (%)
6/7/71	5635	5169	4192	814.9	35.0
3/8	6134	4558	3626	523.5	28.5
31/8	5368	3304	1928	520.2	37.7
28/9	5038	3583	2324	320.2	16.7
19/10	4656	3052	1776	294.2	18.8
9/11	4172	3286	2266	156.9	13.6
23/11	3804	3296	2568	170.4	19.5

* LSD values apply to 5 and 20 treading intensities only.

TABLE 21

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON PLANT DENSITY OF THE PASTURE SWARDS

(Plots sampled on 28.9.71. Data in plants/m^2)

Treading Intensity	Swards				
	Sub. Clover	ARG	Mixture	Cluster	PRG
5	1895	3686	2589	4933	4811
Percentage of the control	59.2%	70.9%	63.6%	82.5%	75.7%
20	1060	1998	1707	2907	3949
Percentage of the control	33.1%	38.4%	41.9%	45.8%	62.1%
	Treading Intensity X Pasture Sward				
LSD (5%)	459				
CV (%)	16.7				

TABLE 22

EXPERIMENT 2 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY ON PLANT DENSITY OF THE PASTURE SWARDS (Plots sampled on 23.11.71. Data in plants/m^2)

Treading Intensity	Swards				
	Sub. Clover	ARG	Mixture	Cluster	PRG
5	1923	3376	2898	4239	4042
Percentage of the control	84.7%	85.3%	83.5%	85.9%	92.1%
20	1172	2889	2523	2476	3780
Percentage of the control	51.6%	72.9%	72.7%	70.5%	86.1%
	Treading Intensity X Pasture Sward				
LSD (5%)	240				
CV (%)	19.5				

TABLE 23

EXPERIMENT 2 - THE INFLUENCE OF TREADING FREQUENCY ON PLANT DENSITY AT DIFFERENT HARVESTS

(Data in plants/m^2)

Harvest Date	Control	Treading Frequency			
		14	28	LSD*(5%)	CV (%)
6/7/71	5635	4297	5065	NS	35.0
3/8	6134	4031	4162	NS	28.5
31/8	5368	2623	2587	NS	37.7
28/9	5038	2932	2975	NS	16.7
19/10	4656	2493	2335	NS	18.8
9/11	4172	2525	3028	156.9	13.6
23/11	3804	2742	3121	170.4	19.5

* LSD values apply to 14 and 28 treading frequencies only.

TABLE 24

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON PASTURE GROWTH AT DIFFERENT HARVESTS

(Data in g/m^2 D.M.)

Harvest Date	Control	Treading Intensity			
		5	20	LSD*(5%)	CV (%)
6/7/71	53.4	42.7	30.0	11.2	49.9
3/8	208.4	163.6	108.4	15.8	27.5
31/8	399.4	230.5	164.5	28.4	13.2
28/9	786.6	624.1	445.4	70.0	21.7
19/10	661.6	462.1	379.5	26.4	18.7
9/11	788.1	570.5	469.0	51.0	15.8
23/11	778.9	689.1	568.9	29.4	11.1
14/12	628.3	551.9	459.6	27.9	18.8

* LSD values apply to 5 and 20 treading intensities only.

TABLE 25

EXPERIMENT 2 - THE RESIDUAL EFFECTS OF TREADING INTENSITY AND DEFOLIATION ON PASTURE GROWTH

(Plots sampled on 19.10.71. Data in g/m^2 D.M.)

Treading Intensity	Defoliation			Mean
	Unmown	Mown		
5	610.0	314.1		462.1
20	470.9	288.0		379.5
Mean	540.5	301.1		
	Intensity	Defoliation	Intensity X Defoliation	
LSD (5%)	26.4	26.4	37.4	
CV (%)		18.7		

TABLE 26

EXPERIMENT 2 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY ON PASTURE GROWTH OF THE SWARDS

(Plots sampled on 23.11.71. Data in g/m^2 D.M.)

Treading Intensity	Swards				
	Sub. Clover	ARG	Mixture	Cluster	PRG
5	646.3	640.0	736.0	626.0	797.3
Percentage of the control	84.5%	83.7%	98.9%	81.4%	93.4%
20	532.0	619.0	514.3	474.3	705.0
Percentage of the control	69.5%	80.9%	69.1%	61.7%	82.5%
	Treading Intensity X Pasture Sward				
LSD (5%)	41.9				
CV (%)	11.1				

TABLE 27

EXPERIMENT 2 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY ON PASTURE GROWTH OF THE SWARDS

(Plots sampled on 14.12.71. Data in g/m^2 D.M.)

Treading Intensity	Swards				
	Sub. Clover	ARG	Mixture	Cluster	PRG
5	436.0	644.7	505.0	457.0	716.7
Percentage of the control	86.7%	85.7%	87.8%	80.9%	96.0%
20	340.3	597.0	423.7	270.0	667.0
Percentage of the control	67.7%	79.4%	73.6%	47.8%	89.3%
	Treading Intensity X Pasture Sward				
LSD (5%)	37.9				
CV (%)	18.8				

TABLE 28

EXPERIMENT 2 - THE INFLUENCE OF TREADING FREQUENCY ON PASTURE GROWTH AT DIFFERENT HARVESTS

(Data in g/m^2 D.M.)

Harvest Date	Control	Treading Frequency			
		14	28	LSD*(5%)	CV (%)
6/7/71	53.4	30.1	42.6	11.2	49.9
3/8	208.4	130.7	141.9	NS	27.5
31/8	399.4	219.3	175.3	28.4	13.2
28/9	786.6	492.1	577.4	70.0	21.7
19/10	661.6	404.6	436.9	26.4	18.7
9/11	788.1	535.3	525.1	NS	15.8
23/11	778.9	605.8	652.3	29.4	11.1
14/12	628.3	492.5	519.0	NS	18.8

* LSD values apply to 14 and 28 treading frequencies only.

TABLE 29

EXPERIMENT 2 - INTERACTION OF TREADING INTENSITY, PASTURE SWARD AND DEFOLIATION ON PASTURE GROWTH

(Plots sampled 28.9.71. Data in g/m^2 D.M.)

Treading Intensity	Defoliation	Swards				
		Sub. Clover	ARG	Mixture	Cluster	PRG
5	Unmown	700.6	820.6	688.8	522.4	767.0
	Mown	469.3	468.0	523.7	404.0	350.2
20	Unmown	530.7	768.5	480.0	314.6	463.3
	Mown	388.8	476.8	389.6	262.6	379.2
LSD (5%)		146.3				
CV (%)		21.7				

TABLE 30

EXPERIMENT 2 - RESIDUAL INFLUENCE OF TREADING INTENSITY ON THE YIELD OF ABOVE-GROUND SEED (Plots sampled on 10.1.72. Data in g/m^2)

Treading Intensity	Swards					
	Sub.Clover	ARG	Mixture	Cluster	PRG	Mean
5	107.5	78.8	116.7	44.1	46.6	78.8
Percentage of the control	66.6%	83.6%	79.8%	73.5%	59.8%	-
20	56.0	49.0	64.9	32.9	31.2	46.8
Percentage of the control	34.7%	52.0%	44.4%	54.8%	40.1%	-
Mean	81.7	63.9	90.8	38.5	38.9	

	Intensity	Swards	Intensity X Swards
LSD (5%)	4.9	10.5	14.8
CV (%)	25.4		

TABLE 31a

EXPERIMENT 2 - THE RESIDUAL INFLUENCE OF TREADING INTENSITY ON THE YIELD OF BELOW-GROUND SEED (Plots sampled on 10.1.72. Data in g/m^2)

Sward	Control	Treading Intensity			
		5	20	LSD*(5%)	CV (%)
1. Sub. clover	23.6	14.9	10.5	2.4	16.9
2. Sub. clover mixed plots	19.7	13.1	7.9	4.0	34.0

* LSD for 5 and 20 treading intensities only.

TABLE 31b

EXPERIMENT 2 - INTERACTION OF TREADING INTENSITY AND TREADING FREQUENCY ON THE BELOW-GROUND YIELD OF PURE SUBTERRANEAN CLOVER PLOTS

Treading Intensity	Treading Frequency		Mean
	14	28	
5	17.5	12.3	14.9
20	8.9	12.0	10.5
Mean	13.2	12.1	
	Intensity	Frequency	Intensity X Frequency
LSD (5%)	2.4	NS	3.1
CV (%)	16.9		

TABLE 32

EXPERIMENT 2 - INTERACTION OF TREADING INTENSITY AND TREADING FREQUENCY ON PLANT DENSITY AT THE TIME OF PASTURE REGENERATION

(Plots sampled on 8/5/72. Data in plants/m^2)

Treading Intensity	Treading Frequency		Mean
	14	28	
5	6480	6370	6435
20	3529	4268	3898
Mean	5004	5329	
	Intensity	Frequency	Intensity X Frequency
LSD (5%)	333	NS	470
CV (%)	16.2		

TABLE 33a

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON PERCENTAGE SOIL MOISTURE AT DIFFERENT HARVESTS

Harvest No. and Date		Control	Treading Intensity			
			5	20	LSD*(5%)	CV (%)
H2≁	6/7/71	19.28	19.53	19.49	NS	17.2
H4	3/8	23.22	22.72	21.31	0.86	14.5
H6	31/8	25.30	23.72	22.39	1.30	16.5
H8	28/9	23.15	21.93	20.99	NS	15.6
RH1	9/11	16.76	14.89	13.57	1.26	10.0
PRH1	8/5/72	22.29	21.13	21.21	NS	13.0

* LSD values apply to 5 and 20 treading intensities only.

TABLE 33b

EXPERIMENT 2 - THE INFLUENCE OF TREADING FREQUENCY ON PERCENTAGE SOIL MOISTURE AT DIFFERENT HARVESTS

Harvest No. and Date		Control	Treading Frequency			
			14	28	LSD*(5%)	CV (%)
H2≁	6/7/71	19.28	19.46	19.56	NS	17.2
H4	3/8	22.72	21.71	22.81	1.05	14.5
H6	31/8	25.30	22.47	23.64	NS	16.5
H8	28/9	23.15	21.48	21.45	NS	15.6
RH1	9/11	16.76	14.44	14.02	NS	10.0
PRH1	8/5/72	22.29	21.33	21.01	NS	13.0

* LSD values apply to 14 and 28 treading frequencies only.

≁ H = Harvest during treading phase
RH = Harvest during recovery phase
PRH = Harvest during pasture regeneration phase

TABLE 34a

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON BULK DENSITY VALUES AT DIFFERENT HARVESTS

(Data in grams/c.c. of soil on moisture-free basis)

Harvest No. and Date		Control	Treading Intensity			
			5	20	LSD*(5%)	CV (%)
H2⁄	6/7/71	1.31	1.32	1.36	NS	14.1
H4	3/8	1.41	1.40	1.46	0.05	13.9
H6	31/8	1.44	1.44	1.47	NS	14.8
H8	28/9	1.46	1.45	1.46	NS	13.1
RH1	9/11	1.34	1.39	1.42	NS	10.0
PRH1	8/5/72	1.45	1.49	1.47	NS	15.2

* LSD values apply to 5 and 20 treading intensities only.

TABLE 34b

EXPERIMENT 2 - THE INFLUENCE OF TREADING FREQUENCY ON BULK DENSITY VALUES AT DIFFERENT HARVESTS

(Data in grams/c.c. of soil on moisture-free basis)

Harvest No. and Date		Control	Treading Frequency			
			14	28	LSD*(5%)	CV (%)
H2⁄	6/7/71	1.31	1.43	1.25	NS	14.1
H4	3/8	1.41	1.47	1.39	0.03	13.9
H6	31/8	1.44	1.45	1.46	NS	14.8
H8	28/9	1.46	1.46	1.45	NS	13.1
RH1	9/11	1.34	1.39	1.39	NS	10.0
PRH1	8/5/72	1.45	1.47	1.49	NS	15.2

* LSD values apply to 14 and 28 treading frequencies only.

⁄ H = Harvest during treading phase
RH = Harvest during recovery phase
PRH = Harvest during pasture regeneration

TABLE 35a

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY ON TOTAL SOIL POROSITY VALUES AT DIFFERENT HARVESTS

(Data in c.c./c.c. on moisture-free basis)

Harvest Date	Control	Treading Intensity			
		5	20	LSD*(5%)	CV (%)
28/9/71	44.74	45.33	44.93	NS	14.3
9/11/71	48.45	47.33	46.49	NS	13.8
8/5/72	45.37	43.95	44.41	NS	16.6

TABLE 35b

EXPERIMENT 2 - THE INFLUENCE OF TREADING FREQUENCY ON TOTAL SOIL POROSITY VALUES AT DIFFERENT HARVESTS

(Data in c.c./c.c. on moisture-free basis)

Harvest Date	Control	Treading Frequency			
		14	28	LSD*(5%)	CV (%)
28/9/71	44.74	45.02	45.23	NS	14.3
9/11/71	48.45	47.31	46.52	NS	13.8
8/5/72	45.37	44.45	43.91	NS	16.6

TABLE 36a

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY AND TREADING FREQUENCY ON PENETROMETER READINGS DURING THE TREADING PHASE
(Date sampled 28.9.71. Data in kg/cm^2)

Treading Intensity	Treading Frequency		Mean
	14	28	
5	5.74	6.39	6.06
20	8.57	8.33	8.45
Mean	7.15	7.36	

	Intensity	Frequency	Intensity X Frequency
LSD (5%)	0.21	NS	0.42
CV (%)	18.3		

TABLE 36b

EXPERIMENT 2 - THE INFLUENCE OF TREADING INTENSITY AND TREADING FREQUENCY ON PENETROMETER READINGS DURING THE RECOVERY PHASE
(Date sampled 9.11.71. Data in kg/cm^2)

Treading Intensity	Treading Frequency		Mean
	14	28	
5	8.95	8.67	8.81
20	11.73	11.01	11.37
Mean	10.34	9.84	

	Intensity	Frequency	Intensity X Frequency
LSD (5%)	0.15	0.15	0.31
CV (%)	13.3		

Plate 8.

Experiment 2 - Views of the mixed pasture plot (subterranean clover and annual ryegrass) on 28.9.71.

Above:	Unmown
Below:	Mown
No. 3 and 4:	Trodden at the highest rate
No. 1 and 5:	Trodden at the lowest rate
No. 2 and 6:	Untrodden control

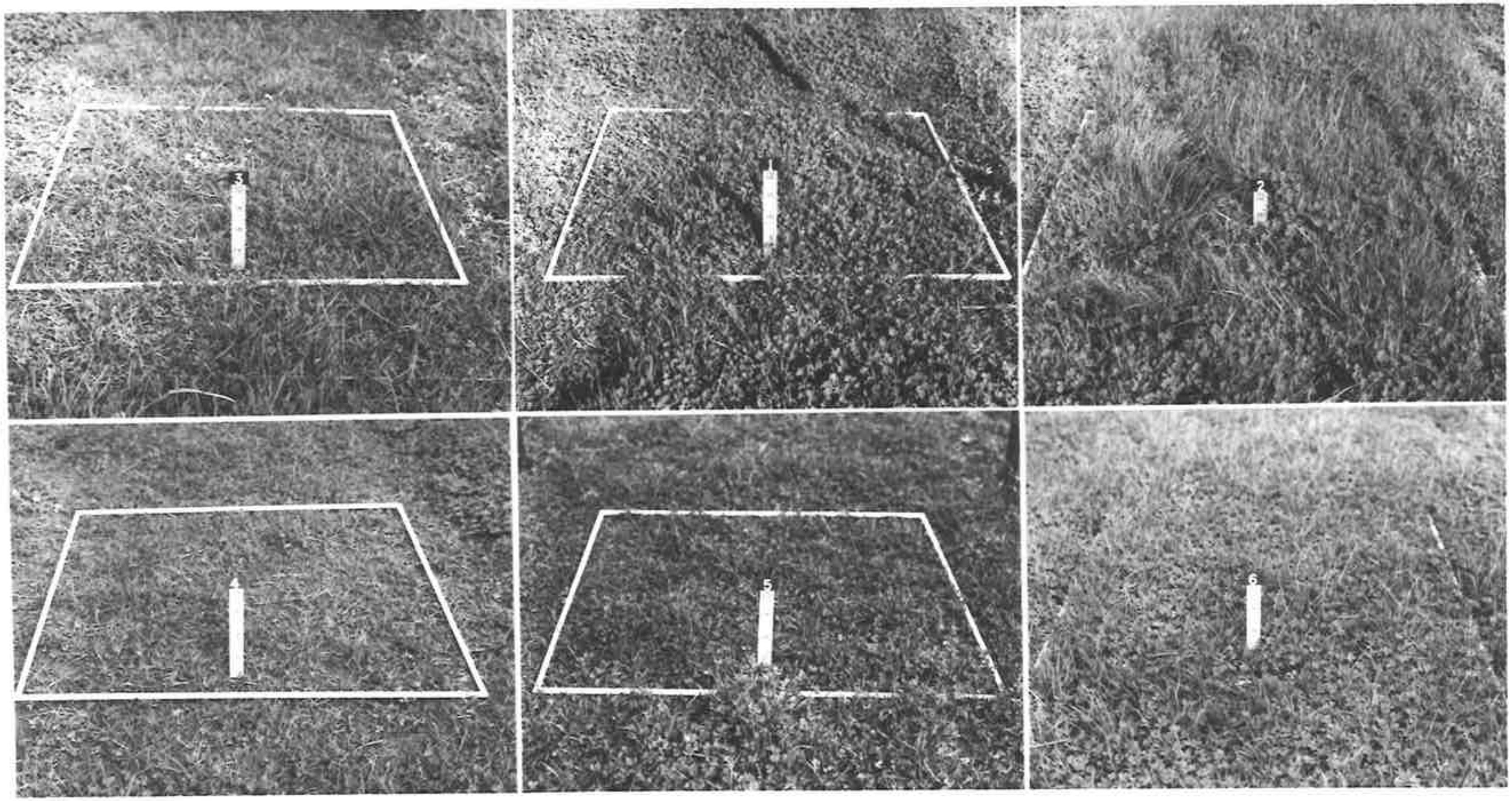
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Plate 9.

Experiment 2 - Views of the five pasture swards on 28.9.71.

Left: Mown and untrodden

Right: Mown and trodden

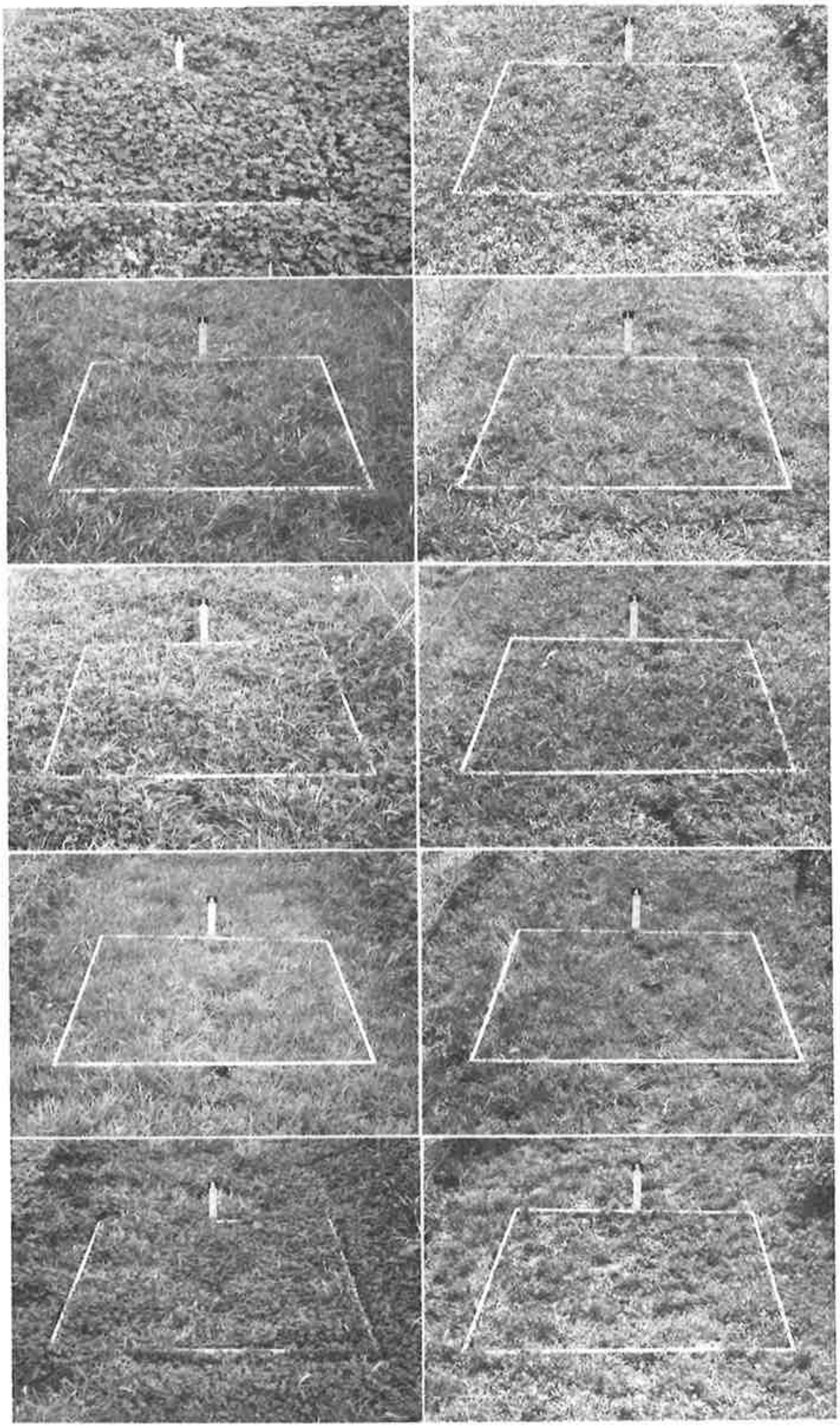
No. 1: Annual ryegrass

No. 2: Mixture of annual ryegrass and subterranean clover

No. 3: Subterranean clover

No. 4: Perennial ryegrass

No. 5: Cluster clover



4.5.3 Discussion

(a) Plant Data

There was a marked reduction in plant density with increasing treading intensity up to harvest 6 (31/8*) during the treading phase; thereafter there was no appreciable reduction but the differences in plant numbers due to differing treading intensities were maintained up to the last recovery harvest (Figure 5). Similar effects of treading intensity in reducing plant number, during the early growth phase, have been reported by Edmond (1964) and Synnot (1969).

The percentage reduction in the plant population of the sward, was less with perennial ryegrass and cluster clover. Earlier evidence reported by Bates (1935) and Edmond (1963, 1964 and 1966) on the treading tolerance of the perennial ryegrass supports the results obtained in this study. The treading tolerance obtained of cluster clover is a point of interest in view of the marked success of this legume in another experiment at the Waite Agricultural Research Institute, involving continuous grazing at a high stocking rate for a period of five years (Carter 1967, 1969).

In comparison to treading intensity, treading frequency did not have much effect on the plant population, but the trend in the decrease of plant number with the 14 day frequency suggests the

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* Date of harvest.

effect of frequent treading.

The effects of treading intensity on the available dry matter yield are similar to the effects observed on plant number. Plant number is a determinant of dry matter yield, hence any reduction in plant number by treading might be expected to influence the yield of dry matter.

The results which showed an interaction between treading intensity and defoliation, giving a significant decrease in the dry matter yield, under mown conditions, agree with the results obtained by Brown (1968). Under mown conditions, the more susceptible parts of the pasture plants (growing points, leaf buds and surface roots) are exposed to treading damage more so than in the unmown situation, which could be the reason for the greater effect of treading intensity on mown treatments in this experiment (Plates 8-10).

Of the pasture species used Medea perennial ryegrass appeared to be most tolerant of intensive treading, there being only a small reduction in the available dry matter (Plate 7). The reduction in the dry matter was proportional to the reduction in the plant population. Hence, the treading tolerance exhibited by the yield of perennial ryegrass appears to be closely related to the maintenance of plant numbers. The reduction in dry matter production of perennial ryegrass supports the results of Bates (1935) and Edmond (1963, 1964, 1966). Cluster clover, though showing a reasonable tolerance to treading as far as plant numbers were concerned, recorded greatly reduced yield in the available dry matter. This could be due to the effect of treading on the growth of the cluster clover plants rather than an effect through plant number. Subterranean clover showed a greater reduction in the available dry matter than did the annual ryegrass (Plate 7). Similar results were obtained in earlier studies at the Waite Agricultural Research Institute (Synnot 1969).

In general, the effects of treading frequency on pasture availability differed little between those of 14 and 28 days, though there was a significant difference between these frequency treatments and the control.

The interaction between treading intensity, pasture sward and defoliation gave a non-significant pasture growth difference at the highest treading intensity (Table 29). At 5 sheep treading intensity the effects of mowing appear to be well expressed on the swards and whereas at 20 sheep treading intensity the effects of treading appear to mask differences due to mowing.

As in the case of the reduction in plant number, the seed yield was also affected by treading intensity. The 20 sheep treading intensity gave the greatest reduction in the yield of seeds. Except for cluster clover, there was a significant reduction in the yield of seeds at the 20 sheep treading intensity. In cluster clover, though a reduction was apparent at the 20 sheep treading intensity, it was not statistically significant. In view of the fact that there was a smaller reduction in the plant density in cluster clover and a similar trend was obtained in seed yield, cluster clover appears to be more tolerant to treading damage under these conditions. Carter (1967, 1969) reported marked success of cluster clover under continuous grazing at a high stocking rate for a period of five years, and the results obtained in this treading experiment lend support to his contention. Medea perennial ryegrass and Yarloop subterranean clover showed the greatest percentage reduction of seed yield as a result of treading treatments.

The reduction in the total seed yield of Yarloop subterranean clover appears to have been caused by the reduction in the below-ground seed yield, probably due to soil compaction and the resistance of the soil to burr burials (Barley and England 1970). Though perennial ryegrass has been reported to resist treading damage by the physical toughness of the stem and other morphological characters (Bates 1935; Edmond 1963, 1964, 1966), the seed yield was reduced by treading treatments. Edmond (1958b) and Brown (1968) reported an increase in seed yield with perennial ryegrass due to treading under perennial pastures. Results obtained in this study are towards reduced seed yield, which could well be the effect of different climatic condition where the studies were made.

The residual effect of treading intensity on the re-establishment of the self-sown pasture species is emphasized by the decrease in plant number with increasing treading intensity. There was a 21% and a 52% reduction respectively in the plant population at 5 and 20 sheep treading intensity. As for the interaction between treading intensity and frequency, there was a significant reduction in plant number at the 20 sheep treading intensity and at the 14 day treading frequency. Frequent treading with a high treading intensity appears to affect the plant density of these self-sown pastures.

At the time of these pasture regeneration studies there was no clear evidence of soil compaction from bulk density, total porosity or penetrability data. Therefore the reduction in seed yields brought about particularly by increased treading intensity were probably responsible for the reduction in the plant population at the normal time of emergence and establishment in the autumn of 1972.

(b) Soil Data

Soil compaction is one of the factors affecting the physical properties of the soil. In this experiment the measurements made to identify soil compaction were on bulk density, total porosity and penetrability.

The bulk density and the total porosity were not affected by the treading treatment. Though there was an instance of an increase in the bulk density at harvest 4 during the treading phase, at the 20 sheep treading intensity and at the 14 day treading frequency, the trend did not persist through the other harvests. The effect could have been a transitory one. Porosity values remained unaffected by any of the treading treatments.

The penetrometer readings showed a significant increase in the resistance of the soil to penetration during the treading phase, and the recovery phase. The progressive increase in the penetrometer readings with increase in the treading intensity during these periods suggest a degree of compaction affecting penetrability more than the bulk density or the total porosity. It appears that the penetrometer resistance is more sensitive to changes of soil compaction under this study than the bulk density and total porosity measurements, as pointed out by Tanner and Mamaril (1959).

The 14 day frequency of treading registered the highest resistance to penetration of the soil, and there was an interaction between the treading intensity and treading frequency. There was some indication of soil compaction during the treading phase and during the recovery phase as indicated by the resistance of the soil to penetration, at high treading intensity. This could have influenced the moisture content of the soil at the various intensity treatments, during both the treading phase and the recovery phase.

Plate 10.

Experiment 2 - A general view of the main plots showing contrasting differences on 28.9.71.

Left: Mown and untrodden

Middle: Mown and trodden

Right: Unmown and untrodden

Plate 11.

Experiment 2 - A view of the unmown trodden main plot on 28.9.71, showing the soiling of the sward (mud splashing) following treading under conditions of high soil moisture.

Plate 12.

Experiment 2 - Close-up view of the soiled and muddied subterranean clover plot trodden after mowing on 28.9.71, under conditions of high soil moisture.


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5.0.0 GENERAL DISCUSSION AND CONCLUSIONS

5.0.0 GENERAL DISCUSSION AND CONCLUSIONS

In an ungrazed pasture the productivity is mainly determined by plant nutrients, soil moisture and sunlight. But in a grazed pasture, the effects of the grazing animal complicate the ecosystem. Treading by the grazing animal is known to affect the grazed pasture: however, this treading influence may remain unnoticed until it is severe (Edmond 1963). Treading may also place a ceiling on herbage and animal production (Edmond 1960; Mitchell 1960).

Treading effects on pasture appear to begin with the influence on plant number and continue to affect the tiller number, dry matter yield, seed yield and the pasture regeneration from natural seeding. In New Zealand, Edmond (1963, 1964, 1966, 1970) and Brown (1968, 1971) reported a decrease in plant number, tiller number and dry matter yield in perennial pastures due solely to treading. In these studies with annual pasture in South Australia the general trends appear to be similar to that obtained with the perennial pastures in New Zealand and elsewhere.

Treading intensity appears to have a greater influence than does frequency of treading The significant decrease in the plant density with increasing treading intensity is suggestive of the treading effect imposed by stock density. In preliminary studies at the Waite Institute Synnot (1969) reported a similar trend in the influence of stocking density on treading damage in annual pasture studied under similar conditions. It is of interest that though the immediate effects of treading were spectacular (Figures 10-12) there was no marked persistence of these effects of treading on annual pastures during the treading phase. Edmond (1964) contended that treading effects during the active period of growth of the pasture were not very persistent because the plants have the ability to recover rapidly from treading damage. During the treading phase the pasture was in the active stage of growth and climatic conditions were favourable. Rain ensured that mud was washed from leaves to allow resumption of active photosynthesis and regrowth to compensate for treading damage.

Though treading frequency had less effect than treading intensity on plant population there appears to be a definite trend towards a decrease in plant density in the case of the most frequent treading.

Treading influenced pasture production in a similar way to plant density: dry matter yield was reduced significantly by treading intensity and treading frequency treatments. As the plant number and the dry matter yields recorded a similar trend, it is probable that the reduction in the plant density may have contributed to the reduction in the dry matter yield. This proportional decrease in pasture yield with increasing treading intensity is in agreement with the results obtained by Edmond (1964). Under the most intensive treading there was an average reduction of 30.4% and 20.5% in the total pasture yield in Experiment 1 and Experiment 2 respectively. This percentage reduction in pasture yield is in agreement with the percentage reduction of 24% reported by Stern (1969) for the impact of treading in an annual pasture of the Mediterranean environment.

The reduction through treading of the tiller number may also have contributed to the reduction in the yield (Silsbury 1966; King 1971). There was a reduction of about 60% in the tiller number at the 20 sheep/ac treading intensity. Edmond (1964) contended that the reduction in the tiller number by treading intensity was a dominant cause of the decrease of dry matter yield of ten pasture species under heavy treading.

In the present studies with annual species the low density pasture showed the greatest effect of treading on plants and soil. Brown (1968) reported the influence of the herbage cover in reducing the effects of treading. Under conditions of low pasture density the pasture cover, being sparse, might not be sufficient to provide a protective cover to withstand possible treading damage. The increase in the penetrometer resistance at the low pasture density also emphasizes the lack of any cushioning influence of pasture cover.

At low pasture densities pasture availability may be limiting and will generally increase the grazing time (Arnold 1964). Hancock (1954) also reported greater grazing time on scant pasture. Hence low pasture density will tend to increase the treading time as well as increase the effect of treading in the absence of sufficient pasture and ground cover.

The significant treatment differences obtained at the time of pasture regeneration indicate a residual influence of treading. As there was no evidence of any persistent effect of treading on the soil, the difference obtained at the pasture regeneration could be through the treading effect on the vegetation.

Of the pasture species, a high degree of treading tolerance was exhibited by Medea perennial ryegrass in the case of both plant number and yield. Similar trends were reported by Bates (1935) and Edmond (1964) for temperate pasture environments where perennial ryegrass showed the highest treading tolerance. It is of interest that though cluster clover showed a smaller percentage reduction in plant number than Medea perennial ryegrass, the dry matter yield showed a greater reduction under treading. This could be due to the treading treatments adversely affecting the growth of the species directly, rather than through the reduction in the plant number. The general trends for subterranean clover, Wimmera annual ryegrass, and the mixture of both, were similar in both the experiments; Wimmera ryegrass appears to be more tolerant to treading than subterranean clover.

The treading of the pasture after mowing resulted in a significant decrease in pasture yield and this is ascribed to the damage of the growing points, leaf buds and surface roots as discussed by Brown (1968). The mowing treatment was imposed to simulate uniform and heavy grazing of the pasture. In a normal grazing situation this effect is brought about by intensive utilization of the pastures generally by a high density of stocking. With greater numbers of grazing animals per unit area, the pasture is more severely defoliated and at the same time the treading damage is increased, as evidenced from the results of these experiments.

The residual influence of treading on the plant population at the time of pasture regeneration could be a function of reduced plant number, reduced dry matter yield and reduced seed yield in the previous growing season. The reduction in the underground seed yield following treading of the subterranean clover and the subterranean clover mixed plots could be due to the soil compaction as recorded by the penetrometer resistance. Barley and England (1970) reported that the limiting penetrometer resistance for burr burial in subterranean clover (cultivar Dwalganup) was of the order of 10 kg/sq. cm. on a hard-setting red brown loam from Parafield, South Australia. Penetrometer resistance readings up to 11.37 kg/sq. cm were recorded at the highest treading intensity in Experiment 2 and such a high resistance could have influenced the burr burial and seed production.

It is clear from the evidence obtained from both the experiments, that the treading effect on pasture is more pronounced on vegetation than on the soil. The effects on pasture were through the reduction of (1) plant number, (2) tiller number, (3) dry matter yield, and (4) final seed yield. The proportional reduction of these variables with increase in treading intensity, and with frequent treading provides clear evidence of the magnitude of treading damage on grazed pastures.

Though the effects of treading were obvious on the pasture at the highest treading intensity of 20 sheep per acre and at the 14 day frequency of treading, such a condition is unlikely in the field situation in the rainfed annual pastures of the Mediterranean environment of southern Australia. Under the normal to high stocking rate of 5 sheep per acre, treading effects appear to be minimal, on the plant as well as on the soil. However, it should be remembered that these experiments were only of short duration.

The differing treading tolerance exhibited by the various pasture species could explain the persistence of certain pastures under heavy treading. However, as the highest treading intensity studied here was outside the normal range of carrying capacity for annual pastures the treading tolerance of the pasture species, though evident, may assume lesser importance. Under the normal stocking rate of 5 sheep per acre the pasture species did not differ much in the degree of treading tolerance.

In a perennial pasture, the treading effect may become additive through the year and this could result in the change of the botanical composition and the productivity of the pasture (Brougham 1969). However, owing to natural changes in the soil (Thomas 1960; Frame 1971) and the reaction of the pasture species to treading damage (Edmond 1963), the effects are sometimes not cumulative (Brougham 1969). But in an annual pasture of the Mediterranean environment, the production being non-continuous, the residual effects of treading on vegetation might not persist through seasons, as in the case of perennial pastures.

The effects of treading on soil are generally expressed by soil compaction, which has a major effect on infiltration and soil moisture movements (Lull 1959). In the present study soil bulk density, total porosity, and penetrability measurements were used as the indices to evaluate soil compaction. However, the treading treatments caused no significant changes in the bulk density and in the total porosity values. There was some indication of soil compaction from the penetrometer readings and it appears that the penetrometer readings were more sensitive to the changes in soil compaction under this study, as contended by Tanner and Mamaril (1959). The degree of soil compaction obtained was apparently sufficient to affect the penetrometer readings taken on the surface, but not high enough to influence the values of bulk density and total porosity taken up to a depth of 6 cm.

Though soil compaction by treading depends upon the soil type and other physical conditions of the soil, the duration of the treading period is very important. Carter (unpublished data), in recent studies at the Waite Institute, obtained a significant increase in the bulk density of 1.24 to 1.55 g/cc during a 5-year grazing period on the same type of soil as used in these experiments. Edmond (1964) reported an increase in the bulk density by treading a perennial pasture for a period of 10 months, using a treading rate of 32 sheep per acre. Knoll and Hopkins (1959) recorded an increase in bulk density from a heavily grazed pasture over a period of a year. It appears that changes in the bulk density and total porosity values are brought about after longer periods of treading. In the present studies, the treading phase occupied only 2-3 months. This was apparently too short a period to obtain significant changes in bulk density and total porosity values.

The soil moisture percentage was unaffected by the treading treatments in Experiment 1; however, in Experiment 2, there was a trend towards a decrease in soil moisture with increase in treading intensity. Differences in penetrometer readings during this period were also significant which indicated soil compaction. Hence the soil compaction registered during this period would have been responsible for the difference in the soil moisture percentages.

Though the effect of treading has been reported to influence the plant and the soil in perennial pastures (Lancashire 1961; Edmond 1963, 1964, 1970; Brown 1968, 1971), the studies described in this thesis indicate greater effect on plant than on the soil. Owing to the short duration of the treading periods in these studies it might not be possible to draw any definite conclusions on the effects on the soil.

Though treading effect on the soil was not severe, the incidence of mud splashing on the vegetation was high. Trampled herbage may be generally rejected by the grazing animal because of soil contamination (Frame 1971) and the consumption of soiled herbage was found to be related to the wear of the teeth (Ludwig et al. 1966). Rejection of the contaminated and unattractive herbage could also increase the grazing pressure on the rest of the sward. Plates 10, 11 and 12 show clearly the soiling of the pasture and the unattractive nature of the sward.

Treading is an integral part of conventional stock grazing and cannot be totally avoided. A better understanding of the factors influencing treading damage will certainly help to mitigate the problem. The effect of treading seems to be linked with the stock numbers and the frequency, which fortunately falls within the purview of the controllable factors in pasture management. With the emphasis on more per-acre production, increased stocking rates are inevitable and there needs to be a better understanding of the limitations caused by the treading damage.

McMeekan (1956) considered stocking rate and grazing method as two of the main factors in animal production from pastures. Treading intensity is a function of stocking rate while treading frequency is related to grazing method. In a rotationally-grazed pasture the frequency is of equal importance to the stocking rate but in a set stocked situation the frequency becomes less important. Since frequency denotes the extent of the rest period between two grazings, and as frequent treading is damaging to the pasture, sufficiently-spaced grazings are important. Under the normal stocking rate of 5 sheep per acre, treading damage does not appear to be severe, but with the tendency to increase stocking rates the treading effects might become dominant in placing a ceiling on herbage and animal production (Edmond 1960; Mitchell 1960). However it should be noted that grazing animals form tracks, especially when walking to water. This is especially true of the arid areas. Lange (1969), using aerial photographs, has identified definite radiating sheep tracks from watering points. Squires (1970) reported overgrazing of the areas closer to the watering points. These tracks not only reduce the pasture availability but also concentrate the treading damage over a smaller area, which, in turn, diminishes the total impact of treading on vegetation and soil over the whole area.

High stocking rate and the susceptibility of the pasture species in combination with the nature and the condition of the soil are reported to be the main factors connected with treading damage (Frame 1971). With conventional stocking rates treading damage appears to be minimal but as stocking rates are raised, methods of minimising treading damage become more important. Treading tolerance of the pasture species appears to be linked with the physical toughness of the shoot, as in the case of the perennial ryegrass (Bates 1935; Edmond 1964, 1966; Evans 1967). Similarly, the ingress of weeds in an overgrazed or trodden pasture could be due to the physical ability of the vegetation to withstand the treading damage. But the physical strength is generally related to the presence of a high proportion of fibrous tissues, as in the case of the perennial ryegrass (Wilson 1965). Since the relationship between the plant strength and the treading tolerance appears to be intimate, plants which can withstand treading may not necessarily be highly nutritive (owing to the high proportion of fibrous tissues) (Johns 1962), and selection of pasture species based on nutritive value alone might not be a sufficient criterion for pasture productivity and persistence under grazing conditions. Pasture species which can persist well despite the harmful effects of treading have obvious productive value under grazing, but might not be related to the quality of pasture production.

Finally, it should be stressed that this study had some limitations in common with other treading studies. The period of treading was short (2 to 3 months duration) and a longer period of treading would have been desirable. However, the salient features are brought out to some extent to be a forewarning of the possible effects of treading on newly-sown pastures. Annual pastures do not have a continuity in production as do the perennial pastures, and any treading effect on plants will necessarily be of a short-term nature and of lesser limitation to production than that imposed by the summer drought conditions.

6.0.0 ACKNOWLEDGEMENTS

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I wish to gratefully acknowledge the supervision and help given by Mr. E.D. Carter, Senior Lecturer, Department of Agronomy, Waite Agricultural Research Institute, throughout the duration of this study.

This project was undertaken with the generous financial assistance provided by the Government of Australia under the Colombo Plan and with the kind co-operation of Professor C.M. Donald and staff of the Department of Agronomy, Waite Institute. I am grateful for their generosity.

Mr. I. Ridgway and Miss C. Norman were helpful in the field as well as in the laboratory. The Farm Manager and his staff provided assistance wherever necessary. Miss S. Chambers assisted with the computer programming and statistical analyses and Mr. B. Palk handled the necessary photographic work. I am very grateful for their generous help.

Dr. W.W. Emerson was consulted regarding the particle density figures and Mr. K.P. Barley suggested the penetrometer modification. Their help is gratefully acknowledged.

Finally I wish to thank the Government of Sri-Lanka for providing the opportunity for this study, and my wife, Sarogini, for her continuous encouragement during my absence from home.

7.0.0 BIBLIOGRAPHY

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8.0.0 APPENDIX

APPENDIX I(a). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR PLANT DENSITY OF SUBTERRANEAN CLOVER

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	7.596 *	1.962 NS	2.447 NS	4.185 NS	10.210 *
Treading Treatment (T)	13.056 ***	17.740 ***	23.100 ***	36.393 ***	35.75 ***
Intensity (I)	1.084 NS	19.661 ***	38.223 ***	37.309 ***	68.220 ***
Frequency (F)	5.079 NS	8.607 *	3.576 NS	6.502 NS	20.370 **
Intensity X Frequency	1.181 NS	0.888 NS	3.484 NS	5.288 *	17.780 **
Sowing Density (D)	12.288 ***	8.997 ***	8.107 **	54.031 ***	80.294 ***
Density X Treading Treatment	4.555 ***	0.442 NS	0.200 NS	5.967 ***	1.429 NS
I X D	5.191 *	0.503 NS	0.289 NS	12.071 ***	3.248 NS
F X D	7.172 **	0.599 NS	0.271 NS	1.500 NS	0.492 NS
I X F X D	1.515 NS	0.104 NS	0.062 NS	1.714 NS	0.401 NS
CV (%)	24.5	19.4	16.1	14.2	10.9

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant.

APPENDIX I(b). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR PLANT DENSITY OF ANNUAL RYEGRASS

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	6.593 *	6.224 *	3.815 NS	9.650 *	11.343 *
Treatment (T)	17.166 ***	19.000 ***	17.516 ***	30.211 ***	32.193 ***
Intensity (I)	4.607 NS	19.713 ***	11.738 *	38.098 ***	34.155 ***
Frequency (F)	18.717 **	25.075 ***	9.424 *	6.576 NS	10.346 *
Intensity X Frequency	1.590 NS	1.862 NS	0.768 NS	1.522 NS	3.007 NS
Sowing Density (D)	13.761 ***	8.784 ***	7.198 **	27.835 ***	21.592 ***
Density X Treading Treatment	8.573 ***	0.301 NS	0.177 NS	10.751 ***	2.371 NS
I X D	1.177 NS	0.117 NS	0.053 NS	0.864 NS	0.871 NS
F X D	6.171 *	0.701 NS	0.244 NS	6.449 **	6.299 *
I X F X D	4.659 *	0.437 NS	0.1131 NS	1.201 NS	0.5817
CV (%)	21.2	18.6	25.7	16.9	12.2

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant.

APPENDIX I(c). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR TOTAL PLANT DENSITY

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	11.039 *	4.525 NS	3.622 NS	8.698 *	10.514 *
Treading Treatment (T)	16.015 ***	19.703 ***	20.922 ***	22.968 ***	24.210 ***
Intensity (I)	2.733 NS	21.864 ***	23.583 ***	24.663 ***	27.794 ***
Frequency (F)	19.261 ***	21.642 ***	10.103 *	8.419 *	20.805 **
Intensity X Frequency	0.936 NS	1.058 NS	1.612 NS	2.036 NS	5.865 *
Sowing Density (D)	17.525 ***	10.093 ***	8.635 ***	26.463 ***	27.342 ***
Density X Treading Treatment	4.636 ***	0.318 NS	0.172 NS	5.346 ***	2.669 *
I X D	2.838 NS	0.162 NS	0.121 NS	2.704 NS	2.373 NS
F X D	8.414 **	0.671 NS	0.264 NS	8.238 **	5.655 *
I X F X D	4.075 *	0.275 NS	0.088 NS	0.729 NS	0.164 NS
CV (%)	18.9	18.5	28.7	15.4	18.9

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant.

APPENDIX II(a). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR DRY MATTER YIELD OF SUBTERRANEAN CLOVER

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	0.855 NS	0.319 NS	0.087 NS	9.570 *	10.562 *
Treading Treatment (T)	2.303 NS	9.210 ***	12.724 ***	12.690 ***	14.712 ***
Intensity (I)	0.753 NS	6.272 *	20.294 ***	22.346 ***	23.582 ***
Frequency (F)	0.071 NS	7.041 *	19.414 **	20.524 **	22.881 ***
Intensity X Frequency	1.504 NS	0.898 NS	21.274 ***	21.393 ***	15.308 **
Sowing Density (D)	10.613 ***	14.978 ***	29.884 ***	27.262 ***	24.952 ***
Density X Treading Treatment	0.787 NS	1.906 NS	2.468 *	5.168 ***	6.154 ***
I X D	1.135 NS	1.833 NS	2.369 NS	6.754 ***	7.356 ***
F X D	1.166 NS	1.923 NS	10.297 ***	4.10 *	9.055 ***
I X F X D	1.061 NS	0.471 NS	6.012 **	6.254 **	6.853 ***
CV (%)	30.0	18.2	14.5	17.2	29.7

* P < 0.05   ** P < 0.01   *** P < 0.005   NS, not significant.

APPENDIX II(b). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR DRY MATTER YIELD OF ANNUAL RYEGRASS

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	1.651 NS	2.399 NS	0.433 NS	11.38 *	10.486 *
Treading Treatment (T)	2.366 NS	2.683 NS	12.304 ***	10.426 ***	12.634 ***
Intensity (I)	1.372 NS	1.581 NS	8.088 *	20.272 ***	19.302 ***
Frequency (F)	1.827 NS	1.331 NS	1.383 NS	16.292 **	16.576 **
Intensity X Frequency	2.819 NS	0.640 NS	1.305 NS	14.076 **	17.791 **
Sowing Density (D)	13.648 ***	3.492 NS	0.357 NS	9.612 ***	8.346 ***
Density X Treading Treatment	0.643 NS	0.137 NS	0.005 NS	5.882 **	8.577 ***
I X D	1.431 NS	0.063 NS	0.004 NS	7.807 ***	6.722 ***
F X D	0.207 NS	0.153 NS	0.001 NS	9.321 ***	9.486 ***
I X F X D	1.144 NS	0.063 NS	0.004 NS	7.171 ***	6.767 ***
CV (%)	22.2	29.6	16.7	18.5	17.5

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant.

APPENDIX II (c). EXPERIMENT 1 - VARIANCE RATIO AND THE LEVEL OF SIGNIFICANCE FOR TOTAL DRY MATTER YIELD

Treatments	Recovery Harvest Dates 1971				
	12/8	7/9	5/10	3/11	23/11
Block	0.04 NS	1.765 NS	3.160 NS	0.989 NS	0.022 NS
Treading Treatment (T)	10.784 ***	11.658 ***	17.012 ***	15.299 ***	17.221 ***
Intensity (I)	19.068 ***	19.519 ***	20.120 ***	19.048 ***	18.677 ***
Frequency (F)	0.062 NS	1.866 NS	0.020 NS	26.130 ***	15.347 *
Intensity X Frequency	2.772 NS	1.145 NS	7.928 *	2.233 NS	5.201 NS
Sowing Density (D)	15.886 ***	3.073 NS	1.214 NS	10.894 ***	11.563 ***
Density X Treatment	4.58 ***	0.29 NS	0.95 NS	0.507 NS	0.341 NS
I X D	3.218 NS	0.045 NS	0.012 NS	0.301 NS	0.010 NS
F X D	7.838 **	0.023 NS	0.008 NS	1.079 NS	0.039 NS
I X F X D	6.759 ***	0.015 NS	0.014 NS	0.146 NS	0.019 NS
CV (%)	15.6	16.3	16.9	15.7	23.9

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant.

APPENDIX III(a). EXPERIMENT 2 - VARIANCE RATIOS AND LEVELS OF SIGNIFICANCE FOR PLANT DENSITY DATA FROM RECOVERY HARVESTS

Treatments	Harvest Dates 1971					
	19.10.71		9.11.71		23.11.71	
Block	1.20	NS	1.65	NS	5.62	*
Treatments (T)	12.76	***	18.00	***	12.45	***
Intensity (I)	14.95	***	26.70	***	18.52	***
Frequency (F)	1.27	NS	13.31	***	11.82	***
Defoliation (D)	4.71	*	16.94	***	0.94	NS
I X F	0.69	NS	1.45	NS	2.47	NS
I X D	0.07	NS	1.45	NS	1.23	NS
F X D	0.07	NS	0.04	NS	1.56	NS
I X F X D	0.09	NS	0.49	NS	0.55	NS
Bet. Controls (Con.)	0.04	NS	0.0	NS	0.42	NS
Con. Vs. Tr.	26.94	***	27.62	***	22.52	***
Swards (S)	20.65	***	17.44	***	13.41	***
D X S	2.39	NS	3.60	*	0.92	NS
I X S	2.86	*	3.45	***	5.38	***
F X S	1.29	NS	1.58	NS	1.29	NS
D X I X S	1.37	NS	1.83	NS	2.24	NS
D X F X S	1.90	NS	0.64	NS	1.58	NS
I X F X S	1.16	NS	0.60	NS	2.14	NS
D X I X F X S	0.55	NS	2.04	NS	1.26	NS
Bet. Con. X S	1.52	NS	0.97	NS	0.78	NS
Con. Vs. Tr. X S	5.64	**	5.51	**	9.49	***
CV (%)	18.8		13.6		19.5	

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant

APPENDIX III(b). EXPERIMENT 2 - VARIANCE RATIO AND LEVELS OF SIGNIFICANCE FOR DRY MATTER YIELD. DATA FROM RECOVERY HARVESTS

Treatments	Harvest Dates 1971 19.10.71		19.11.71		23.11.71		14.12.71	
Block	0.95	NS	2.75	NS	2.30	NS	0.03	NS
Treatments (T)	9.14	***	10.09	***	6.47	***	7.15	***
Intensity (I)	13.17	***	10.99	***	13.71	***	16.25	***
Frequency (F)	6.61	*	0.17	NS	11.02	***	3.90	NS
Defoliation (D)	16.62	***	15.16	***	12.98	***	12.70	***
I X F	4.17	NS	0.19	NS	4.29	NS	1.78	NS
I X D	10.17	***	0.85	NS	7.76	*	1.03	NS
F X D	10.29	***	0.93	NS	0.25	NS	1.36	NS
I X F X D	0.15	NS	0.14	NS	1.59	NS	0.06	NS
Bet. Controls	16.47	***	18.73	***	14.90	***	17.10	***
Con. Vs. Tr.	29.58	***	29.62	***	31.71	***	18.08	***
Swards (S)	6.21	***	5.68	**	5.82	***	6.89	***
D X S	6.33	**	4.27	**	9.37	**	15.69	***
I X S	2.00	NS	0.82	NS	6.21	**	8.92	**
F X S	0.51	NS	0.71	NS	0.64	NS	1.08	NS
D X I X S	0.59	NS	1.76	NS	1.41	NS	1.26	NS
D X F X S	1.81	NS	1.10	NS	0.83	NS	0.49	NS
I X F X S	5.13	***	0.41	NS	1.96	NS	0.81	NS
D X I X F X S	0.22	NS	1.21	NS	1.03	NS	0.77	NS
Bet. Con. X S	2.25	NS	0.11	NS	3.55	*	3.38	*
Con. Vs. Tr. X S	6.47	***	2.08	NS	2.0	NS	6.10	***
CV (%)	18.7		15.8		11.1		18.8	

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.005$ NS, not significant

APPENDIX IV(a). EXPERIMENT 2 - RESIDUAL EFFECTS OF TREADING TREATMENTS ON PLANT DENSITY (Dates sampled 19.10.71. Data in plants/m^2.)

Treatments	Swards					
	Sub. clover	A.R.G.	Mixture	Cluster	P.R.G.	Mean
A	3039	4614	3339	5702	6453	4629
B	2514	4915	4202	5477	6303	4682
C	2101	2514	2926	4427	4840	3361
D	1313	3264	2701	3451	4352	3016
E	900	1201	1651	2476	3602	1966
F	600	1238	1163	1613	3526	1628
G	1651	2213	2889	3414	4877	3009
H	1238	2664	2476	4052	3677	2821
I	713	1613	2026	2138	3151	1928
J	600	1501	1688	1613	2514	1583
Mean	1467	2574	2506	3436	4329	2862

	Treatments	Sward	Treatment X Sward
LSD (5%)	588	309	874
CV (%)	18.8		

APPENDIX IV(b). EXPERIMENT 2 - RESIDUAL EFFECTS OF TREADING TREATMENTS ON PASTURE GROWTH (Date sampled 19.10.71. Data in g/m^2)

Treatments	Swards					
	Sub. clover	A.R.G.	Mixture	Cluster	P.R.G.	Mean
A	1041	1033	761	776	703	863
B	499	553	437	393	419	460
C	537	601	515	497	542	539
D	375	437	272	273	280	328
E	457	327	563	293	511	430
F	370	376	356	196	313	322
G	639	801	796	445	725	681
H	360	279	271	297	297	301
I	455	587	605	295	617	512
J	285	251	247	263	224	254
Mean	502	525	482	373	463	469

	Treatments	Sward	Treatment X Sward
LSD (5%)	53	51	143
CV (%)		18.7	