SIX HOOF FEATURES OF DAIRY CATTLE

THEIR DEFINITION AND MEASUREMENT IN RELATION TO TRAMPLING OF SOILS AND PASTURES

by

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INTRODUCTION.

Trampling of pastures is an inevitable accompaniment of normal grazing, and although the ecological approach to grassland problems has succeeded in unravelling many of the problems of grazed pasture, the exact role of trampling has by no means been fully elucidated. Present scientific thought in respect to this problem was well summarized by Melville (1954):-

> The grazing animal has an effect other than as a manurial and defoliative agent. Pasture plants are continuously being trodden by animals ranging in weight from a few pounds to over half a ton, with loadings up to many pounds per square inch of hoof surface. The effect on plant growth and on soil consolidation is never negligible; on certain soil types and at certain seasons it is the major limiting factor in carrying capacity.

The work reported in this thesis deals with a small facet of this total problem, a facet which is claimed to be the initiating point in the chain of reactions involved in the effects of treading on soils and plants. The aim was to define and measure the important animal determinants of these effects.

The problem of definition was approached in two stages. Firstly, the literature was reviewed to determine the consideration given to treading in recent management practices, and more important, to determine the known role of trampling in the ecology of the animal pasture complex. In addition, a priori information regarding the physical effects on the soil of trampling, or analagous sources of stress was examined.

Secondly, from the foregoing study a model of the forces involved in hoof action (the mechanics of the support by the soil of a hoof bearing a superimposed load) was set up. The factors involved in trampling which were likely to be of importance either in hoof action, or in their effects on soils and pastures, or both, could then be defined for measurement. Techniques of measurement were then developed. This portion of the study is reported in Part I.

Part II deals with a preliminary investigation in which three hoof factors were measured for a sample of forty animals. This was designed to enable the repeatability of the measurement tedhniques to be determined.

The knowledge of the probable outcome, and other findings from Part II were used in planning Part III. In this main investigation, six hoof features for five Jersey animals, comprising five age classes, were measured. In the analysis of the results differences between classes and sub classes were examined. Where possible, the aim was to precisely evaluate differences, then to effect a summary of the results obtained, by pooling similar classes or sub classes and calculating combined estimates.

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PART I

I. REVIEW OF LITERATURE.

II. DEFINITIONS AND PROBLEMS IN HOOF FACTOR MEASUREMENT.

III. THE DEVELOPMENT OF TECHNIQUES OF HOOF MEASUREMENT.

CHAPTER I

REVIEW OF LITERATURE

A. THE IMPORTANCE OF THE TRAMPLING FACTOR IN THE DEVELOPMENT OF RECENT HUSBANDRY PRACTICES

Two management practices each of which claim to reduce the effect of trampling on pastures, have recently secured the attention of animal husbandry workers. In New Zealand, the use of a "Winter"stock holding paddock has been the subject of trial at Massey Agricultural College. In America, the relative merits of "Soilage" or chopped green forage, fed in troughs, and normal pasturing of stock, have been investigated at several of the main research centres.

1. The "Winter" Holding Paddock

At Massey Agricultural College, a "Winter" holding paddock was employed, in a "Production Per Acre Trial" designed to achieve maximum production of dairy produce per acre. (Riddet 1954).

In the 1954-55 season the "Winter" paddock was used for lengthy periods during late summer, autumn and winter, as a holding pen for the 33 cow Jersey herd, plus the 20 per cent replacement stock. Between January and August a total of over 4000 animal days was spent on the 4½ acre "Winter" paddock.

Animals were fed chopped summer forage crop, hay and silage, on the paddock; and pastured off for approximately three hours per day, on autumn saved pasture or on other pasture if such was available.

Grazing on the remainder of the 31.4 acre experimental area could thus be controlled, by the best known methods, to maximize pasture growth. It was also claimed that "poaching" on this remaining area was reduced and resulted in greater herbage production and improved utilization.

The implication that trampling, and/or "poaching", reduced pasture production, was borne out by the appearance of the "Winter" paddock where, due to the combined effects of overgrazing and treading, little herbage was visible by the early spring (Nalson 1956). Figure (1) shows the animals on a half acre portion of the paddock, which was used as the holding area for 10 weeks of the autumn and winter, and was consequently more heavily trampled than the remainder. Little pasture remained. Soil changes observed are recorded later (page 24).

The "Winter" paddock was ploughed in the spring and sown to summer forage crop, then recultivated and sown to normal pasture. Although some difficulty was found in preparing a seed bed on heavily trampled zones, no permanent ill-effects were noted. By fitting the use of the "Winter" paddock into the management practice of pasture renewal every 10 years, the effects of trampling were concentrated in one area, where they were then corrected by the normal

Figure (1). The Massey Agricultural College "Winter" paddock.

Figure (3). Single footprint in the "Winter" paddock.

cultivation programme.

The success claimed for this system poses two questions. Firstly, does trampling or "poaching" cause a reduction in production, sufficient to justify the use of a "winter" paddock? Secondly, does the ill treatment of the "winter" paddock actually result in no loss of fertility or production? Each of these questions suggests that a close examination of the trampling factor has now become necessary.

2. "Soilage" or Chopped Green Forage Feeding Systems

Chopped green forage,(termed "soilage" in the United States) cut with a forage harvester, has been fed to penned animals, often in dry lot, with varying degrees of success. When this system was applied to pasture, the animal effects of trampling, fouling by dung and urine, and selectivity of grazing, were eliminated. These were replaced by mowing - defoliation and by rolling by implement wheels. The return of dung and urine is not mentioned in any of the literature cited. If losses of plant nutrients, especially of urine, are high, then this may be a serious criticism of the workers' methods, and possibly of the system itself. Information on this point should at least accompany reports of experimental work.

Research designed to compare the efficiency of soilage feeding systems and normal pasture management, is in progress at several centres in America. Beeson and Perry

(1953) report such an experiment with beef cattle. No conclusions could be drawn from their data, due to lack of information regarding actual areas clipped and grazed, and the type of "rotational" grazing employed.

At the University of California, Ittner et al. (1954), in a similar experiment on irrigated barley-alfalfa and alfalfa pastures, claimed highly significant increases in beef production per acre to result from feeding fresh soilage, compared with 8 to 10 days per paddock "rotational" grazing. The increased efficiency under more intensive management was attributed to a reduction in the wastage of forage produced, due in turn to a reduction in trampling, fouling by excreta, and selectivity of grazing.

Similar results were obtained at Iowa State College (Scholl et al. (1955), Hale et al. (1955)) with beef cattle on brome alfalfa pastures. Drought and grasshopper damage to pastures interfered with this work, and meal feeding was used to supplement pasture and soilage. The results, though not supported by statistical analysis, show the same trends as in the Californian experiment.

Conflicting results in different seasons, obtained at the University of Minnesota (Gullickson (1954 and 1955)), were explained by the observation that the soilage system showed to best advantage on "tall" crops. On "short" crops little advantage was gained by using the harvest feed system. If the alfalfa, and alfalfa-brome pastures used in the other experiments were harvested and grazed at relatively tall growth stages, this could help to explain the success of the soilage system claimed by other workers. According to Gullickson trampling and fouling losses were greater with "tall" crops.

This explanation served to emphasise the importance of the analytical approach to problems of this nature. All the work mentioned above compared the gross effects of two systems of management, thus making the results of limited use when applied to other conditions. The actual factors responsible for the differences observed were neither separated nor evaluated. Trampling was frequently mentioned as being of importance, but the considerable effort expended in this research did little to measure its importance.

The advocates of the "winter" paddock in New Zealand and of the soilage feeding system in America, each claimed to have reduced trampling losses. There is a need, therefore, for factual information on the fundamental nature of trampling and its effect on soil and pasture. Such information is only likely to be obtained by an approach which considers trampling in its proper place, as part of the animal - pasture complex.

B. TRAMPLING IN RELATION TO THE ANIMAL-SOIL-PASTURE COMPLEX

1. Introduction

The ecological approach to grassland problems is based on the work of early ecologists, represented in New Zealand by L. Cockayne (L. Cockayne (1918)). In England, Stapledon led in the application of ecological principles to problems of grassland farming (Trumble (1952)). The ecological method of approach takes into account the whole complex of environmental factors which govern the nature, distribution, behaviour and performance of particular plants and animals and associations of either or both. This approach has proved to be a fundamental prerequisite to the unravelling of grassland problems.

The goal of all grassland workers has been described by McMeekan (1953) as being the "continued maximum production of human food from the grasslands of the world". To achieve this, management of animals and pastures should aim to provide, within the relatively rigid framework of climate and topography, a year round balance between animal requirements and herbage production. Another part of this problem, namely, the short term effects on the utilization of pasture herbage has been reviewed by McArthur (1949). Workers generally considered the animal factors of defoliation (including selectivity of grazing as a cause of clumping), excretion and trampling to be factors affecting wastage of pasture grown. However, McArthur states:-

> No figures are available either to indicate the wastage of feed that occurs on pasture grazed by dairy cows in New Zealand or to show the relative importance of clumping or treading losses.

2. Long Term Effects of the Animal on Pasture

For the purposes of this review the Long Term Effects of the animal on pasture will be considered under the headings of Defoliation, Excretion and Trampling, a division similar to that used by Donald (1946).

(a) Defoliation

The effects of artificial defoliation on pasture yield and chemical composition of herbage were studied by Woodman and colleagues at Cambridge (Woodman and Norman (1932)). Other early work was reviewed by Donald (1946), Edmond (1949) and more recently by Schwass (1955). The bulk of the evidence reviewed showed that frequent cutting, severe cutting, or a combination of both, will lead to decreased yields; whereas light infrequent cutting was accompanied by higher yields of herbage. Associated with reduced yields, was a reduction in the vigour of the root system (Jacques and Edmond (1952), Schwass (1955), Weinmann (1948), Donald (1946)). With increased yields, however, palatability and nutritive value of the herbage decreased. Thus the maximum yield of digestible nutrients appeared to be obtained at a slightly more severe, or more frequent cutting intensity, than at the point of maximum yield of dry matter.

Variations in response to defoliation were attributed to species differences and to species interactions with the environment.

A more analytical method of study has been used by Mitchell (1953a, 1953b, 1954a, 1954b, 1955a, 1955b, 1956). The effects on growth of nine common species of New Zealand pasture plants at different levels of light and temperature, in conjunction with defoliation, were examined in controlled climate cabinets. Attempts were made to relate treatment factors to field measurements of microclimatic conditions and tiller densities, in a wide range of pastures.

In these studies the tiller was taken as the basic unit, rather than the plant. Defoliation was shown to affect tiller regeneration, as well as the production of dry matter per tiller. In the responses obtained interactions were shown to exist between species, light intensity and temperature.

It was inferred that grazing, by removing shading foliage and thus altering light intensity at the plant crown was important in the field. Defoliation was further considered to be important in depriving the plant of photosynthetic tissue which is vital to growth as an energy factor and as a possible source of regulating hormones.

The further elucidation of these effects is proceeding.

(b) <u>Excretion</u>

The value of animal excreta was realised from very early times, but the importance of the return of plant nutrients to the sward by the grazing animal, was only fully appreciated with the development of the ecological approach to grassland problems.

Experimental work at Jealott's Hill and Aberystwyth in Britain (Martin Jones (1933), Davies, W. (1937)) foreshadowed the results obtained in New Zealand by Sears and Newbold at Palmerston North (Sears and Newbold (1942)). It was shown that on a high producing, grazed pasture, the return of either urine or dung increased pasture yield. The full return of dung and urine together still further increased yield. There were associated changes in botanical composition.

Despite the stated limitations of the techniques used, as indicated by discrepancies in the balance between mineral nutrients consumed and excreted, the results were indicative of the importance of animal excreta to high pasture production. They were also in agreement with the findings of other workers which were reviewed by Donald (1946). However, a further similar trial (Sears and Thurston (1952)) at Lincoln, Canterbury, failed to show a yield response to the return of excreta, due apparently, to an interaction between botanical composition (which did show a treatment effect) and climate.

More comprehensive trials were conducted at Palmerston North, Lincoln and Gore (Sears (1953), Melville and Sears (1953), Sears and Evans (1953 III), Sears (1953 IV), Sears (1953 V). Sears et al. (1953 VI) examined the influence of red and white clovers, superphosphate, lime, and sheep grazing (including the effect of excreta) on pasture yields, botanical composition, chemical composition of the sward, soil composition, earthworm and grass-grub populations, and on the growth of subsequent forage crops.

The results of these trials were claimed to show "very clear cut growth responses to dung and urine", both under mowing and grazing. These responses were reflected in subsequent forage crop yields. Manifest also were the exceedingly complex interactions between animal, soil (physical and chemical properties) and botanical composition of pasture in affecting yield. These complexities were further exemplified by Doak's work (Doak (1952)) on the chemistry of dung and urine patches, and in the finding of an inhibitor of root growth in urine (Doak (1954)).

Although the findings of Sears et al. quoted above, appear quite conclusive, the difficulties of research in ecological pasture problems are such that deficiencies can be found in the techniques used in pasture yield determination, and even in the artificial nature of the return of dung and urine. The possibility of confounding effects due to trampling was not eliminated. Likewise the note:

> "All mowing and grazing was done when the tallest pasture was at the 4-6 inch stage."
> (Sears (1953 I))

indicates the possibility of a further confounding factor, in that plots having different treatments may have been harvested at different physiological ages. The significance of this, with the evidence available, is difficult to determine. Nevertheless, the evidence appeared to justify Sears' explanations and conclusions (Sears (1953 VII)):-

> Thus it can be concluded that although the grazing animal does not normally add any plant nutrients, it does play the extremely important role of transforming most of the nitrogen fixed in the clover plant, into a form very suitable for the growth of associated grasses. Also, by its action in "filtering" out for its own needs the metabolizable energy constituents with a minimum of the nitrogen and minerals in the herbage, and returning to the pasture the balance of the latter in its dung and urine, the grazing animal conserves soil fertility to an extent depending on the class and condition of the animal. In so far as the rapid turn over of soil nutrients through the animal stimulates growth of high producing species and grazing and treading assist in maintaining them against the poorer species, the animal can be said to build soil fertility.

(c) Trampling

Although defoliation and excretion have been shown to produce profound effects in the pastoral complex, and although trampling is admitted by most authors to be an equally obvious channel of animal action, no reference could be found in which animal trampling was the subject of direct experiment.

Bates (1929-30, 1930-31, 1935) examined the zonation of vegetation along footpaths and experimented with mechanical treatments which were intended to simulate trampling. He found that plant species differed in trampling tolerance.

The same thesis was the basis of Levy's (1940) treatment of the now accepted place of trampling, in the problem of control of hill country regrowth. Conversely, trampling on high producing swards was claimed to be detrimental, in that it encouraged the ingress of spring weeds.

In the work by Sears, already mentioned, although the production from mown and grazed pastures was compared, any trampling effect was obscured by the difference between slow selective grazing and instantaneous and complete mowing defoliation.

Extreme trampling effects often seen in gateways, and noted in the "winter" paddock at Massey Agricultural College (page 2) may produce obvious detrimental effects which are greater in wet conditions. If, as observed, hooves penetrate the soil, root disturbance must occur. Edmond (1949) found evidence, from his own experimental results and the literature, that root pruning tended to restrict yield.

3. Discussion

The three main channels by which the animal was shown to affect pasture herbage production are represented diagrammatically in Figure (2). The cycle is completed through the harvesting, by the animal, of the utilized portion of the herbage. This quantity of nutrient, according to the nutritive level at which the animals are fed (determined in part by management and in part by their requirements), decides the number of animals carried per acre.

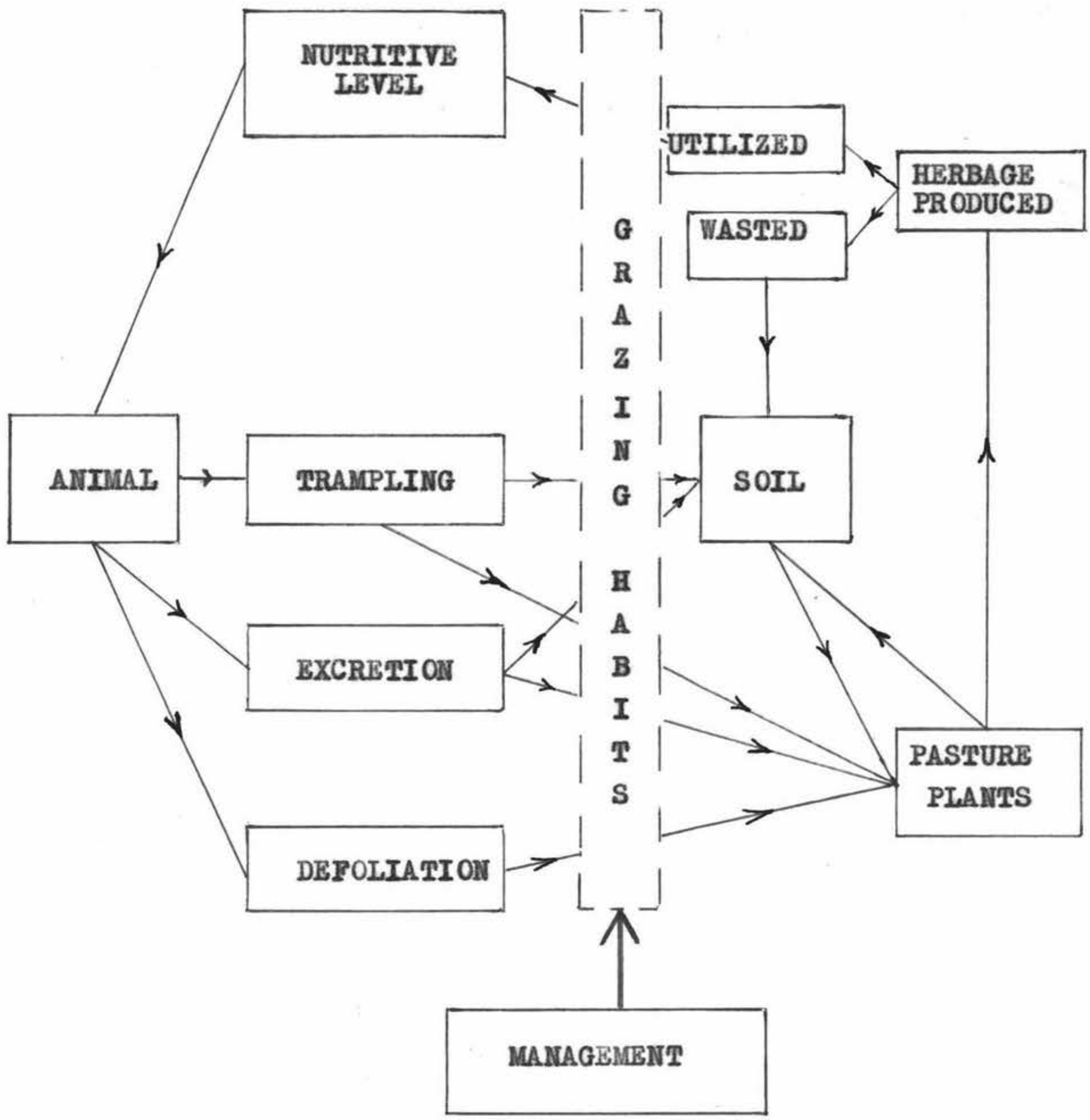


Figure (2). A Diagrammatic representation of the principal channels of action in the animal pasture complex.

Management is shown to operate by modifying the grazing habits of the animals. This, at present, can only act through control of defoliation; excretion and trampling accompany defoliation as inseparable and largely uncontrollable consequences.

It is clear that there is a favourable "correlation" between defoliation and excretion. Optimum defoliation by the animal will, by definition, maximize nutrients utilized per acre. This will increase carrying capacity, and also maximize the excretion of plant nutrients (provided the drain of nutrients removed in animal products does not become a limiting factor). Thus excretion is complementary to optimum defoliation in boosting herbage production. Wastage of herbage produced due to fouling by excreta will presumably become greater at higher stocking rates.

Trampling fits into this picture of spiralling production, as a factor increasing in magnitude as the number of hooves per acre increases. Moreover, its effects have been observed to be greater and in some cases detrimental at high soil moisture levels. This means that trampling will have its greatest effect during the winter, when seasonal pasture production is low, and is itself restricting carrying capacity.

Hancock (1953) found that the grazing times, and presumably therefore the amount of trampling, increased when the quantity of feed available was low, and/or the quality poor.

Thus seasonal winter reduction in the quantity of feed available, by causing alterations in grazing habits, could result in increased trampling, unless counteracted by some device of management such as the use of a winter paddock.

The major role of trampling may be to make more difficult the equating, during winter, of pasture production to animal requirements. This problem described by McMeekan (1953) is mentioned in the introduction to this section (page 6).

Melville (1953) gives a second aspect of trampling in this problem:-

> It is surely significant that more and more research workers and farmers are thinking of winter feeding problems, not in terms of the grass which they can grow, but of the sheer physical capacity of the soil to carry the necessary hooves at moisture levels which are above field capacity.

The physical effects of trampling will be discussed further in Section C of this review.

It may be concluded that the animal factors of defoliation and excretion have been shown to produce profound effects on pasture production. The trampling factor has been shown to affect the botanical composition of pastures. Obvious detrimental effects due to extreme trampling have been observed. However, no evidence could be found to show the effect on pasture production.

In the light of Sections A and B of the review of literature it is postulated that trampling could produce an effect on pasture growth through:-

(a) Short term wastage loss of pasture herbage already produced.

(b) Long term effects on growth due to:-

(i) Crushing of foliage causing defoliation of tillers and leaves.

(ii) Hoof penetration of the soil causing root disturbance.

(iii) Soil physical changes.

Different species of pasture plants may react differently to these effects, and due to an interaction with soil moisture contents, it is further postulated that the effects will be seasonal in nature.

C. SOIL PHYSICAL EFFECTS OF TRAMPLING AND THEIR RELATION TO PLANT GROWTH

Trampling may at all times exert an influence on soil; even under dry conditions surface soil granules may be pulverised into dust and thus cause a deterioration in surface soil structure. At high soil moisture contents the effects of trampling become obvious and produce the condition known as "poaching". Winter "poaching" may be the most important effect of trampling. Before proceeding to review the literature relevant to trampling, the term "poaching" must be defined.

1. Definition of "Poaching"

The Shorter Oxford Dictionary gives the following definition of "poach":-

> Of land: To become sodden, miry and full of holes by being trampled.

Used in this sense poached is synonymous with the colloquial term "puddled" or "pugged". In engineering terminology these last two terms refer to situations where clay materials etc. are worked into a compact or impervious condition.

Bodman and Rubin (1948), in an investigation of soil puddling, defined "puddling" as : "The amount of decrease in apparent specific volume of a confined mass of soil material". This quantity, they used "as a measure of the extent to which the investigated material was puddled by the application of stress".

There is another aspect to puddling, however. Puddling implies a dispersion of the clay colloids in the soil. In a study of the physical characteristics of puddled soil, McGeorge (1937) demonstrated that there were many measurable points of difference between puddling and conventional methods of mechanical dispersion of soils. For instance, when a soil was puddled by working with a spatula, at or near its moisture equivalent, (which coincided with the sticky point), a putty like mass was produced. On dispersion by shaking in water, soil so treated displayed its greatest percentage of suspended solids and its maximum settling volume. If worked with an excess of water, the soil formed a near liquid suspension, indicating dispersion; however, the settling volume and percentage of suspended solids, was considerably less. This indicated a lesser degree of puddling, as measured by the ratio:-

$$\text{" Per cent suspended solids for any soil condition} \over \text{Per cent suspended solids by mechanical dispersion in NaOH solution "}$$

These experiments were, however, not supported by statistical analysis and did not place any emphasis on soil organic matter, which today is considered of great importance in building soil structure. Nevertheless, the manifold effects of puddling were emphasized, and the need for new techniques in determining their magnitude was demonstrated. Also, the importance of the state of flocculation and suspension of the clay and colloidal fractions, in relation to soil structure, was apparent.

McGeorge produced these puddling effects by kneading the soil with a spatula. The stress applied to the soil was one of compression, resulting in sheer failure and soil flow.

Bodman and Rubin (1948) emphasized a second aspect of puddling. They measured puddling as an increased density presumed to be due to a closure of large pore space. Both tangential (sheering) stresses and normal stress were effective. However, they claimed that relative destruction of air filled pores was greater with compression alone.

Thus, compressive stresses might be expected to produce in the main, increases in soil density due to the closure of air filled pores. Similarly, sheering failure could be expected to produce more marked puddling effects, as defined by McGeorge above, and lesser soil density changes.

Thus, in examining the literature, associations between compressive stresses and density increases, sheering failure and puddling effects, would appear to be important.

There is reason, therefore, to divide trampling into two parts:-

(a) An unknown trampling factor which is a measure of any soil changes not associated with visible poaching effects.

(b) A macroscopically visible poaching factor, which is defined as:

> The physical change in soil structure, due to the application of normal and sheering stress to the soil, by the hooves of animals, measured by:
>
> (i) The change in soil volume weight.
> (ii) The change in state of soil colloids.

For present purposes property (ii) "The change in state of soil colloids" will be termed puddling, and McGeorge's (1937) method of measurement of this property, accepted as one way in which its magnitude may be estimated.

2. Soil Physical Changes Attributed to Trampling Poaching or analogous causes

In the past, trampling by animals has been used to compact earth structures. Middlebrooks (1943) noted that droves of sheep were marched across earth dams, as the embankment was placed, to provide the necessary compaction. Thus it might be expected that the grazing animal would cause soil compaction. Only circumstantial evidence for this could be found in the literature.

The most direct evidence was found in a review of German and Austrian work on soil compaction by Brind (1952). Work by Gliemeroth (1948) was reported as showing that:-

> Compaction due to treading by a two-horse team, although serious, was shallower and less intense than that due to the tractor (a wheel tractor), and affected only a quarter of the area affected by the tractor.

Treading (by technicians apparently) was also claimed to increase volume weights.

On the other hand many investigations, reviewed by Fountaine and Payne (1952) establish the analogous case of tractor tyres as a cause of soil compaction, especially at some relatively high "optimum soil moisture content". Compaction was greatest at the surface and diminished with depth, although it was reported to be detectable at 18 and 20 inches in two instances.

From their own work, Fountaine and Payne concluded that volume weight changes were insensitive in detecting soil "damage" and noted the existence of surface puddling as a separate phenomenon.

At certain densities, very small changes in density produced extremely large changes in air permeability according to Buess (1950), and in water infiltration rate (Doneen and Henderson (1953), Parker and Jenny (1945)). The presence of puddling could account for this apparent anomaly. Fountaine and Payne concluded, that in future work on tractor damage to soil structure, water and air permeability should be studied.

No corresponding studies of the immediate and direct results of animal trampling on soils,could be found in the literature. However, survey type data of the cumulative effects of the grazing animal on soils reveal conditions directly analogous to tractor tyre compression.

Alderfer and Robinson (1947) reported,in Pennsylvania, a denser layer (as measured by volume weight) at 0-1 inch in soil profiles under grazed Kentucky blue grass - white clover pastures, despite the higher organic matter content of this layer. Low total porosity, non capillary porosity, and high soil density were associated with prolonged grazing; indicating closure of pore space, especially large pore space . The impervious nature of the compact layer was shown by a highly significant correlation ($r = 0.8$) between volume weight and average run off per cent. Run off was measured after clipping vegetation, to equalize the defoliative effects of different grazing intensities. This was not reported by some other workers in this field (Van Doren (1940) and their results are therefore not relevant to the effect of trampling on soil physical properties.

In a further more extensive investigation, Robinson and Alderfer (1952) found soil compaction, as measured by volume weight and pore size distribution to be more intense in the 1-5 inch layer than in the 0-1 inch layer. The authors do not explain the greater depth of this layer as compared with those mentioned in their earlier report. However, the 0-1 inch soil layer appeared to be higher in organic matter in the second investigation. Free et al. (1947) demonstrated that soil samples high in organic matter, were compacted to a lesser degree than those low in organic matter, by a given compactive effort at a given moisture content.

Also at variance with their earlier findings, Robinson and Alderfer (1952) found that:

> Attempts to correlate run off with soil organic matter, volume weight, pore size distribution, slope and productivity rating of the pasture were unsuccessful, yet an examination of the soil indicated that compaction was an important factor affecting infiltration capacity and run off.

The authors also attributed the evidences of soil compaction to the common practice of allowing animals to "tramp through pastures regardless of how wet the soil may be".

Physical properties of soils on adjacent pairs of plots, on grazed and ungrazed farm wood lots in Wisconsin, were compared by Steinbrenner (1951). Volume weights were higher, but organic matter contents were lower under grazing. Special techniques developed to determine air permeability (Wilde and Steinbrenner (1950)) and water permeability (Steinbrenner (1950)) were claimed to show lower air and water permeabilities on grazed areas. Results of a similar study by Chandler (1940) were in general agreement with these findings. However, the validity of comparing absolute soil properties, even on adjacent areas, which have been subjected to different treatment for years, must be questioned. Many factors, such as outright profile truncation by erosion, or simple vegetative cover differences, could account for the effects attributed to trampling. Thus, in this and in all the survey type data discussed above, trampling is not implicated as a causal factor, except by circumstantial evidence, and the accuracy of the workers' subjective observations.

This criticism applies in a lesser degree to a study reported by Johnson (1952), of soil changes due to eight years grazing on a wooded water shed, in the Southern Appalachian Mountains.

Physical changes in the soil were observed to be more intense where cattle tended to congregate. A comparison of fenced and unfenced plots showed a compacted layer to develop, under visibly trampled areas, in the 2-4 inch layer even under litter. Frost heave was believed to loosen the 0-2 inch layer. Again, compaction was accompanied by a marked decrease in total pore space and a very marked decrease in water permeability. No significant changes were observed on soils in areas seldom visited by animals.

In view of the confusion between trampling and grazing effects in survey type studies, an attempt by Packer (1953) to isolate the effect of trampling on range land run off, is of interest. Artificial trampling was shown to increase runoff aboveasafelevel on certain cover classes of range.

Effects, however, were attributed to disturbance of vegetation, and not to physical changes in the soil. Trampling treatments were applied by means of a manually operated "iron hoof". This consisted of a circular piece of steel, one inch thick and 0.20 square feet in area, to the lower circumference of which iron lugs were welded, to represent "the sharp edge of the hoof". The "hoof" was welded to a steel pipe four feet in length. The assembly weighed 50 pounds and when dropped from a height of 4 feet, was calculated to exert a force of 200 foot pounds on the ground surface (Packer (1955)).

Most of this American work is concerned with soil factors affecting summer run off and erosion, and thus soil moisture contents and pasture production during the drier months.

No published reports of New Zealand work on the effects of animal trampling could be found. However, observations on two heavily trampled areas were obtained by private communication.

On the Massey Agricultural College "Winter" paddock mentioned earlier, observations (Nalson (1956)) during the 1954-55 season throw some light on the development and nature of the poached soil condition.

The area, situated on a Manawatu silt loam soil, was heavily grazed during summer use, but no macroscopic trampling effects were visible, except around feed troughs. Early autumn rains merely accentuated these effects.

As the soil moisture contents rose in the early winter, macroscopic trampling effects were observed and foot prints were visible as in Figure (3). Hooves penetrated the surface soil to a depth of one to three inches and most sod disappeared. In hollows water lodged and there the top-soil was worked into a slurry from one to three or four inches deep, and in areas of heavy trampling, even deeper. Such a poached soil condition is shown in Figures (1) and (4).

When ploughed in the spring, (Figure (4)) the profile showed three zones or horizons extending with almost unbroken continuity over the whole field. These zones were:-

(a) <u>A zone of soil disturbance</u> corresponding to the surface kneaded layer which varied in depth from one to four inches, according to the intensity of trampling. It was structureless, darkcoloured and moist or wet in deeper areas. It tended to merge into the underlying layer.

Figure (4) The Massey Agricultural College "Winter" Paddock at the spring ploughing. Only the deeper parts of the gleyed layer, bluish and glazed, are visible (right foreground). The light brown granular layer is visible in the remainder of the upturned sod.

(b) A "gleyed" layer underlying the disturbed zone, two to three inches thick, bluish, dark, and water logged. This layer was glazed by the plough and showed no structure. The bluish colour changed to brown on exposure to the air, and was described as resembling a plough pan.
(c) A light brown granular layer extending beneath plough depth to the clay subsoil. This layer was crumbly and obviously drier than the overlying layers.

On a Manawatu silt loam, Edmond (1956) determined soil volume weights and soil moisture content in a winter sheep holding paddock. This paddock was part of the experimental plots of the Department of Scientific and Industrial Research, Grasslands Division, Palmerston North.

The paddock originally carried a permanent pasture of perennial ryegrass, white clover and red clover. During the late autumn and winter of the 1955-56 season, twelve ewes per acre were held on the 2 acre area for thirteen weeks. The animals were grazed off for approximately three hours per day during daylight. Under this treatment the pasture sod mainly disappeared as in the "Winter" paddock at Massey College. Poaching of the surface was observed.

In the twenty five soil cores collected, a gleyed layer from 0 to 1.4 (± 0.9) cm. deep was visible in sixteen samples. Volume weights and soil moisture contents were determined at three levels:- From the surface to the lower margin of the gleyed layer, from the lower margin of the gleyed layer to 2.5 cm., and from 2.5 to 5.0 cm. This combination of natural and arbitrary sampling margins made the results difficult to interpret. Therefore, the data were divided into three groups, according to depth and presence or absence of the gleyed layer.

Table 1

Mean Volume weight, at three levels, of twenty five soil samples from the winter sheep holding paddock at Palmerston North.

Gleyed Layer depth class	No. of Samples	Mean Depth of Gleyed Layer (cm.)	Mean Volume Weight		
			Gleyed Layer	Gleyed Layer to 2.5 cm.	2.5 cm. to 5.0 cm.
Absent	9	0	-	1.323 ±0.05	1.309 ± 0.11
0.5 cm. to 1.5 cm.	13	1.03 ±0.37	1.315 ±0.17	1.355 ±0.17	1.277 ±0.074
1.5 cm. to 3.8 cm.	3	2.9	1.133	-	1.320

Only by this grouping could the small differences in volume weight shown in Table I be brought out. Observations on the area suggested that the effects, though shallower, were similar to those noted on the Massey Agricultural College "Winter" paddock.

Soil moisture content showed a decrease with depth, consistent with the hypothesis that trampling causes a sealing of the surface soil.

The gleying phenomenon was attributed to the presence of hydrated ferrous phosphate compounds (Vivianite compounds). Their presence was believed to be associated with poor aeration and reducing conditions. On exposure to the air, oxidation to the ferric state is believed to account for the change in colour from bluish to yellow brown. (Fife (1956)). Gleyed zones may be demonstrated under normal grazed pastures on other areas of the Massey College Dairy farm, under wet soil conditions.

The physical effect of sheep folding on a light sandy soil in early winter was studied by Keen and Cashen (1932) at Woburn Experimental Station in England. Using an impact penetrometer, soil compaction was shown to be produced by 880 lamb days and 1760 sheep days per acre.

Although statistics were not applied to the results, the evidence indicated that compression was greatest at a depth of 3-4 cm. and extended to a depth of 10 cm. Effects were not substantially different after one month's rest.

Sieving experiments revealed that compression caused increases in soil crumb size, which was still apparent, though to a lesser degree, even after ploughing. The total effect of sheep folding was believed to be beneficial on this soil type.

Summary of Soil Physical Changes attributed to trampling, poaching or analogous causes

(a) A surface layer of soil disturbance has been noted; in overseas reports due to tractor tyre compression; and in New Zealand, due to heavy trampling, in one case by dairy cattle and in another by sheep. This has been described as a puddled zone. Reports of American Surveys of effects of prolonged grazing on pastures did not mention such a layer.

(b) A compacted soil layer has been reported at, or near, the soil surface, and extending several inches into the soil profile, after either tractor tyre compression or prolonged periods of grazing and trampling by cattle or sheep.

(c) A gleyed layer has been observed on a Manawatu silt loam, subjected to heavy stock concentrations during autumn and winter. This layer appeared to correspond to the compacted layer mentioned above. On a sheep trampled area on the same soil type, the gleyed layer was much shallower and corresponded in position to the disturbed or puddled zone mentioned above.

(d) Low infiltration rates of air and water, high run off, and changes in pore size distribution, according to overseas reports, were associated with soil compaction as measured by volume weight. These effects indicated a sealing of the surface soil attributable to a closure of the large pore space in compacted surface layers.

(e) There was a fundamental difference between the American and New Zealand approach to the problem of trampling. American work centred on the effects of soil physical changes responsible for high rainfall run off, and consequent low summer production due to low soil moisture contents, and erosion damage. New Zealand workers have observed only the direct effects of winter trampling on soil. As postulated in the discussion in Section B (page 14) and implied by the use of the "Winter" paddock, the prime interest in New Zealand was in increasing winter production.

(f) The importance of moisture content of the soil in regulating the degree of soil change, due to a given treatment, was indicated by work on tractor tyre compression. Observations, rather than measurement, indicated that trampling produced a greater effect on soils at high moisture content.

The mechanism of soil compaction and sheer and its relation to soil moisture content will be considered in the next section.

3. The Mechanism of Soil Compaction, Soil Sheer, and the Influence of Soil Moisture Content

(a) Soil compaction

Evidence in part 2 of this section indicated that soil compaction, as measured by volume weight change, and infiltration rates of air and water were accompanied by changes in pore size distribution, indicating macro pore collapse.

The mechanism of this change was investigated by Day and Holmgren (1952). Sieved aggregates of each of a clay loam and a silty clay loam were placed under controlled confined pressure. Microscopic examination of samples at increasing stages of compression, as measured by increased volume weights, showed progressive closure of inter-aggregate spaces, due to plastic deformation of the soil aggregates. Plastic deformation of the soil occurred readily at a moisture content corresponding to the lower plastic limit (Figure (6)).

At lower moisture contents, incomplete closure of inter-aggregate spaces, and reduced compression of the sample, were attributed to increased resistance to sheer failure (deformation) of the aggregates. In this work inter-aggregate spaces were largely air filled.

In saturated soils Krynine (1947) stated, as a basic concept of compression of non-aggregated clay masses, that since soil particles and water are both incompressible, compression could only occur by expulsion of water. Compression is thus delayed, especially in soils of low porosity, due to the time lag as water is squeezed from the mass.

Nichols and Baver (1930) in laboratory tests with five soils under continuous confined compression, found

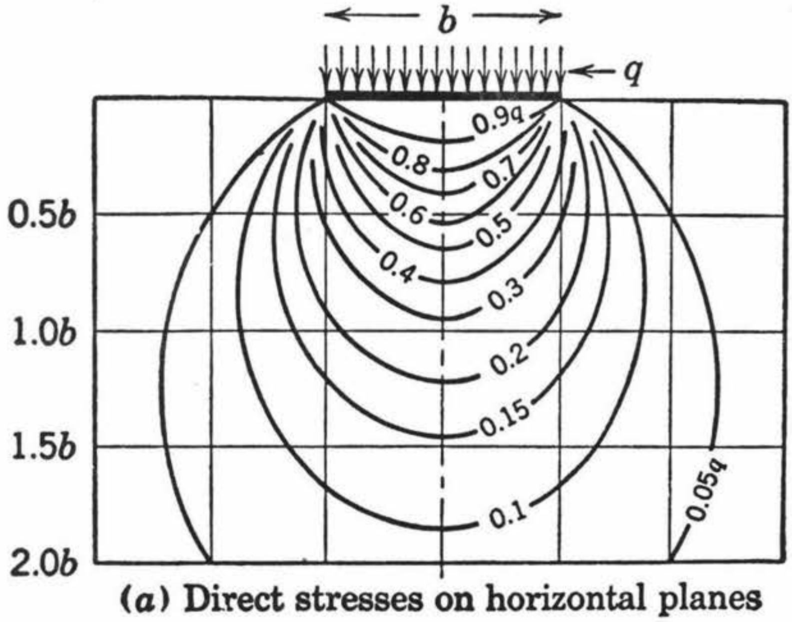


Figure (5). Surfaces of equal stress beneath a loaded circular footing (Taylor (1948)).

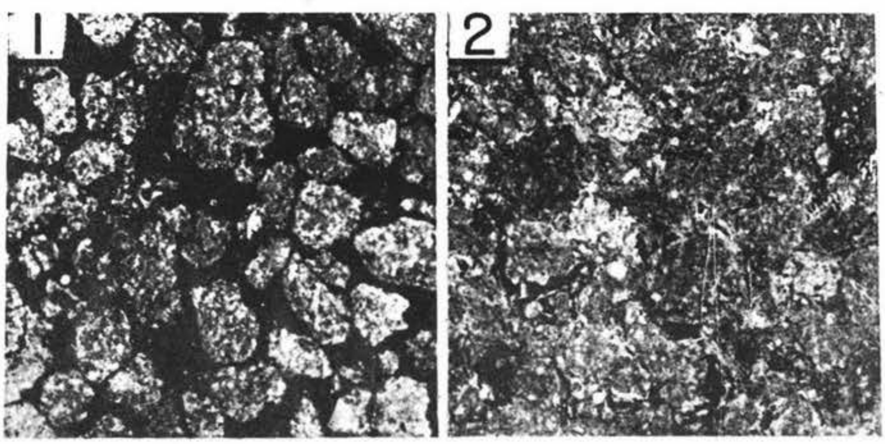


Figure (6). Sieved soil aggregates (1); and (2) after controlled confined compression (Day and Holmgren (1952)).

that the per cent compression achieved was a function of soil moisture content. Soils reached their maximum state of compressibility through the plastic range. At lower moisture contents two soils showed a marked fall off in compression. Data were incomplete for other soils. No statistical treatment was applied to these results. Soils with different plasticity numbers, a factor related to their clay contents, varied in their compressibility.

This draws attention to the fact that all work quoted deals with clay, silt clay loams, or loams, all of which were almost certainly plastic soils.

Fountaine and Payne (1952) found evidence in the literature, for the existence of an optimum soil moisture content for tractor tyre soil compression.

In engineering, an optimum soil moisture content, determined by the "Proctor Compaction Test", at which compaction was greatest for a given compactive effort, has long been an established principle (Taylor (1948) page 533).

The evidence presented above suggests that soil compression, by transitory trampling stresses, will be greatest for plastic soils at an "optimum" soil moisture content. At this optimum point the soil crumbs will have a low sheer strength, and the inter-aggregate spaces will be mainly gas filled. This defines a moisture content similar to the moisture equivalent.

The proportionality of compaction to compacting stress has been demonstrated by several workers. Reviewing the effects of implements on soil, Fountaine and Payne (1952) concluded that compaction was "to a degree" proportional to the load on the roller concerned. Baver (1948 page 325) likewise quoted Nichol's finding that the percentage compaction increased with pressure in connection with soil tillage.

Bodman and Rubin (1948) showed a proportionality existed between the magnitude of the applied stress, whether normal or tangential, and the increase in volume weight of confined soil samples. Using the same apparatus, Day and Holmgren (1952) in their work noted above, confirmed this finding for normal stresses.

Thus, the proportionality between compacting stress and the intensity of compaction produced appears to be well established.

Stress Distribution in the Underground

No data were available demarking the location, if present, of zones of compaction caused by a single hoofprint. Soil mechanical theory provided several methods of predicting zones of stress (Taylor (1948) Krynine (1947)) which might be expected to correspond to zones of compaction. In theory, surfaces of equal stress beneath loaded circular footings were found to form a series of envelopes or bulbs as in Figure (6) (Taylor (1948) page 567). The magnitude of these was specified as a fraction of the unit load (q p.s.i.). In all such theories, stress was predicted to diminish with depth, in a manner similar to the fall off in the intensity of soil compaction caused by tractor tyres and prolonged animal grazing.

In all methods used to estimate stress distribution in the underground, the breadth of the footing determined the depth to which any given fraction of the unit load was transmitted. Thus, the breadth of the hoof, and the unit load on the hoof, might be expected to be determinants of the stress distribution under an animal's hoof, and hence of compacted soil zones.

However, an examination of the basic assumptions involved in the calculation of these stress distribution envelopes, led to the conclusion, that the exact nature of the proportionality of the stress envelopes to breadth and unit load, must be determined by experiment, before the theory could be applied to surface soils in situ.

(b) Soil Sheer

In the foregoing section, laboratory evidence of sheer failure of soil aggregates during compression was presented.

It has also been noted, that in the "Winter" paddock at Massey Agricultural College, the hooves of dairy stock penetrated the surface soil and caused soil displacement. Krynine (1947 page 131) defined the displacement of a mass of soil relative to the remainder as the second aspect of soil sheer. Krynine considered that any such displacement was opposed by the soils sheering resistance, a "passive" stress called forth by, and equal to, the applied or "active" sheering stress. When an increase in the applied stress failed to produce a corresponding increase in the passive stress, soil failure occurred. At this point the sheering resistance reached a maximum value termed the sheering value.

In the special case of a footing, on the surface of an earth mass carrying a superimposed vertical load, the sheer value, defined as the minimum unit load causing failure of the earth mass, was termed the "ultimate bearing capacity".

This theory applies to all cases, and there was no apparent reason why it should not apply to the case of an animal's hoof (the footing) carrying a superimposed load in the form of a portion of the animal's weight.

The soil's sheering resistance and ultimate bearing capacity

The sheering value of a soil may also be termed its sheer strength, sheering strength, ultimate sheering resistance, or yield value.

The sheer strength of some top soils in situ has been determined by Payne and Fountaine (1952). From their results they calculated values for the two soil parameters c and ϕ, in the usual equation for sheer strength, developed by Coulomb in the 18th Century.

$$s = c + P \tan \phi$$

where s = sheer strength
c = apparent cohesion
P = Total pressure normal to sheer plane

ϕ = Angle of sheering resistance

The parameters c and ϕ are constant only for a given soil, under given conditions of moisture content, pretreatment and numerous other factors. No value of c or ϕ obtained by Payne and Fountaine, on ten soils, ranging from sands to clays, was small enough to indicate that either term could be neglected in Coulomb's equation.

Taylor (1948 page 577) showed mathematically that for an actual footing the ultimate bearing capacity of that footing was proportional to both c and ϕ, and also to the breadth of the footing. Only when $\phi \approx 0$ could breadth be ignored, i.e. in a "highly cohesive soil".

Summary of the mechanism of Soil Compaction, Soil Sheer, and the influence of Soil Moisture content on these Properties

(i) Closure of inter-aggregate spaces in soil under confined compression, due to sheer failure of soil aggregates, has been demonstrated experimentally as one mechanism of soil compaction.

(ii) Evidence from many sources showed that an optimum soil moisture content existed for each soil, at which compaction was greatest for a given compactive effect. In theory this should be a value close to the moisture equivalent, at which soil aggregate sheer strength is low and large pores are gas filled.

(iii) Soil compaction has been shown to be proportional to the compacting stress in laboratory and field.

(iv) Theory exists by which stress zones can be predicted in idealized soil masses. The basic assumptions involved, however, make their direct application to surface soils unwarrantable until tested by experiment. Stress distribution was, in theory, determined mainly by breadth of footing and unit load.

(v) The ultimate bearing capacity of the soil, in plastic soils, was shown to be dependent on the breadth of the loaded footing, and on the sheer strength of the soil.

(vi) Sheer strength was shown to be dependent on cohesion (c) and the angle of sheering resistance (ϕ). A method is available for determining these parameters in situ for surface soils. At high moisture contents, the property of sheer strength is replaced by the property of viscosity in plastic soils.

4. The Relation of Soil Physical Changes Induced by Trampling to Plant Growth.

Evidence reviewed earlier in this section indicated that trampling, in certain circumstances, produced a sealing of the surface soil through puddling and/or compaction.

The effect of "soil physical conditions on plant growth" form the subject of a series of monographs edited by Shaw (1952). A sealing and compaction of surface soil layers, could adversely affect plant growth through mechanical impedance of roots, decreased soil aeration, and adverse soil moisture relationships. The importance of these factors to plant growth was emphasized, but the critical levels at which each became a limiting factor were not known. Still less was known of the probable interactions between these factors and other climatic and eudaphic factors. Clearly, channels existed through which trampling could affect pasture growth, but their magnitude was unpredicted.

Experimental work carried out recently by Edmond (1956) investigated the effect of soil physical treatments on the growth of pasture grasses. The Manawatu silt clay loam on which poaching observations were reported earlier was used in all experiments.

In the first study seedlings of perennial ryegrass (Lolium perenne) and short rotation ryegrass, (a New Zealand selection from hybridizations between L. perenne and L. multiflorum) were grown in soils hydraulically compressed in steel pipes. Only the highest level of compression (200 p.s.i.) produced any significant effect on growth, in the form of a reduction in root weight in the 4-8 cm. layer. Top yields were unaffected, but some growth habit changes were observed.

It was also observed that the soil "pumped", due to diurnal temperature changes and slight drying and wetting of the soil, which was believed to cause a reduction in the effects of the compression treatments.

In the second study, seedlings of the same grass species were planted in small field plots, previously subjected to four soil treatments; control, puddled by raking when wet, compacted, and puddled and compacted. Compaction was effected by walking over the plots on short "stilts", designed to give a compressive stress of 50 p.s.i. when all the technician's weight was on one stilt. The diameter of the bearing area was 37 cm.

With both grass species, compaction produced a highly significant increase in yield of dry matter. Puddling significantly decreased yield, and puddling plus compaction was consistent in raising yields over puddling alone, although statistically this comparison was non significant.

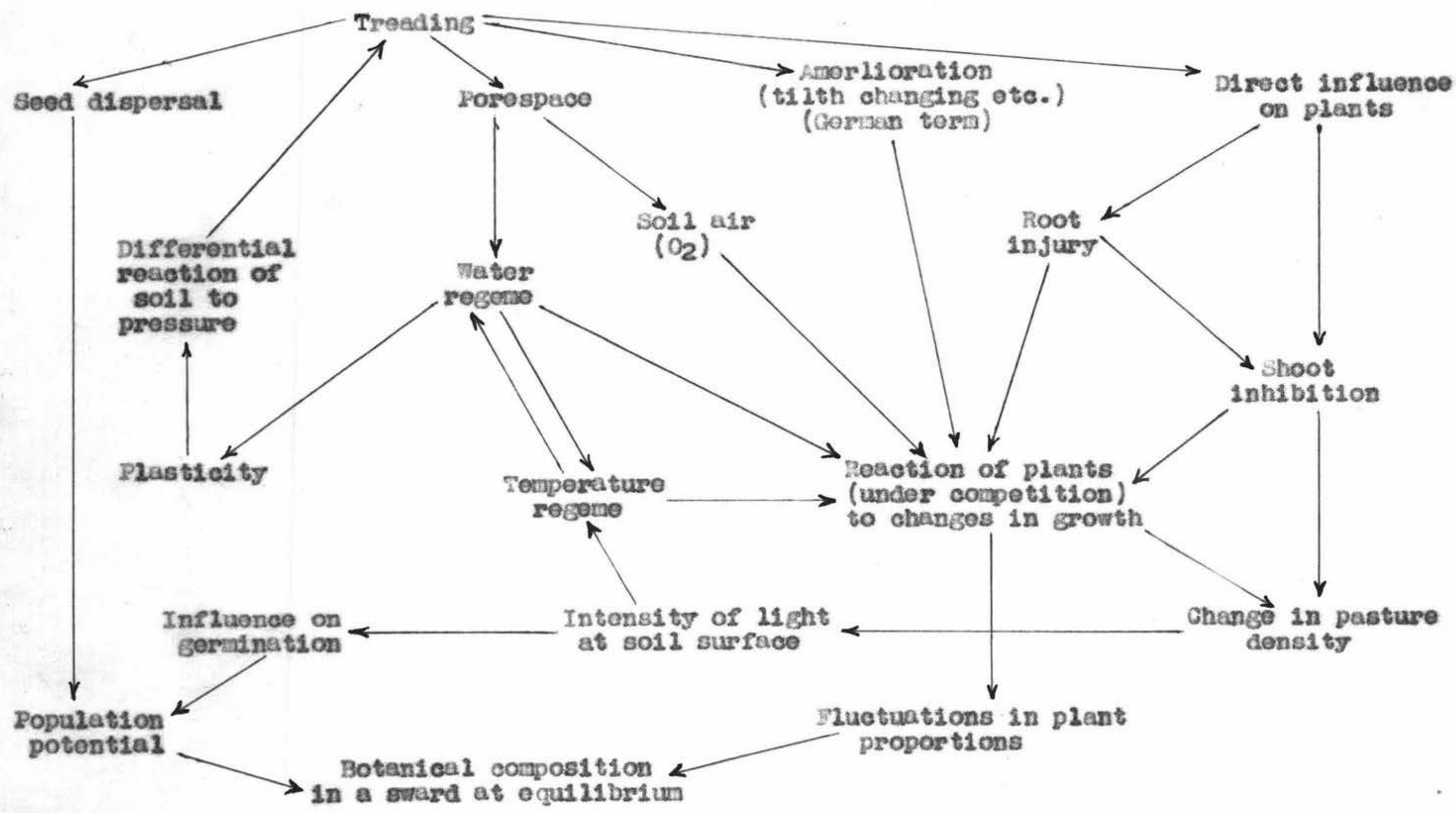
These results served to emphasize the complexity of the effect of trampling on growth, rather than helping to clarify the problem. Soil treatments were applied at very high moisture contents, possibly too high for effective compaction. However, the division of poaching into puddling and compaction, as in the earlier definition, appears to be justified by these results.

In this review of literature, evidence from several sources suggested that trampling caused a reduction in pore space of the soil. Lieth (1954) reached a similar conclusion from a brief review of German literature on the subject. In his own experimental work, Lieth showed a relationship to exist between pore space in the 0-5 cm. layer and the distribution of different grassland plants. It was claimed that statistically significant differences in the distribution of the individual species (apparently skewed distribution curves) were demonstrated, and that these, in turn, were related to the per cent pore space of the various soil types studied. Except for a few species of universal occurrence, these findings agreed with earlier work by Bothmer (1952) who related the occurrence of different species directly to estimated trampling intensities.

Lieth considered that these differences in pasture plant distribution, which were related to pore space, were due to treading by animals. In his discussion he summarized the effects of trampling in the diagram shown in Figure (7).

This diagram summarizes most of the paths through which trampling was, in the earlier part of this review of literature, considered to produce effects in the animal pasture complex. To the effects already mentioned, the effects of treading, in seed dispersal, and of light on seed germination, have been added. The factors are considered to operate on an association of plants in competition, and to determine the ultimate botanical composition of the sward.

The botanical composition of the sward may influence



Figure(7)- A scheme for the treading complex. (Lieth (1954)) pasture production. The work of Edmond (1956), already quoted, showed a direct effect of artificial treading on growth. The effect of trampling on growth, as discussed earlier, was shown to act through a similar pattern, to that considered by Lieth to affect botanical composition.

The effects of trampling are not necessarily always detrimental. Beneficial effects in hill country regrowth control were noted earlier (Levy (1940)). Trampling is likewise recommended for the breaking in of light soils (sands and peats) in need of consolidation, prior to the establishment of permanent pasture.

The next chapter considers the animal factors which determine the magnitude of trampling, and definition of these factors is attempted.