# 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 techniques 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. <u>The "Winter" Holding Paddock</u>

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) Excretion

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.

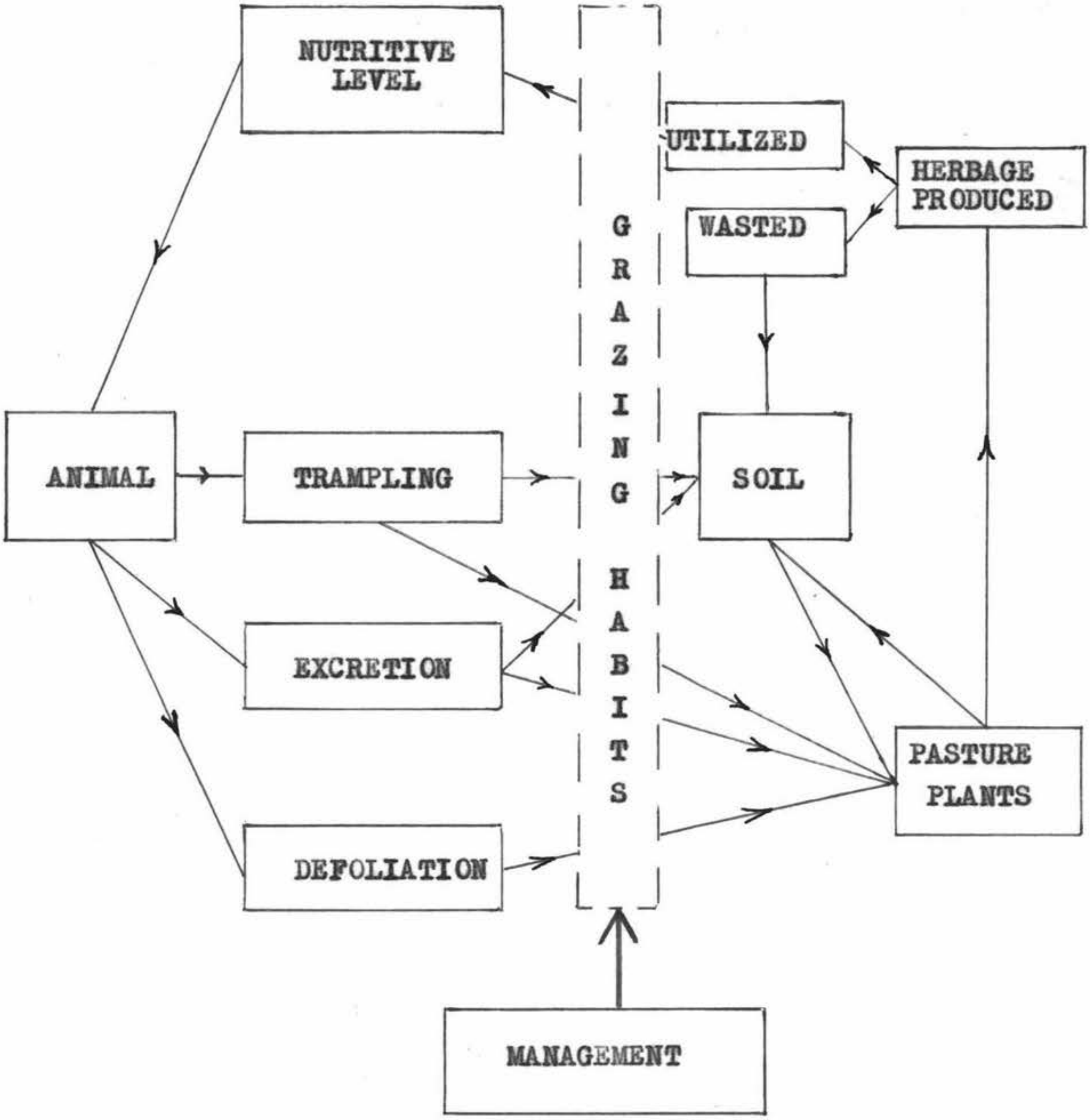



Figure (2). A Diagrammatic representation of the principal channels of action in the animal pasture complex.

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:-

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

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 above a safe level 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 topsoil 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) A zone of soil disturbance 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.

<u>Summary of Soil Physical Changes attributed to trampling, poaching or analogous causes</u>

(a) <u>A surface layer of soil disturbance</u> 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) <u>A compacted soil layer</u> 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) <u>A gleyed layer</u> 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) <u>Low infiltration rates of air and water, high run off, and changes in pore size distribution</u>, 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

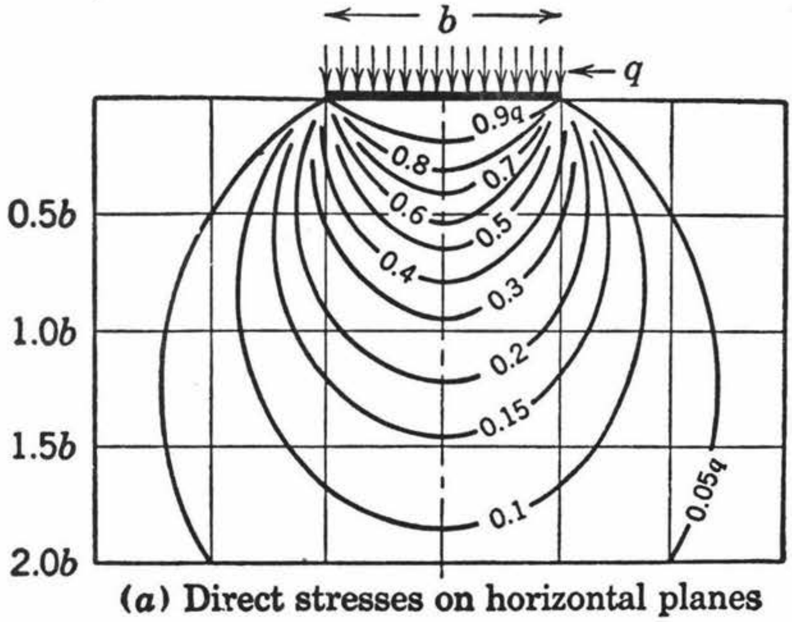



Figure (5). Surfaces of equal stress beneath a loaded circular footing (Taylor (1948)).

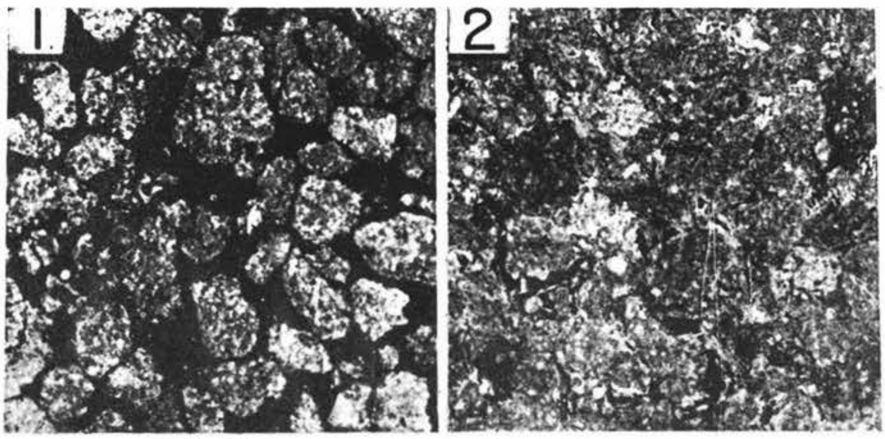



Figure (6). Sieved soil aggregates (1); and (2) after controlled confined compression (Day and Holmgren (1952)).

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 $\phi$, 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

$\phi$ = Angle of sheering resistance

The parameters c and $\phi$ are constant only for a given soil, under given conditions of moisture content, pretreatment and numerous other factors. No value of c or $\phi$ 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 $\phi$, and also to the breadth of the footing. Only when $\phi \simeq 0$ 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 ($\phi$). 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.

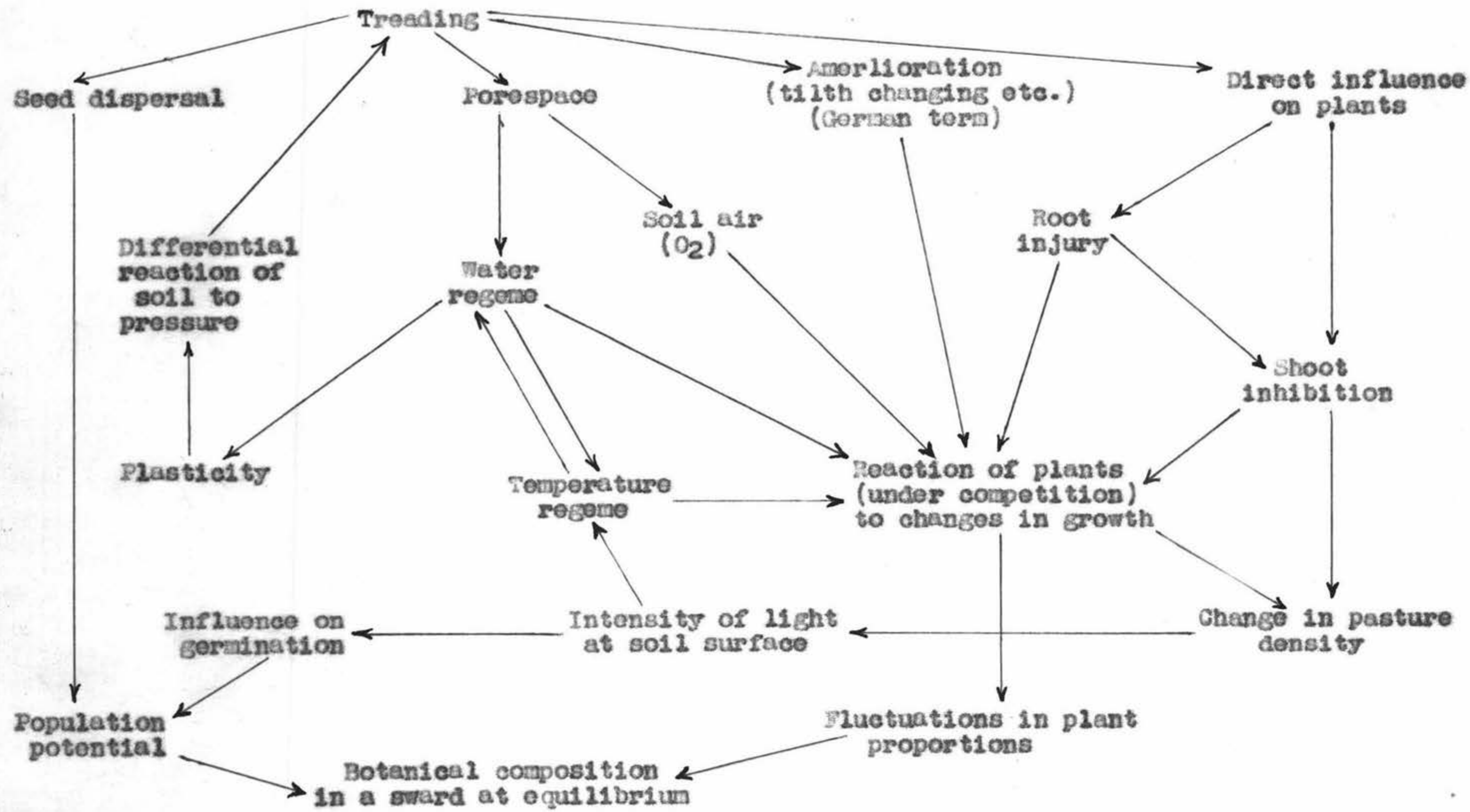
These results served to emphasize the complexity of the effect of trampling on growth, rather than helping to clarify the problem. Soil treatments were applied at very high moisture contents, possibly too high for effective compaction. However, the division of poaching into puddling and compaction, as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

# CHAPTER II

## DEFINITIONS AND PROBLEMS IN HOOF MEASUREMENT.

In order to measure the animal factors which determine the magnitude of trampling, these factors had first to be defined. This definition is attempted in Section A by considering the channels through which trampling could act in relation to the mechanism of hoof action. In Section B the problems to be investigated in measuring these factors are stated.

## A: THE DEFINITION OF ANIMAL FACTORS IMPORTANT IN TRAMPLING

### 1. Factors to be Measured

From the review of literature, trampling was suggested to exert its effects through the following channels.

1. Short term wastage of pasture grown.
2. Long term effects on pasture through:-
   (a) defoliation of tillers and leaves
   (b) root disturbance
   (c) physical changes in the soil

It is postulated in this thesis that the most important, essentially animal, factors controlling these effects are three:

1. The number of hoof prints.
2. The average area of the hooves.
3. The unit load carried by these hooves.

Thus the area affected by trampling will be given by:-

Area affected = f (Number of hoof prints x mean hoof area)

(Where f = "some function of" and its purpose in the equation is to allow for overlapping of hoof prints and any difference between hoof area and hoof print area.)

In each of the above mentioned channels of hoof action, wastage, defoliation, root disturbance and physical changes in the soil, it is postulated that the greater the area affected by trampling the greater will be the effect on pasture or soil.

In this equation the hoof print is taken as the unit of trampling. The magnitude of this unit is supposed to be determined in part by the area of the hoof that made the print.

It is further postulated, however, that to specify fully the magnitude of a hoof print, a measure of the intensity of the effect of the print must be added to the equation above. Thus the magnitude of any trampling treatment (T) is given by:-

T = f (Number of hoof prints x mean hoof area x intensity of hoof print)

The intensity of the hoof print is regarded as being a function of a postulated interaction of the unit load on the hoof, and the physical condition of the soil, when the print was made. Upon penetration of the surface of the soil this relationship would be expected to change and there would be a marked increase in all channels of hoof action.

The determination of the unit load upon a hoof during trampling demands the full solution of the constantly changing equilibrium of forces and vectors involved in the action of an animal walking. The data required for such a solution, as far as can be ascertained, has yet to be collected.

As a first step towards the solution of this problem it was decided to deal only with the static case of a cow standing in a standardized "static position". Measurements obtained could be used for comparisons between animals and classes, but not for absolute values.

The number of footsteps was considered to be a partly managemental, rather than an essentially animal factor. The determination of number of hoof prints was thus a different type of study and was not included in this thesis. Instead measurements were confined to hoof features determining the magnitude of the hoof print, which has already been taken as the unit of trampling.

There are two hoof features therefore to be defined, namely, average area and unit load. In order to define these features a model case will be considered of the forces involved in the supporting of a loaded hoof by the soil (termed "hoof action"). In this particular case attention will be given to those factors which govern penetration of the hoof into the soil, as it is postulated that this will cause an increase in all phases of trampling effects, and especially in root disturbance and physical changes in the soil.

2. The Mechanics of Hoof Action on Soil

The following analysis of hoof action on soil is modelled on Krynine's approach to the "basic problem of soil mechanics" (Krynine (1947), page 91) ). The hoof is regarded as a footing, "A" square inch in area, resting on a horizontal soil surface and carrying a superimposed load of W. lb. (Figure 8(a) ).

Two problems are posed:

(a) Stability

Will the soil under the hoof support the hoof and its superimposed loads, or will it fail in some way and thus allow the hoof to penetrate the soil surface?

(b) Deformation

Whether the soil mentioned in the preceding question fails or not, provided an equilibrium is reached, either before or after failure, what are the conditions of this equilibrium and what are the orders of the deformations of the soil, in the form of compression, and/or sheer failure zones?

(a) Stability Problems

(i) Conditions for Stability. In Figure 8(a) the load W causes the hoof to exert an active stress of P p.s.i. upon the soil, where

$P = \frac{W}{A}$ (P = Unit load on hoof)

This causes the soil immediately beneath the hoof to deform slightly. This deformation, measurable as the strain, calls forth a "passive" or resistive stress of Q p.s.i. The total soil reactive force R lb. is given by

$$R = Q \times A$$

Q increases as the strain increases, provided Hooke's Law holds, until at equilibrium

$$R = W \text{ (but opposite in direction)}$$

and deformation ceases, with negligible hoof penetration.

This then is a condition of stability.

(ii) Conditions for failure. Suppose W to increase to a point at which the proportionality between stress and strain ceases. (Hooke's Law no longer holds). The resistance of the soil to the deforming stress is considered to be exhausted and failure occurs.

At this point the ultimate bearing capacity has been exceeded. Thus if Q' p.s.i. is the ultimate bearing capacity of the soil, the condition for failure is that:

$$P > Q'$$

And the condition for stability is that:

$$P < Q'$$

The value of Q' (ultimate bearing capacity) as discussed in the review of literature is dependent upon the sheer strength of the soil. This, however, is an over simplification, for as noted earlier the ultimate bearing capacity of an actual footing on a soil is also proportional to the breadth of the footing.

Thus the animal factors which affect hoof penetration are the determinants of P and breadth.

Since $P = \frac{W}{A}$ the animal factors are the weight on the hoof, the bearing area, and the breadth of the hoof (and for even greater exactness, the shape of the hoof would ultimately be required).

Termination of Penetration

Penetration of the hoof will continue until $R \geq W$. This condition could arise through an increase in bearing or contact area A, (since $R = Q \times A$), by the dew claws coming into contact with the soil (breadth and load being regarded as constant). Alternatively Q' could increase, through an increase in the sheer strength of the soil, due to physical changes in the soil with increasing depth.

While other explanations for this are possible, it was seen in the review of literature that surface soils are not homogeneous and it need only be assumed that the hoof strikes a deep layer of inherently higher sheer strength, due either to increased density, decreased soil moisture content, or different soil structure. Thus penetration ceases at a depth of d inches.

Area affected by penetration

It is obvious that the area affected by hoof penetration includes the area between the two claws of the hoof as well as the bearing area. This will be termed the enclosed area. $A_e$ square inches. This enclosed area is the area involved in the calculation of area affected by trampling.

(b) Deformation Problems

Two cases of equilibrium have already been shown in Figure (8):- (a) at the surface without sheer failure and (b) at the termination of hoof penetration at a depth d. The distribution of sheer and compression zones for each case will now be considered.

(i) Soil Sheer Zones. By definition no sheer failure occurs in the case of diagram (a). In the second instance sheer has obviously occurred and the volume of soil displaced is given by:

$$A_e \times d \text{ square inches.}$$

This displaced soil must occupy space in the immediate vicinity of the hoof where zones of soil flow are located. These zones can be predicted for idealized masses, but because, as mentioned earlier, surface soils are not homogeneous, such predictions can hardly be justified for surface soils.

(ii) Soil Compression Zones. Zones of soil compression can be predicted for idealized masses, but, as with zones of soil sheer, this theory cannot be applied to surface soils with any guarantee of exactitude. It is possible, however, to predict that stress zones will exist, and that unit load, P, and breadth of the hoof will be the most likely determinants of their dimensions. Compressed zones are likely to correspond to these zones of stress.

The possible location of zones of compaction (-c-) have been sketched in beneath the hoof in Figure (8) (a) and (b) using the stress distribution envelopes of Figure (6) as a model. Whether compaction will occur in any given stress zone will depend on soil factors. In the light of Day and Holmgrens work, cited earlier, if the stress in any zone exceeds the sheer strength of the soil aggregates, compaction would be anticipated to occur due to closure of the large pore spaces.

(c) Effect of concavity of Bearing Area

Sisson (1914) stated that the under surface of the hoof of the ox is slightly concave. Field observations in the Massey Agricultural College dairy herd also suggested that the cross section of the hoof is more accurately represented by Figure (8) (c). Clearly, if no hoof penetration occurs, extremely high pressures will be exerted on the soil due to the small bearing area. Further, there will be gradients in the intensity of the vertical components of the resistive soil forces ($Q_v$) and hence in the applied stresses, due to unequal deformation, or strain, as the hoof penetrates the soil. Krynine (1947) showed that stress distribution depends on the rigidity of the footing, and on the nature of the earth mass.

Thus while the factors of weight and bearing area may be estimated, and the unit load calculated, the actual pressures beneath the hoof may be quite variable, especially in the case of a concave hoof.

The bearing area to be used in calculating average unit load is the vertical projection of those parts of the hoof, as shown in Figure (8) (c) actually in contact with the soil. Further the area (A square inches) in contact with the soil in the case of a concave hoof will be determined by the weight on the hoof, and the mean vertical soil reaction per square inch ($\overline{Q}_v$) given by

$$A = \frac{W}{\overline{Q}_v}$$

The greater the hoof load (W), the greater will be the bearing area (A). Conversely the greater the vertical soil resistive forces ($\overline{Q}_v$) the smaller the bearing area (A). Bearing area (A) is thus only in part an animal factor. If however, A reaches a maximum value at a certain depth of penetration then at this, and at greater depths, A is a fixed animal hoof characteristic. This maximum value of A therefore, appears to be the area to be measured for the calculation of average unit load on the hoof.

In the case of a concave hoof, there will be a horizontal component of the soil reaction which will act outwards on each claw of the hoof, so as to spread the toes apart. Frictional forces and the reaction of the soil surrounding the outer wall of the hoof will tend to oppose this. With the concave hoof, however, the actual enclosed area would be expected to vary under the influence of these horizontal soil forces, and possibly to increase on soil penetration.

(d) Hoof Shape. In discussing the mechanics of hoof action it was assumed that the hoof was composed of two claws or hooflets of the cross section shown in Figure (8). These hooflets were considered to be equal in area and to act as a unit, each bearing an equal share of the hoof load.

As mentioned earlier, breadth is the main hoof shape factor, important in problems of hoof action. The precise determination of relative hoof shape poses a very difficult problem. For present purposes, hoof shape would appear to be sufficiently determined by the measurement of the bearing area of each hooflet and by measurement of breadth and length of the hoof.

In the event of the hooflets of the hoof being unequal in area, the assumption would automatically be made, that the hoof load was distributed to each hooflet in proportion to its respective area. Thus the unit loads on the hooflets within each hoof are considered to be equal.

(e) Summary. The animal factors involved in the trampling unit defined as the footprint may thus be restated:-

1. Enclosed area of hoof (The determinant of the area affected by the hoof print.)

2. Bearing area of hoof }
3. Load on hoof } The animal determinants of depth of penetration and of deformed zones,
4. Breadth of hoof } in problems of hoof action.

5. Shape of bearing area of hoof. (Important for the reasons given above and especially in determining the depth of penetration at which area measurements of an animal, rather than an animal soil nature should be taken).

6. Hoof shape: The determination of the relative bearing area of each hooflet of the hoof is a secondary aspect of bearing area measurement. (Hoof shape may further be defined by length of the hoof, and breadth of the hoof).

These factors are defined, for the purposes of measurement, in the following section.

3. Definition of the Animal Features to be Measured

As preliminary observations indicated that the hoof bearing surface was concave, it was necessary to introduce the concept of hoof contour lines in order to define hoof factors. These are virtually lines demarcating the contact areas of the hoof at different depths of soil penetration.

(a) Hoof Contour Line (or "Contour Line")

A line analogous to a contour line in mapping; it marks the intersection of any horizontal plane with the surface of the hoof, when the hoof is at rest on its normal "Zero Bearing Surfaces" on a horizontal hard surface.

Individual contour lines are specified by their vertical height from the basal horizontal surface.

(b) Hoof Bearing Area (or "Bearing Area")

The area of the vertical projection of any specified contour line, or the outer margin of any lower part of the hoof which projects beyond the margins of the contour line, so as to increase the projected area.

The bearing areas are specified in terms of the specific contour line from which they have been measured. There is a bearing area for each hooflet or hoof claw. The term "bearing area" when applied to a hoof or hooves means the summation of the bearing areas of each claw of the hoof.

(c) Enclosed Hoof Area ("Enclosed Area")

The area of the vertical projection of the hoof bearing surfaces, plus the area of the vertical projection of the space between the hoof bearing surfaces, bounded in front by the straight line joining the two foremost points of the bearing surface of each hooflet (the front terminal line), and at the rear by the straight line joining the two rearmost points of the bearing surface of each hooflet (the rear terminal line).

In the measurement of the enclosed area the position of the toes was either "the toes together position" in which case the toes touched or almost touched or "the toes apart position", in which case the toes were spread as far apart as possible with finger pressure.

(d) Length of Hoof

The length of the straight line joining the mid-points

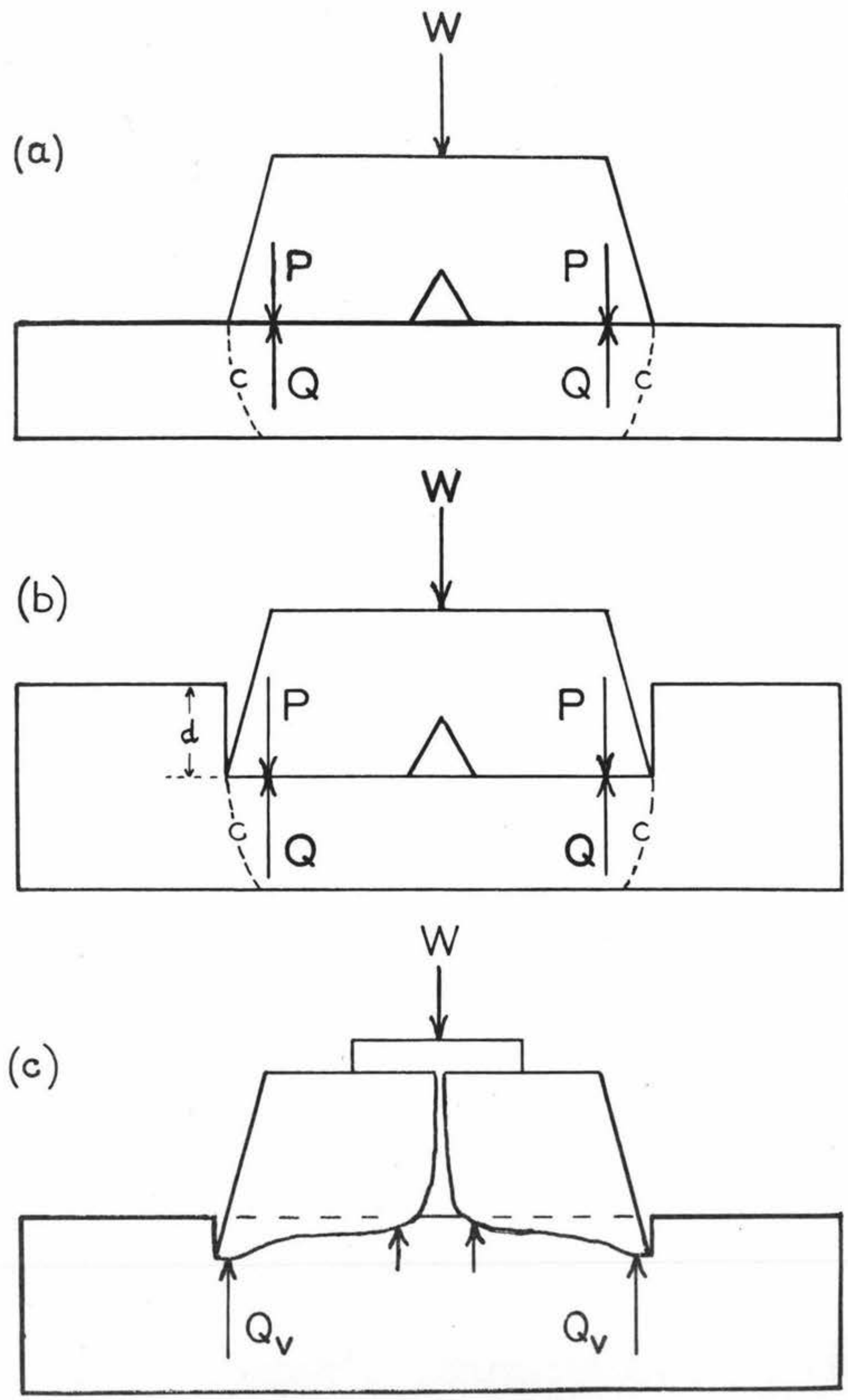



Figure (8). Diagram of hoof action at three equilibriums.

of front and rear terminal lines of a hoof. This straight line is termed the centre line or axis of the hoof, and its mid-point termed the "centre of the hoof".

(e) Breadth of Hoof

The length of the longest straight line, at right angles to the centre line, joining two points in the bearing area of the hoof. This line is termed the "breadth line".

(f) Static Stance

For the purposes of measuring the static weight carried on an animal's hooves, the following definition of a static condition or stance was adopted;-

In the "static stance" the animal should stand motionless on all four feet with its legs approximately vertical, and head held in an idling position so that the back line is relatively horizontal.

## B. PROBLEMS TO BE INVESTIGATED BY HOOF FACTOR MEASUREMENT IN RELATION TO THE GENERAL EXPERIMENTAL LAY OUT

In Section A of this chapter the trampling factors to be measured were reduced to:

1. Bearing Area ) and hence Unit
2. Hoof Load ) Hoof Load
3. Enclosed Area
4. Shape of Bearing Area
5. Breadth

6. Length

7. Relative area of each hooflet of the hoof.

For practical reasons measurements were restricted to animals of Massey Agricultural College Jersey and Friesian herds.

1. Problems to be investigated and classification of animals and hooves

The hypotheses concerning the measurements and the purposes for which the data could be used determined the animals which were selected for measurement.

In formulating hypotheses little helpful information was obtained from the literature. However, after the investigation was in progress, the limited data presented in full in Table II was obtained by private communication from Swett (1955).

Table II

Bearing Surface Area and Weight Supported

per square inch in Dairy Cattle

| No. of Cow | Live Weight | Front Quarters | Rear Quarters | Bearing surface area of feet (Square inch) | | | Weight supported per square inch |
|---|---|---|---|---|---|---|---|
| | | | | Front | Rear | Total | lbs. |
| 220 | 1465 | 820 | 643 | 29.64 | 25.71 | 55.40 | 23.5 |
| 407 | 1187 | 703 | 490 | 29.34 | 25.00 | 54.30 | 21.0 |
| 50 | 1390 | 790 | 627 | 35.32 | 26.82 | 62.20 | 21.4 |
| 3½ Mo. Holstein | 220 | | | 9.06 | 8.02 | 17.10 | 12.6 |

It appears that nature builds the foundation in proportion to the load to be carried.

Report prepared by Mr. A.R. Kelly, Bureau of Public Roads.

This data was collected "several years ago" and no information as to the techniques used or the method of calculating weight supported per square inch was available. This data tended to confirm hypotheses which had already been formulated.

From field observations, it was postulated that Friesians, the larger breed, would have larger hoof factors than Jerseys. It was also postulated that mature animals would have larger hoof factors than immature animals. Animals were therefore classified according to breed and age for two reasons.

Firstly, to evaluate statistically these postulates and so obtain information useful in future experimental work or in animal and pasture management.

Secondly, if class differences were found to exist; by eliminating class differences from the group variance, estimates of sub-group population parameters could be made with greater precision than corresponding estimates for the total population.

Thus, depending on the magnitude of age and breed differences, estimates of sub-class parameters may at the one time be more useful and more precise.

To obtain an indication of the reliability of sampling and to test the appropriate hypotheses, an estimation of the variation of cows within ages within breeds was required. This then provided a further breakdown of the groups to individual animals.

Knowledge of the variation of hoof factors within animals between each of the four possible hoof positions, termed "corners", was also required. If variation within cows between corners was very small, then only one hoof need be measured to obtain a satisfactory estimate of the hoof features of that animal. It was postulated that bilateral symmetry existed between corners within cows. In order to test this hypothesis, corners were classified into "sides" (left or right). It was also postulated that a front-rear difference would be found and corners were therefore further classified into "Ends" (front or rear).

Repeat measurements were required within hooves in order to estimate the repeatability of the measurement techniques employed.

2. General Layout of Experimental Work

The first step in the experimental work was the development of techniques of hoof measurement. For this part of the work, randomly selected mature cows were used and the repeatability of measurements of a single hoof was used as one criterion of the value of the measurement technique under test.

In this and other preliminary work investigations were confined mainly to hoof bearing area measurement. This was justified by the fact that all hoof factors were defined in terms of the bearing area boundaries. In this way a method of producing a replica of the hoof, by means of a hoof cast, and a technique for the measurement of the hoof area of this replica was developed. This is described in Chapter III.

It was necessary to test these techniques over a wide range of hooves. The hoof sampling system employed was made comprehensive enough to obtain preliminary information on all the factors which were postulated to cause variation in hoof measurements, as summarized by:-

1. Breed
2. Age within breed
3. Animals within ages
4. Corners within animals (Sides / Ends)
5. Repeat measurements within corners

Because Jerseys are the dominant breed in New Zealand work centred on this breed. Thus the animals of Group I consisted of thirty Jerseys (ten mature, ten 3-year-olds and ten 2-year-olds) and ten mature Friesians. The measurement of bearing area shape and the measurement of hooflet bearing area was confined to the Jersey animals.

The source of the Group I sample of animals, the method of obtaining the hoof casts and the measurement of these casts form the basis of the three chapters of Part II of this thesis.

It was necessary to specify a standard contour height for measurement of hoof factors. This was done after determining the bearing area at seven different contour levels on a sub sample of the Jersey hoof casts. This gave a measure of bearing area shape and is reported in Chapter IV. Measurement of the hoof bearing areas of the animals of Group I was then possible. The results are reported in Chapter V of this thesis.

In order to obtain an estimate of the relative bearing area of each hooflet of the hoof, hooflet bearing areas were recorded for the Jersey animals of Group I. These results are also presented in Chapter V.

The static hoof load for front and rear hooves of these animals was determined concurrently with hoof moulding. Individual hoof loads were not determined because the necessary equipment was not available. It was considered that differences between sides (unlike end differences) could not be related to any obvious feature of animal shape.

The techniques used and the results of the load determinations are presented in Chapter VI. Calculated unit loads on the front and rear hooves, from the weight and bearing area data, are also presented in the second section of Chapter VI.

The conclusions drawn from Chapters V and VI determined the design of Part III of the thesis in which a full survey of hoof features of Jersey animals from the College herd is described.

# CHAPTER III

## THE DEVELOPMENT OF TECHNIQUES OF HOOF MEASUREMENT

### Introduction

A search of the literature provided little information on techniques of hoof measurement. Scott Blair (1937) mentioned measurement of the contact area of the foot of a man by "observing the wear on a pair of old rubber boots". This worker also quoted work by Ballu (1937) (the original of which was not available), who calculated that:-

> An ordinary farm horse exerts, under its own weight, compressive stresses of the order of 2000-4000 $gm/cm^2$. if the ground is hard enough for the whole weight to be taken by the shoes.

Apparently the area of the shoe was taken as the bearing area of the hoof in this calculation.

As neither of these methods of contact area measurement was applicable to this study, it was clear that new techniques would have to be developed. In this, techniques were required to be as simple as possible and were also required to measure hoof features in terms of their definitions. Finally, under test, techniques were required to be repeatable, and if possible unbiassed.

Work dealt mainly with the development of a technique of bearing area measurement, as this was regarded as the basic hoof feature. The successive steps in the development of satisfactory techniques are given in Sections A to E of this Chapter.

## A. PRELIMINARY TECHNIQUES

Direct measurement of the hoof in the field was found to be impossible, due to the difficulty of controlling the animal. Efforts were made therefore to make a tracing, print or other replica of the hoof, which could be taken to the laboratory for measurement. The following methods of producing an essentially two dimensional replica of the hoof were tested first, because of their simplicity, using several randomly selected mature dairy cows as test animals:

(i) Direct Tracing. In this method the hoof was placed upon a sheet of paper and the outline traced with a pencil.

(ii) Photographic Method. A photograph was taken of the underside of the hoof and the image so obtained was treated as a hoof print.

(iii) Printing techniques. These included inking the hoof and printing direct on to paper, standing the hoof on a sheet of paper overlying an inked pad, and standing the hoof on a rubber diaphragm inked on the underside and stretched over a sheet of paper. In each case different underpads of sponge rubber were used of three thicknesses, $\frac{1}{8}$, $^{3}/16$ or $\frac{1}{4}$ inch.

(iv) Tinfoil impression method. In this method the hoof was placed on a sheet of foil over a sponge rubber pad. The foil retained an impression of the hoof in the form of bruised areas.

In all, over 150 prints of sufficient quality for laboratory study were made by these methods. However, in no case could the contact areas of the hoof be related to any contour line at an imaginary depth of soil penetration. This was because the inner margins and heel of each hooflet were poorly demarked. Thus these techniques did not fulfil the first criterion that features must be measured in terms of the definitions of those features. These techniques were therefore discarded.

It was further concluded that a hoof moulding and casting technique was required to produce a three dimensional replica of the lower hoof, on which hoof features could be delineated by actual contour lines. The development of such a casting-moulding technique is described in the next section.

## B. HOOF MOULDING AND CASTING TECHNIQUE

By this method a replica of the lower hoof surfaces was produced in the form of a plaster of Paris "cast". Two steps were involved in this process which is termed "hoof casting". Firstly, a mould was made of the hoof (hoof moulding). Secondly, the mould was used to make the plaster of Paris replica or "hoof cast" (hoof casting).

1. Hoof Moulding Technique

(a) Materials and Treatment of Materials

The moulding material used consisted of a wax mixture semi-plastic at normal field temperatures, but with sufficient rigidity to retain the impression of a hoof indefinitely. The mixture showed no definite point at which solidification occurred, but a very marked increase in viscosity occurred between 51°C and 47°C. The composition of the mixture was:

| | | |
|---|---|---|
| Paraffin Wax | M.P. 125°-130°C | 33% |
| Petrolatum | | 31% |
| Liquid Paraffin | | 22% |
| Microcrystalline Wax | M.P. 155°-160°C | 14% |

For mould containers 1 inch x 7½ or 8½ inch circular pressed tinned steel dishes were used.

The wax was heated and poured into the containers to form a layer approximately half an inch deep (Figure (9) ). After use the wax was removed from the containers and heated with water. Water and contaminants in the form of grit, dirt and plaster of Paris, sank to the bottom and the clear wax could then be re-used.

(b) Method

In hoof moulding, hooves were first cleaned with water from a high pressure hose. Then, with the animal haltered

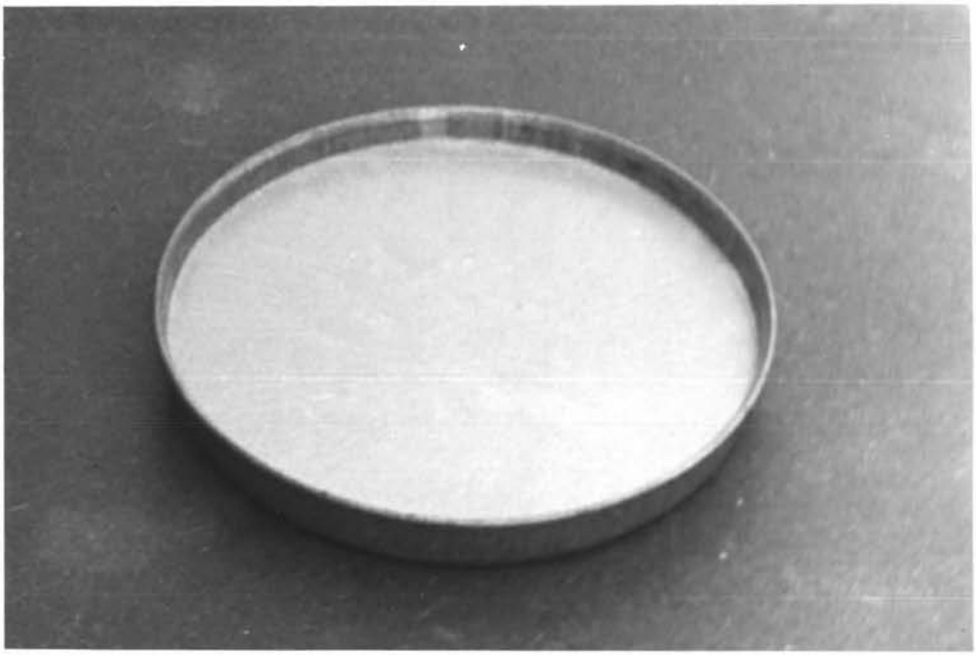


Figure (9). Freshly prepared wax in a moulding dish.

Figure (10). Hoof in process of moulding.

on a short lead on a level concrete yard, the hoof to be printed was examined for cleanliness and abnormalities. After inspection, while still wet, the hoof was placed on top of the freshly prepared wax layer in a mould container. The animal's weight was moved squarely on to the hoof, so that the hoof penetrated the wax to the bottom of the mould container. This required several seconds due to the rigidity of the wax. The mould was then very closely inspected to ensure "all round" contact of the wax to the hoof (Figure (10)). Wherever necessary, mainly at the heel, the wax was forced into firm contact with the hoof.

After careful removal from the hoof, the mould was checked for defects, and if found satisfactory, labelled with the experimental number of the animal, and with letters to identify the particular hoof which had been printed. The mould (Figure (12) ) was then ready for casting.

2. Hoof Casting Technique

(a) Materials and Tests of Materials

The casting material used consisted of casting plaster of Paris obtained from builders' suppliers. A shrinkage (or expansion) test was carried out on this material and is reported in Appendix A. Three wax moulds were made (Dimensions 12 x 1½ x ¾ inch) and in the bottom of each, an impression was made of the edge of a sheet of glass $11^{27}/32$ inch long. Three plaster bars were cast from the moulds, each from plaster slurries of different consistency. Measurements were taken of the lengths of the casts of the glass sheet, at various intervals of time. The maximum difference observed between any of these measurements and the length of the glass sheet was less than $^{1}/32$ inch and could be attributed to measurement error.

It was concluded that neither shrinkage nor expansion, due to either the nature of the casting material or its consistency, was likely to introduce any significant bias into the casting technique.

Keyway blocks were made of wood to the pattern of the master keyway block (Figure (20) ). These blocks were used in casting to make a keyway in the upper side of the cast, as shown in Figure (11). This keyway was used later to mount the hoof during measurement (Measurement technique II page 76).

(b) Method

Hoof casts were made by pouring a thick slurry of plaster of Paris and cold water into the hoof moulds. Before setting commenced a keyway block was pressed into the top of the plaster, at right angles to the centre line, as shown in Figure (1I) and the cast labelled.

During hardening the moulds and casts were immersed in cold water. This reduced heating and drying of the plaster, and was essential for clean separation of cast from wax. After a minimum of one hour the casts were removed from the

Figure (11). Key Way block in use in hoof casting.

Figure (12). Hoof mould ready for casting.

moulds and were then ready for measurement.

Tests of the repeatability of this technique could not be undertaken until measurement techniques were developed. This is reported in the next section, C, and tests of the combined measurement and casting techniques form the subject of the pilot trial, D. (Keyway blocks were not used in this trial, as a satisfactory hoof cast mounting device had not been made at that time.)

## C. TECHNIQUES OF MEASUREMENT OF HOOF CAST

Two steps were involved in the measurement of a hoof cast. First, a contour line was marked on the cast (contour lining) and second, features delineated by this line were measured (measuring).

At first a "waterline" technique of contour lining was used. This was used in the pilot trial and is described below. Later (Section E) a "scratchline" technique was developed and used in all subsequent work.

Similarly, area measurement progressed through two stages. The first of these is described below, and was used in the pilot trial. The second measurement technique (II) is described in Section E.

The measurement of linear features was straight forward, and the few preliminary tests carried out do not warrant report.

Figure (13).
Levelling Assembly:
Elevation.
(1) Bracket
(2) Upper Pointer
(3) Lower Pointer

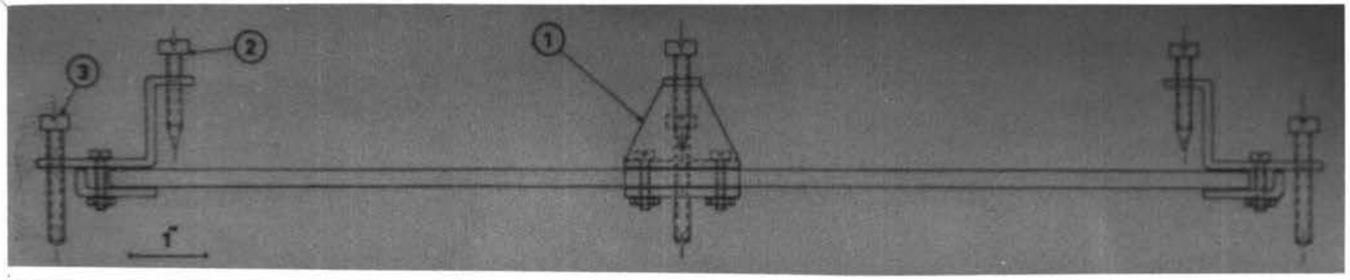
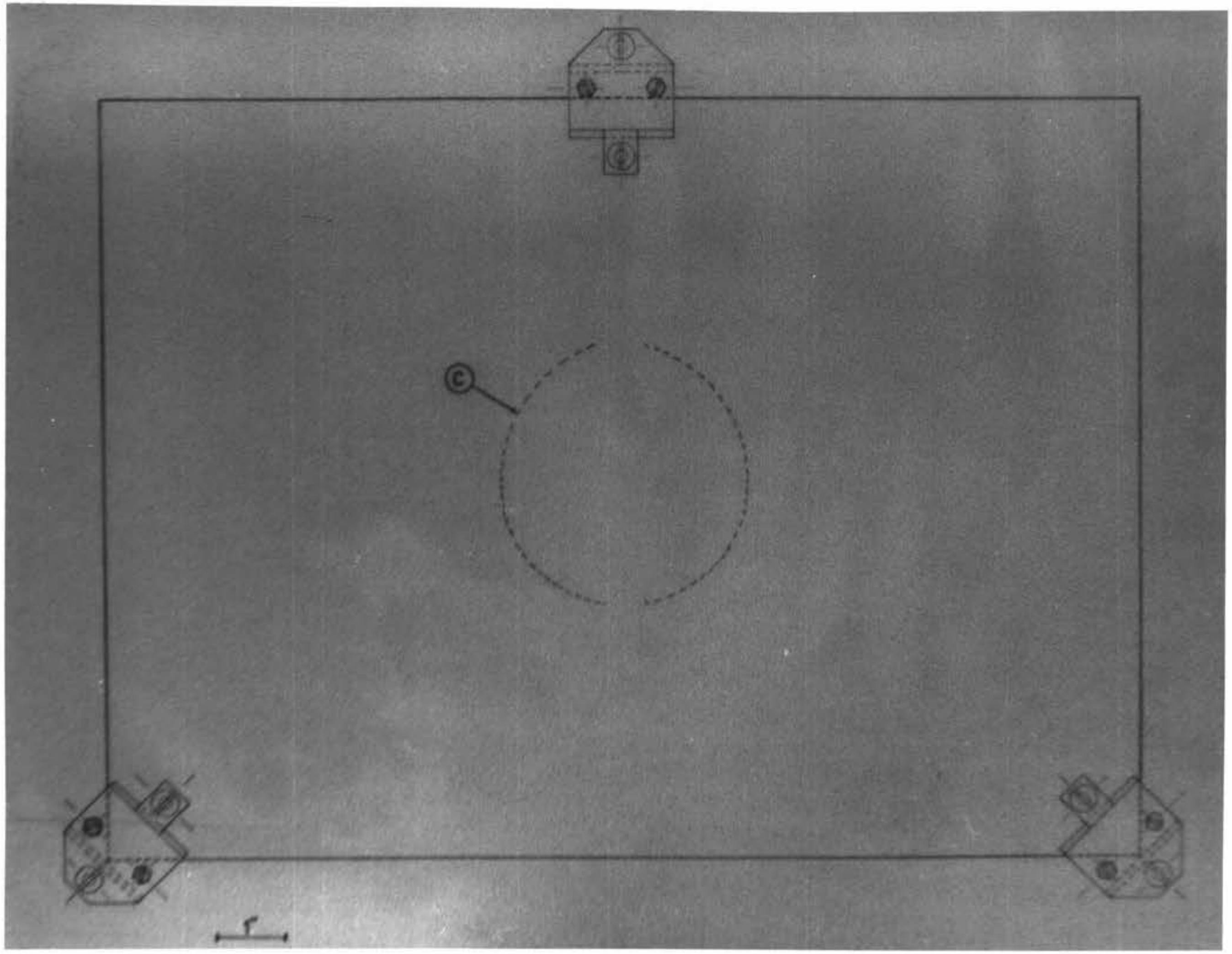



Figure (14).
Levelling Assembly Plan:

Showing position of cast (c) on plate glass during contourlining.



1. Waterline Contouring Technique

(a) Materials

The apparatus used comprised the levelling assembly shown in Figure (13), and a plastic trough 22 x 13 x 1½ inch. The levelling assembly consisted of a sheet of plate glass 15 x 11 x ¼ inch carried on three identical brackets. Each bracket carried two threaded pointers. The upper pointers were adjustable to any predetermined height above the plate glass. The lower pointers were used to level the assembly.

(b) Method

In operation, after adjustment of the upper pointers to the required height, the levelling assembly was placed in the plastic trough containing methylene blue dye solution. The lower pointers were then adjusted until each of the upper pointers appeared to touch its own reflection in the dye solution.

The hoof casts to be contour lined were then placed in turn on the plate glass for approximately three seconds (Figure (14)). A waterline contour, the height of which was determined by the setting of the upper pointers, was marked on the casts by this process (Figure (15)).

2. Measurement of Hoof Areas (Technique I)

(a) Materials

A fixed arm "Allbrit" Polar Planimeter, Instrument No.

8610, was used to measure area. A drawing board and an acetate sheet 15 x 15 x 0.025 inch completed the equipment.

(b) Method

The inverted hoof cast was placed alongside the drawing board, and the upper surfaces of each brought level by means of cardboard supporting strips. The acetate sheet was placed over the board and the cast. The planimeter was placed in position on the acetate sheet. The bearing area of the hoof was measured by tracing the dyed outlines of the cast, visible through the acetate sheet, with the planimeter in the normal manner. Enclosed areas were similarly measured.

During measurement, the acetate sheet was essential to keep the planimeter tracer bar level, and to support the planimeter measuring wheel when this moved off the drawing board.

These techniques were tested in the pilot trial described in the next Section, and modifications were subsequently made (Section E).

## D. PILOT TRIAL

It was considered that the hoof moulding - casting - contour-lining technique, and the measurement technique, although complex, fulfilled the first criterion of a satisfactory hoof measurement method, in that features could be measured in accordance with their definitions. This Pilot Trial was intended to appraise the practical usefulness of these techniques and their accuracy in terms of the repeatability of measurement. No practical method of detecting bias in measurement could be conceived.

1. Objects

(a) To test the hoof moulding - casting - waterline-contouring technique, and the method of measurement (Technique I) from a practical aspect.

(b) To obtain an estimate of the repeatability of each of the two above groups of techniques.

2. Source of Data and Techniques

Ten successive hoof casts of one hoof of a mature Jersey cow were made by the hoof moulding and casting technique described in Section B. These casts were contour lined at a height of $^5/_{20}$ inch by the waterline technique (Section C). Bearing areas and also enclosed areas were measured in triplicate by measurement Technique I (Section C).

3. Results

The measurements obtained of bearing area and enclosed area are recorded in Appendix B. In order to calculate the components of the variance due to moulding - casting - contour-lining technique, and planimeter measurement technique, an analysis of variance was carried out on each set of area results. These analyses together with means, and the standard deviations of the respective components of the variance, are presented in Table III.

Table III

**Pilot Trial: Analyses of Variance of bearing area data and of enclosed area data; estimates of the standard deviations of the moulding - casting - contour-lining technique, $S_c^2$, and of the measurement technique $S_m^2$.**

| Source of Variation | d.f. | Expectation of Mean Square | Bearing Area | | Enclosed Area | |
|---|---|---|---|---|---|---|
| | | | Mean Square | F | Mean Square | F |
| Between Casts | 9 | $S_m^2 + 3\ S_c^2$ | 0.1293 | 15.90** | 0.4748 | 6.83** |
| Measurements within casts | 20 | $S_m^2$ | 0.008135 | | 0.06956 | |

(** p 0.01)

| | Bearing Area (Sq. in.) | Enclosed Area (sq.in.) |
|---|---|---|
| Mean | = 11.46 ± 0.21 | 13.43 ± 0.57 |
| $S_c$ | = ±0.20 | ±0.37 |
| $S_m$ | = ±0.090 | ±0.264 |

The highly significant F ratio, obtained in each analysis of variance, indicates that the method of planimeter measurement employed was sensitive enough to detect differences between casts of the one hoof, when three measurements were made on each of the ten casts.

Estimates of the repeatability of the casting - moulding and contour-lining techniques (termed "casting") or the measurement techniques are given by the square root of the respective components of variance. For instance, the estimate of the standard deviation of measurement of bearing area, $S_m = \pm 0.09$ may be interpreted to mean that two thirds of all repeat measurements of a standard hoof cast would be expected to differ from their mean by less than $\pm$ 0.09 square inch (assuming normality of distribution).

The estimate of the standard deviation of casting, $S_c = \pm 0.20$, for bearing area, similarly indicated that, given a standard hoof to mould, cast and contour-line repeatedly, (provided the casts could be measured without error) two thirds of all measurements of bearing area of the standard hoof would be expected to differ from their mean by less than $\pm$ 0.20 square inch.

The components of variance for the enclosed area data may be interpreted in a similar way. The slightly larger estimate of $S_c$ was attributed to variation in position of the claws of the hoof. Similarly, the larger $S_m$ was attributed to the difficulty in tracing the rear terminal line with the planimeter.

In practice, the field work was simpler and more rapid than any of the hoof printing techniques tried previously. However, the laboratory contouring and measuring techniques were not so satisfactory.

In waterline contouring, meniscus effects were observed to increase the height of the contour line where the hoof met the solution at an acute angle.

In measurement of the cast there was a possibility that parallax errors produced a bias in area estimates. Levelling of the hoof cast for measurement was slow and inaccurate.

4. Conclusions

It was concluded that:-

(a) From a practical aspect the hoof - moulding - casting technique was feasible. Its repeatability was sufficient to justify its use in a further trial in which the repeatability could be rechecked over a wide range of hooves. Thus hoof casting of the animals of Group I was undertaken.

(b) The water-line contouring technique, because of the observed meniscus effects, required further investigation, especially in relation to the absolute height of the contour line. This is reported in Section E, using hoof casts from Group I animals.

(c) The measurement technique (Technique I) required extensive modifications to eliminate the possibility of parallax errors, and to facilitate cast levelling. Such modifications are reported in Section E.

## E. MODIFICATION OF CONTOUR LINING AND MEASUREMENT TECHNIQUES

### 1. Measurement of Waterline Contour Height

(a) Object

To determine the absolute vertical height of the water-line contour, at the side and at the heel of each hooflet, on a range of hoof casts.

(b) Source of Data

Thirty hoof casts were selected, one from each of the six casts per Jersey cow of the animals of Group I. Ten casts were thus obtained from each of the Jersey age classes, mature, three year and two year olds. Sampling ensured that within cows, each corner had an equal opportunity of being represented, and further, that sampling was at random within repeat casts of the one corner.

(c) Techniques

Waterline contours were marked on the hooves by the technique described in Section C, with the upper pointers set at $^{3}/20$ inch, so as to give a contour line at a vertical height of approximately $^{5}/20$ inch. The height of this water line was measured at random points at the side and heel of each hooflet by placing the hoof on a sheet of plate glass and gauging the height of the water line with glass measuring blocks of known thickness. The blocks were 1 inch square and the smallest vertical interval between blocks was $^1/20$ inch. Measurements were estimated to half this interval.

(d) Results

The measurements obtained are presented in Appendix C. Inspection of these data reveals a rounding effect due to the estimation of heights to half the unit of measurement. Thus the apparent constancy of height of the water-line in some groups is misleading. The mean, standard error and range for side and heel positions of each age class are presented in Table IV.

Table IV

Mean Vertical Contour Line Height, at side and heel positions on a subsample of hoof casts, from three Jersey age classes of the animals of Group I.

| Age Class | Heel | | Side | |
|---|---|---|---|---|
| | Mean | Range | Mean | Range |
| | ($^1/20$in.) | ($^1/20$in.) | ($^1/20$in.) | ($^1/20$in.) |
| Mature | 5.275 ±0.067 | 5 - 6 | 4.875 ±0.062 | 4 - 5 |
| 3-year-old | 5.175 ±0.055 | 5 - 5.5 | 4.850 ±0.089 | 4 - 5.5 |
| 2-year-old | 5.025 ±0.025 | 5 - 5.5 | 4.675 ±0.09 | 4 - 5 |

The measurements show that the contour line was not absolutely constant in height. The higher means for the heel position, compared to the side position, also tend to confirm the hypothesis that meniscus effects caused the water-line to rise, where the cast met the solution at an acute angle. In such circumstances a slight increase in contour height must, of geometrical necessity, produce a disproportionately large increase in bearing area. The errors in the waterline contour heights were, however, quite small and did not exceed ± $^{1}/_{20}$ inch.

During measurement of vertical contour height, it was found possible to etch a scratchline on the hoof with a corner of the measuring block. It was apparent that this could be used as a method of contouring the hoof cast. Such scratch lines etched round hoof casts formed contour lines which, because of their accuracy of height, fulfilled the definition of contour line exactly. This method was therefore adopted as the standard technique, the full description of which is given below.

(Further preliminary tests showed that the lowest contour that could be marked on a cast by the water-line method was at $^{3}/_{20}$ inch, with the depth of the marking solution $^{1}/_{20}$ inch. The scratchline technique could, however, be used to etch a $^{1}/_{20}$ inch contour on a cast).

2. <u>Scratchline Contouring Technique</u>

(a) <u>Materials</u>

The materials comprised a sheet of plate glass 9 x 7 x ¼ inch and seven glass marking blocks 1 inch square, ranging in thickness from $^1/_{20}$ to $^7/_{20}$ inch in $^1/_{20}$ inch steps. The maximum error in thickness of all blocks used was less than 0.0025 inch.

A trough of methylene blue dye solution was also used.

(b) Method

Hoof casts to be contoured were first dipped to approximately the half inch contour in methylene blue dye solution.

Each cast was drained and broken in two along the centre line. Each hooflet was placed in turn on its zero bearing surfaces on the plate glass. While held firmly in this position, a scratchline was etched around the hooflet with an upper corner of the appropriate marking block. The scratchline appeared as a white line on the blue stained cast (Figures (15) and (16) ).

3. Modified Measurement Technique (Technique II)

Two faults were noted in measurement Technique I (page 72), the possibility of parallax errors, and the tedious method of hoof levelling. These faults were virtually eliminated by using modified apparatus. A measuring board was made on which to mount and level the hoof during measurement, and a new planimeter adapted for use in conjunction with the board.

(a) Materials

(i) Planimeter. An "Allbrit" Polar Planimeter, with adjustable tracer bar, Instrument No. 22967, was obtained.

Figure (15). End view (from heel) of contour - lined casts. Upper waterlined; lower scratchlined.

Figure (16). Bearing surfaces of scratchline contoured casts.

Its accuracy was checked using the checking rule supplied, which enabled a standard circle to be described without tracing errors (Figure (17) ). After several adjustments had been effected, it was concluded from these tests that no detectable bias ($< 0.01$ square inch.) would be introduced by using the instrument in the "right hand position" (Figure (18) ) only. (Otherwise, averaging of right and left hand position measurements would have been necessary). It was also found that errors due to inherent inaccuracies of the planimeter were not larger than the smallest quantity that could be read on the measuring wheel (0.01 square inch.). (The results of these tests are lodged with the Dairy Husbandry Department, Massey Agricultural College).

(ii) Planimeter Attachments. The tracer bar extension was constructed from the drawing reproduced full size in Figure (19). The shaft (3) was drawfiled to the dimensions of the tracer bar, and drilled from each end for lightness. The four locking screws (2), when tightened evenly, clamped the shaft rigidly to the tracer bar of the planimeter.

The adjustable skid (4) served to level the tracer bar and extension and was held in position by a locknut. A finger grip was later fitted to its upper end.

The purpose of the extension was to mount the adjustable skid at the end of the shaft, instead of at the pointer, as supplied by the manufacturers.

The pointer mounting was fitted to the tracer bar as

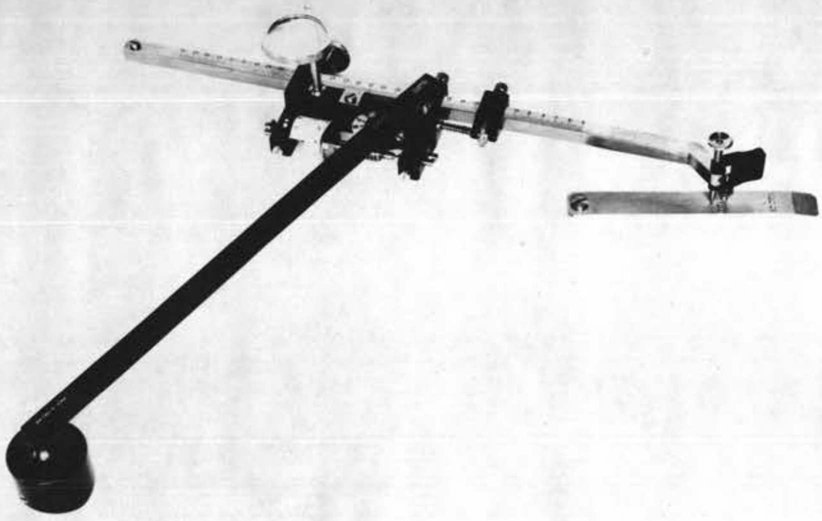


Figure (17). Planimeter on checking rule, in left-hand position.

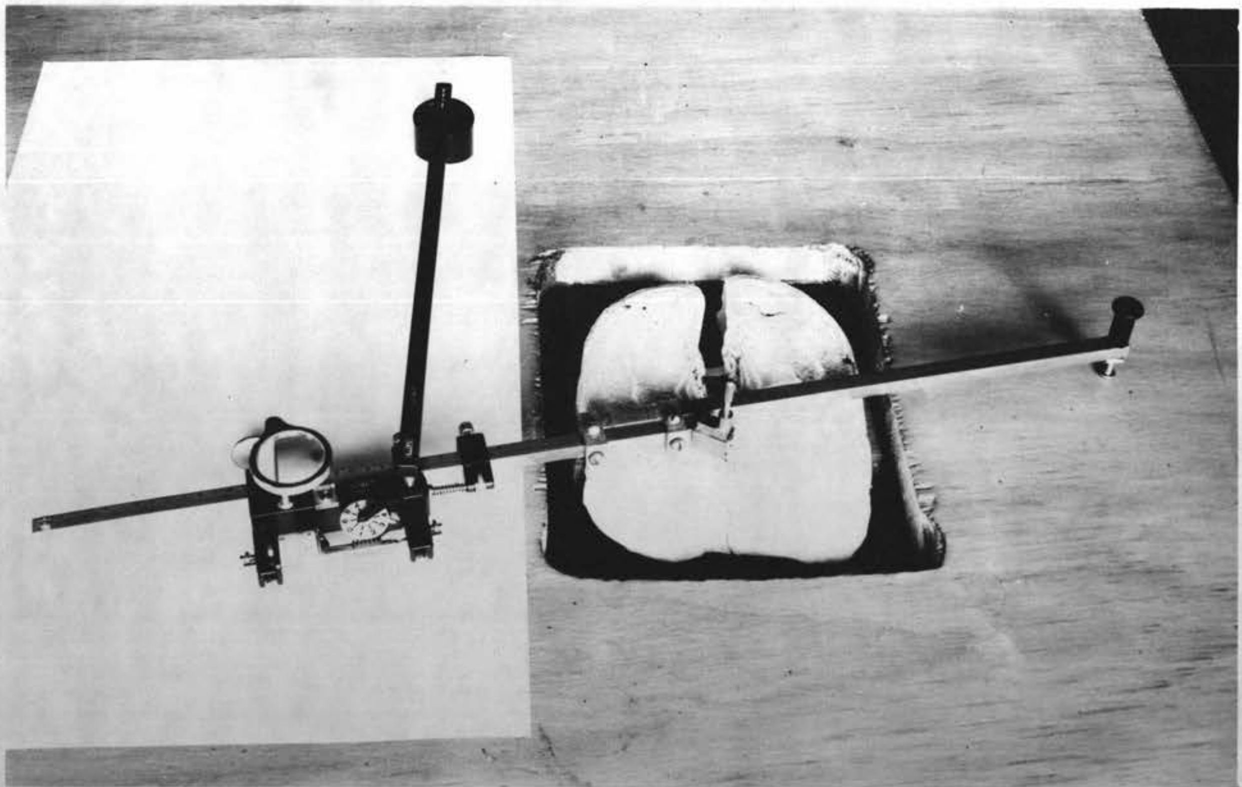


Figure (18). Planimeter in use on the measuring board, in right-hand position.

shown (Figure (19) ). Its purpose was to allow friction damped vertical travel of the pointer without undue pointer wobble. To further reduce pointer wobble, a new pointer was machined to a diameter approximately 0.0002 inch less than its mounting bearings. The lower bearing was formed by the original bearing in the end of the tracer bar, and the upper bearing was located in the top of the mounting block. When the pointer mounting was locked in position on the tracer bar, by tightening grub screw (8), precautions were taken to ensure that the pointer axis occupied the position intended by the manufacturers. Tests on the checking rule after all attachments had been fitted, revealed no alteration in accuracy. Once fitted, all attachments were left in position until all measurements had been completed. No permanent alteration was made to the Planimeter.

(iii) <u>Measuring Board</u>. The measuring board was made as shown in Figure (20). The board (1) was made of core-board to minimize warping. The clamping screw (2) was of brass, to ensure that the point did not cut into the mild steel shaft (3). The ball (4) of the ball and socket joint was hardened steel. The master keyway block (6) was made to the same pattern as the keyway blocks used in casting, but slightly oversize, to ensure that hooves were a firm friction fit on to this block. A sheet of plate glass 9 x 7 x ¼ inch and two steel strips 7 x ¼ x ¼ inch

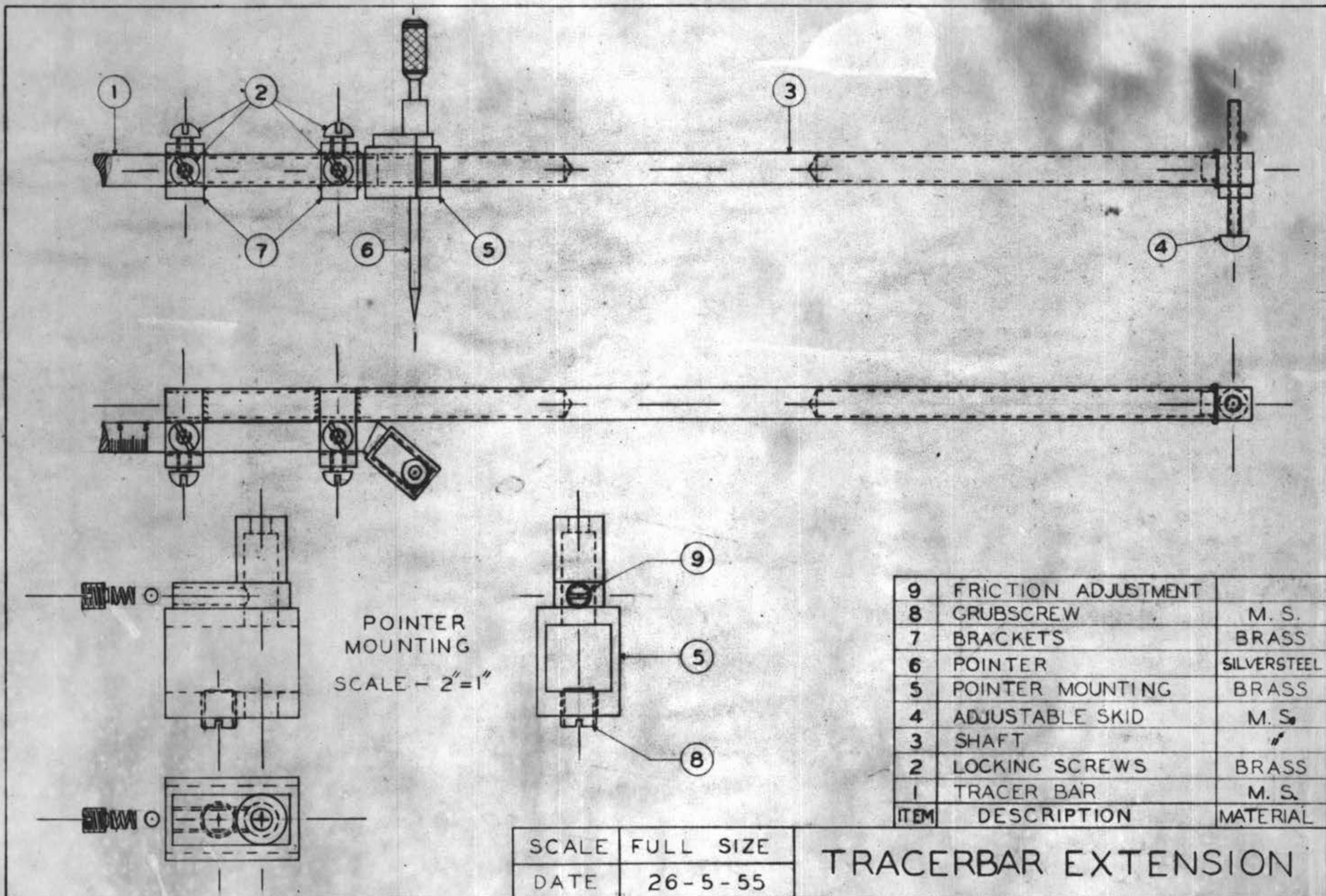



Figure (19). Tracerbar Extension.

were used in conjunction with the measuring board, to level hooves for measurement.

(b) **Method**

Hooves to be measured were mounted in turn on the key-way block of the measuring board. The sheet of plate glass was supported over the cast by the steel strips, to form a surface parallel to, and ¼ inch above, the measuring board. The ball socket clamping nut (5) and the clamping screws (2) (Figure (20) ) were loosened. The ball socket shaft assembly, carrying the cast, was then raised until the zero bearing surfaces of the hoof made firm contact with the plate glass. The nut (5) and the screw (2) were then tightened to lock the whole assembly.

Thus the hoof was levelled accurately at a convenient height for measurement.

The glass and steel strips were then removed and the hoof bearing areas measured in the normal way, with the planimeter disposed as shown in Figure (18).

During measurement, the pointer was raised and lowered so that its point was virtually kept in contact with the contour line being traced, or the outer edge of the hoof cast, as each in turn demarcated the limits of the bearing area. Parallax was thus virtually eliminated.

Levelling and measuring could both be performed more rapidly by these methods than by Technique I. Preliminary tests revealed that measurements of scratchline contoured

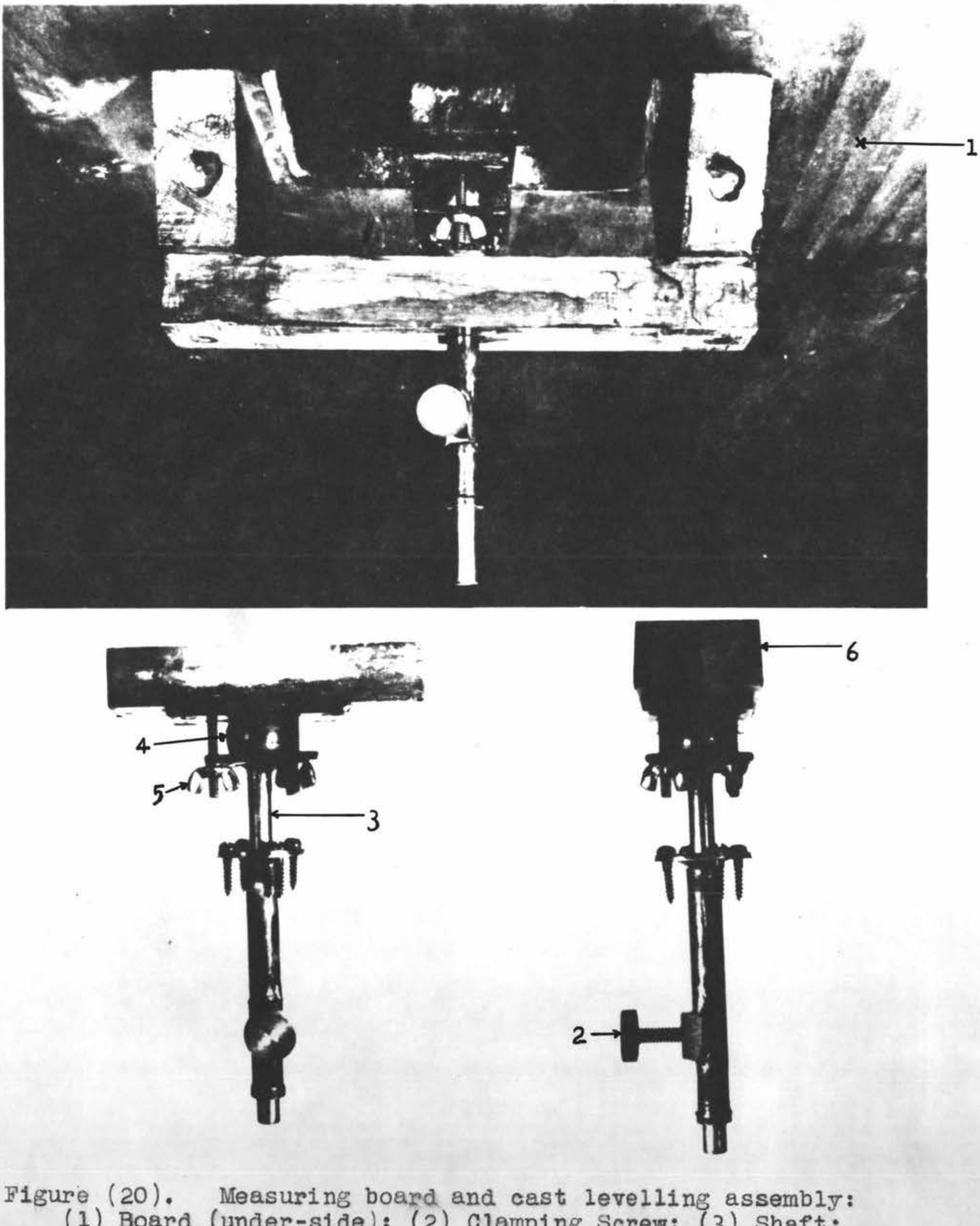



Figure (20). Measuring board and cast levelling assembly: (1) Board (under-side); (2) Clamping Screw; (3) Shaft; (4) Ball; (5) Clamping Nut; (6) Master Key Way Block.

hoof casts by Technique II were highly repeatable. A comprehensive test of the repeatability of this technique is described in Part II Chapter V of this thesis.

# PART II

## THE MEASUREMENT OF THE ANIMALS OF GROUP I.

# P A R T  I I

## PRELIMINARY INVESTIGATION OF HOOF FACTORS

## THE MEASUREMENT OF THE ANIMALS OF GROUP I

### Introduction

Measurements and the analyses of measurements from hoof casts of the animals of Group I form the subject of the next three chapters (IV, V and VI). The source of the sample of animals termed Group I and techniques used in casting are given below. In addition, hoof load determinations, taken during the period in which the animals were hoof moulded are reported in Chapter VI, together with the techniques employed.

The problems involved in this study, as discussed in Chapter II Section B (page 53), determined in part the class of animals chosen. Sampling was further confined to milking cows of the Massey College herds.

(a) Source of Sample

The Group I sample comprised thirty Jersey and ten Friesian cows, from the respective purebred registered herds at Massey Agricultural College. The Jersey sample was selected at random, with the restriction that ten animals were chosen from each of the following age classes; mature (over 4-year-old), 3-year-olds, and 2-year-olds, and that only animals expected to calve during the following spring were eligible.

The ten mature Jerseys chosen in this way ranged in age from 4 to 9 years, six being 4 years old. With the exception of one 6-year-old cow, born in June, all Jerseys were born during July, August, September or October. The Jersey sample was hoof moulded and weighed between 26th March and 16th April 1955.

The ten Friesians were selected at random from the mature Friesians of the College herd. The animals chosen ranged in age from 4 to 8 years, four being 4-years-old. Month of birth varied from May to October. The Friesian sample was hoof moulded and weighed between 1st May and 13th May 1955.

All animals were lactating during the experimental period. The Friesian and Jersey herds were run as separate units, on a similar pattern of predominantly rotationally grazed, grassland farming. Pasture supplied the bulk of the feed and grass-clover hay and silage were fed as supplementary fodder in early spring, summer and winter, when necessary. In addition, choumoellier (Marrow Stemmed Kale) was fed during the summer months, and the Jersey herd grazed irrigated pasture.

Within breeds, animals were hoof moulded and weighed in random order, with the Jerseys and Friesians being treated as separate groups. In this way, the element of the variance due to time was reduced to a minimum within breed groups, but increased between breeds. Thus comparison within breed groups may virtually be regarded as being made at a point in time, with a common environmental component of the variance. Between breed comparisons, however, could be affected by a time factor of approximately four weeks, during which seasonal and managemental changes occurred. Between breed comparisons may be further affected by the different conditions under which the respective herds were managed.

(b) Technique of Hoof Casting

Hoof casts were made by the standard moulding and casting technique already described (page 62). Six moulds and casts were made from every cow in Group I. One mould and cast was made from each hoof of each cow, and a further two repeat moulds and casts were taken from diagonally opposite front and rear hooves. The particular diagonal on which repeat casts were taken was chosen at random with the restriction that within each age (or breed) sub group of ten animals, half the animals had repeat casts taken on front left and rear right hooves, and half on front right and rear left hooves. Thus for the purposes of estimating the repeatability of casting, each sub group was divided into two classes depending upon which diagonally opposite hooves were moulded and cast in duplicate.

# CHAPTER IV

## BEARING AREA AT DIFFERENT CONTOUR HEIGHTS THE CHOICE OF A STANDARD CONTOUR HEIGHT FOR HOOF MEASUREMENT

In the statement of the problem, attention was drawn to the importance of bearing area shape in relation to the contour height at which bearing area (and hence other hoof features) should be measured. In this chapter an investigation of the change in bearing area with contour height on a sample of hoof casts is reported. These factors are discussed in relation to the problem of hoof action and are used as the main basis in the choice of a standard contour height for hoof measurement.

### A. THE RELATIONSHIP BETWEEN HOOF BEARING AREA AND CONTOUR HEIGHT IN JERSEY COWS

(a) Object

To obtain a graphical representation of the change in mean bearing area as vertical contour height increased from $^1/20$ inch to $^7/20$ inch within a sample of Jersey hoofcasts.

(b) Source of Data

The sample of hoof casts employed in the measurement of waterline contour height (page 73) was again used. This sample consisted of thirty Jersey hoof casts, containing equal subclass samples from mature, 2-year-old, and 3-year-old age classes.

(c) Techniques

Hoof casts were scratchline contoured and measured in duplicate by Measurement Technique II at seven contour levels, from $^1/_{20}$ inch to $^7/_{20}$ inch at $^1/_{20}$ inch intervals.

(d) Results

The measurements obtained of bearing area are recorded in Appendix D.

The mean bearing area, standard error, and coefficient of variation for each age class, at each contour level, are given in Table V. These results are shown graphically in Figure (21). The points were plotted from the data in Table V and the curves for each age class drawn by hand. The per cent increase in bearing area for each age class for each contour interval is also shown in Table V.

Table V

**Mean Bearing Area (sq. in.) for Three Age Classes of Jerseys**

| Contour Height ($^1/20$ in.) | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Age Class | | | | | | | | |
| Mature | Mean in.$^2$ | 5.01 | 8.11 | 10.61 | 11.82 | 12.52 | 13.07 | 13.54 |
| | S.E. | 1.37 | 1.56 | 1.32 | 1.34 | 1.34 | 1.37 | 1.42 |
| | C.V. % | 27.28 | 19.22 | 12.42 | 11.30 | 10.72 | 10.52 | 10.48 |
| % increase | | | 61.9 | 30.8 | 11.4 | 5.9 | 4.4 | 3.6 |
| 3 year | Mean in.$^2$ | 6.59 | 9.21 | 10.60 | 11.35 | 11.92 | 12.39 | 12.82 |
| | S.E. | 1.32 | 0.86 | 0.74 | 0.75 | 0.77 | 0.83 | 0.83 |
| | C.V. % | 20.08 | 9.30 | 6.94 | 6.57 | 6.47 | 6.70 | 6.46 |
| % increase | | | 39.8 | 15.1 | 7.1 | 5.0 | 4.0 | 3.5 |
| 2 year | Mean in.$^2$ | 6.62 | 8.76 | 9.88 | 10.62 | 11.15 | 11.56 | 11.96 |
| | S.E. | 1.25 | 1.19 | 0.99 | 0.84 | 0.85 | 0.82 | 0.78 |
| | C.V. % | 18.90 | 13.61 | 10.06 | 7.91 | 7.63 | 7.09 | 6.56 |
| % increase | | | 32.3 | 12.8 | 7.5 | 5.0 | 3.7 | 3.5 |

The graphs showed a marked increase in bearing area with height of contour level at the lower contour heights. Above the $^4/20$ inch level this increase was smaller. In addition it was similar for all age classes and almost linear.

The position of the contour lines on the hoof provided an indication of hoof shape (Figures (15) and (16) ). The bearing areas were often concave, with the outer hoof wall forming the zero bearing surfaces. This concavity was reflected in the marked increases in bearing area with height,at the lower contour levels. At higher contour levels, above $^4/20$ inch, increases in bearing area came only from added contact areas around the sloping heel or bulb of each hooflet and the sides of the cleft between hooflets.

Some hooves, however, were not concave, and resembled a concave hoof worn away to the $^2/20$ inch or $^3/20$ inch contour, so that the underside of the hoof appeared flat (Figure (16) ).

This variation in hoof shape at lower contour levels was accompanied by higher coefficients of variation. Above the $^4/20$ inch contour, the coefficients of variation were low and remarkably constant within age classes.

The ranking order of the means of bearing area for age class changed with contour height. However, above the $^4/20$ inch contour the ranking order was consistent and the differences between age class means were more regular. Below $^4/_{20}$ inch the converse was true.

(e) Conclusions

It was concluded that in all age classes, bearing area increased with contour height up to at least the $^7/_{20}$ inch level. It was observed that many hooves were concave with the outer hoof wall forming the zero bearing areas. However, some hooves were flat underneath and this had the appearance of being caused by wear.

## B. DISCUSSION OF RESULTS AND CHOICE OF STANDARD CONTOUR HEIGHT FOR HOOF MEASUREMENT

If the mean bearing areas for the sub sample of hooves presented above provided accurate estimates of the age class means for the full Group I sample, then it was clear from the results presented that age class differences may be predetermined by the choice of the contour height at which the hoof casts were to be measured. In deciding a standard contour height for hoof measurement an explanation for the change in ranking order of the mean bearing areas for each age class was sought. In view of the large standard errors at the lower contour levels (Table V) these changes in ranking order may not be statistically significant. This being so, an explanation of the increased variation in bearing area at the lower contour levels would still be required. The final choice was then made after considering the change in bearing area with contour level in relation to problems of hoof action.

(a) Explanation of change in ranking order of the mean bearing area for each age class

It was observed that hoof bearing surfaces varied in shape from flat to concave. It was postulated that this variation in shape was responsible for the increased variability and for the differences between the mean bearing area for each age class below approximately the $^{4}/20$ inch contour. The difference in shape of hooves is attributed not to any size of hoof effect, but to differential rates of wear and growth of tissues forming the integument of the hoof.

Thus a hoof would become concave when the horny outer hoof wall grows rapidly and/or wears slowly. Where growth is slow, and/or wear is rapid, the hoof would become flat.

Alternatively, rate of wear and growth of the sole of each hooflet could account for the variation in shape. Since the animals spent most of their time on pasture, wear could cause a hollowing out of the hoof, rather than a flattening.

Above the $^{4}/20$ inch contour, examination of the contour lined casts showed that concavity produced an effect on bearing area in relatively few hooves. The steady but small increase in the mean bearing area above this level was mainly a reflection of the angle at which the bulb or heel of each hooflet met the planes of the contour lines. It was postulated, therefore, that at these contour levels, bearing area provides an estimate of hoof size.

Therefore if an animal-size factor is to be measured, rather than a factor determined by an unknown interaction between rate of growth and wear of different hoof tissues, bearing area should be measured above the $^4/20$ inch level. The lower coefficients of variation above this level indicated that it should be possible to demonstrate statistically significant differences between age classes with fewer animals per sample. Thus, at the higher contour levels, differences appeared to be not only consistent and at a maximum but should be more easily detected.

For these reasons therefore, measurements should be taken at a contour above the $^4/20$ inch level. However, inspection of casts showed that abnormalities occurred due to technique above approximately the $^7/20$ inch contour, so that measurements should be taken below this level.

(b) Discussion of Change in Bearing Area with Contour Height in Relation to Problems of Hoof Action

In Chapter II it was shown that in the case of a concave hoof (from the point of view of problems of stability) the only important bearing area determined by animal hoof factors was a hypothetical maximum bearing area (page 49). Within the limitations of the casting and moulding technique employed, no such maximum could be demonstrated, and inspection of the hoof suggested that with the definition of bearing area adopted, the hoóf would penetrate several inches into the soil before a maximum value was reached.

From the point of view of solving problems of hoof action there is little point in searching for a maximum bearing area at high contour levels. All that is required is an estimate of bearing area at a certain contour level, about which the following statements may be made.

(a) Penetration of the hoof into the soil to the level of the specified contour will not involve the displacement of a large mass of soil likely to involve sheer failure of the soil mass. (Penetration to this depth may be regarded as a seating of the hoof into firm contact with the soil, preparatory to fulfilling its function of support).

(b) For small changes in the depth of hoof penetration, either positive or negative, the bearing area of the hoof may be regarded as nearly constant, at the specified contour level.

To comply with these requirements the $^{6}/_{20}$ inch contour was chosen as the standard height at which to measure hoof features.

At this depth of hoof penetration into the soil, the volume of soil displaced, as estimated from the area beneath the bearing area curves (Figure (21) ) would be expected to be less than one cubic inch.

It would also be expected that at a penetration of $^{6}/_{20}$ inch, the change in bearing area produced by a change in penetration of $\pm\ ^{1}/_{20}$ inch would be less than five per cent.

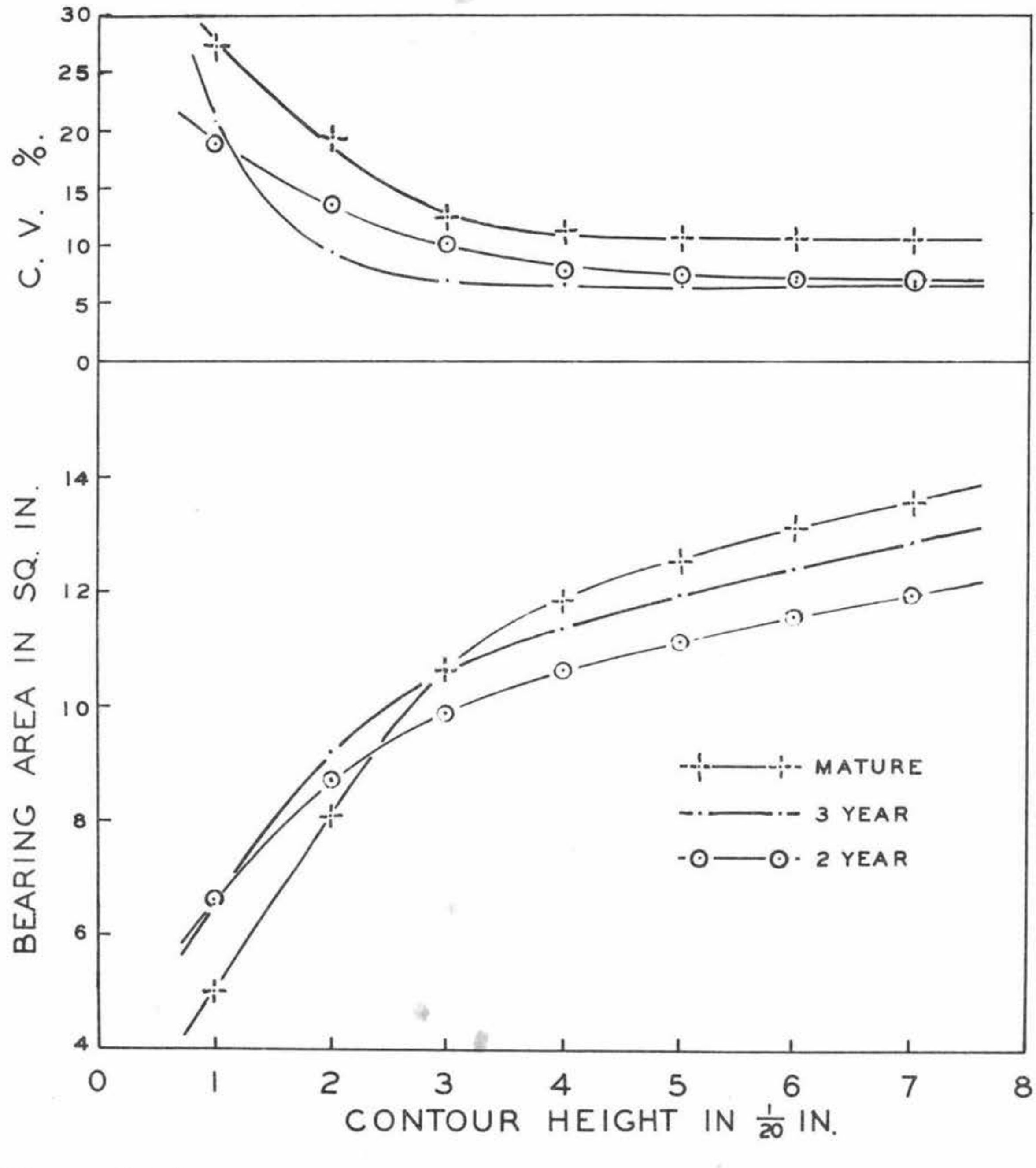



Figure (21). Bearing area and coefficients of variation at seven contour heights for three age classes of Jerseys.

# CHAPTER V

## BEARING AREA: GROUP I

As stated in Chapter II the main purpose of this investigation was to test the repeatability of techniques of hoof casting and measurement, and to obtain preliminary data from which Part III of this study could be designed.

### 1. Objects

The objects of this investigation were:

(a) To investigate the relationships between the bearing areas of the hooflets within the age classes of the Jersey animals.

(b) To obtain estimates of age (or breed) bearing area means of the animals of Group I; to statistically evaluate these differences, and to investigate the relationships between the bearing areas of hooves within cows.

(c) To obtain an estimate of the repeatability of the moulding - casting - contour lining technique, and of the measurement technique (Technique II).

(d) To obtain estimates of the relative importance of the various sources of variation in the measurements of bearing area.

### 2. Techniques

All casts from the Group I sample of animals were scratchline contoured at the $^6/20$ inch level, and two repeat measurements were taken of the bearing area by

Technique II.

For each of the thirty Jersey cows, hooflet bearing areas were recorded. One cast per hoof was used in each instance, two area measurements being made of each cast.

3. Treatment of data

The Hooflet bearing area data were divided into three groups, according to age class (i.e. mature, 3-year-old and 2-year-old) and each analysed separately.

The Hoof bearing area data were divided into two groups. The first group consisted of data derived from the first cast taken from each hoof of each animal of the sample (termed "one cast per corner" data). The second group consisted of measurements, only of casts from those hooves which had been cast in duplicate (termed "duplicate cast" data). This group was further naturally subdivided into data from left front - right rear, and from right front - left rear, diagonally opposite corners.

All data were further classified into four groups according to age (or breed). Tests were carried out on the "one cast per corner" data to determine the validity of combining age (or breed) classes for analysis.

Bartlett's test (Snedecor 1946 p. 249) of homogeneity of variance was carried out on the mature, 3-year-old and 2-year-old Jersey data and Chi square value of 30.83

(d.f. = 2) was obtained, which was highly significant. Furthermore a log transformation did not reduce the heterogeneity of the variances sufficiently to make this grouping of the Jersey data satisfactory.

Accordingly the mature Friesian and Jersey data were grouped together, and the F-test of the homogeneity of variance (Snedecor (1946) ) yielded an F ratio of 1.03 ($n_1$ = 80 $n_2$ = 80), which was non significant.

It was therefore concluded that the mature cow data could be analysed together.

The data for the immature Jerseys (3-year-old and 2-year-old) were similarly grouped, and the F- test yielded an F ratio of 1.38 ($n_1$ = 80 $n_2$ = 80) which was non significant.

The groupings of data for analysis may therefore be summarised :

(a) "One cast per corner" data

Two groups of 20 animals each; 10 in each age or breed class

| MATURE | IMMATURE |
|---|---|
| (Friesian and Jersey) | (3 and 2-year-old Jersey) |

(b) "Duplicate" cast data.

Four groups of 10 animals each; 5 in each age or breed sub class

MATURE

| Friesian | and | Jersey |
|---|---|---|
| (a) | | (b) |
| Left front-<br>Right rear | | Right front-<br>Left rear |

IMMATURE

3 and 2-year-old Jersey

| (c) | (d) |
|---|---|
| Left front-<br>Right rear | Right front -<br>Left rear |

4. Results

(a) Hooflet bearing area data

The hooflet bearing area data are recorded in Appendix E. Each item in these results was obtained by averaging the two repeat measurements of each hooflet.

The mean hooflet bearing areas, for each of the eight possible hooflet positions within the animal, for each Jersey age class, are presented in Table VI. This involved classification of the data according to the position of the hooflet as follows:-

(a) sides (belonging to a left or right hoof)

(b) ends (belonging to a front or rear hoof)

(c) classified as "medial" or "lateral" according to the position of the hooflet (or claw) within the hoof.

Table VI

Mean Hooflet bearing area (sq. in.) for each of the eight possible hooflet positions within the animal for each Jersey age class

| AGE CLASS (JERSEY) | END | SIDE | | | | STANDARD ERROR OF MEAN |
|---|---|---|---|---|---|---|
| | | LEFT HOOF | | RIGHT HOOF | | |
| | | Hooflet within hoof | | Hooflet within hoof | | |
| | | Lateral | Medial | Medial | Lateral | |
| Mature | Front | 6.478 | 6.724 | 7.132 | 6.446 | ± 0.233 |
| | Rear | 6.538 | 6.120 | 6.214 | 6.530 | |
| 3-year-old | Front | 6.147 | 6.242 | 6.328 | 6.172 | ± 0.158 |
| | Rear | 6.244 | 5.852 | 5.988 | 6.269 | |
| 2-year-old | Front | 5.816 | 5.970 | 6.036 | 5.818 | ± 0.138 |
| | Rear | 5.986 | 5.606 | 5.576 | 6.137 | |

Table VII

Analyses of Variance of hooflet bearing area data for each class of the Jersey animals of Group I

| Source of Variation | | d.f. | MATURE | | 3-YEAR-OLD | | 2-YEAR-OLD | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean Square | F | Mean Square | F | Mean Square | F |
| Between Classes: Medial Vs. Lateral (M. vs. L) | | 1 | 0.0488 | <1 | 0.2247 | <1 | 0.4068 | <1 |
| Corners | Front v. Rear | 3: 1 | 2.375 | <1 | 0.3578 | <1 | 0.1415 | <1 |
| | Right v. Left | 1 | 0.2651 | <1 | 0.0918 | <1 | 0.0439 | <1 |
| | End x Side | 1 | 0.1040 | <1 | 0.0030 | <1 | 0.0036 | <1 |
| (M v L.) x Corners | (M.v.L.) x End | 3: 1 | 3.467 | 6.38* | 1.067 | 4.27* | 2.160 | 11.34** |
| | (M.v.L.) x Side | 1 | 0.3665 | <1 | 0.0370 | <1 | 0.0170 | <1 |
| | (M.v.L.) x End x Side | 1 | 0.1424 | <1 | 0.0031 | <1 | 0.0747 | <1 |
| Within Classes | | 72 | 0.5437 | | 0.2504 | | 0.1905 | |
| Total | | 79 | | | | | | |

(**$p < 0.01$; *$p < 0.05$)

Analyses of variance were carried out for each age class (Table VII). The results of the analyses showed that the medial versus lateral by end interaction was the only significant effect in each age class. In Table VII effects were tested against the variation of hooflets within classes. Effects higher in the table than the significant interaction, (medial versus lateral) by end, were tested against this interaction.

It was concluded that the only significant differences in Table VI lay between the medial and lateral means within the ends of the animal. In front hooves the medial hooflet was the larger. Conversely in rear hooves the lateral hooflet was the larger. This pattern of hooflet size was repeated in a similar fashion in each age class.

However, the size differences were small in magnitude. The greatest difference between the mean hooflet areas for any two claws of the one hoof in Table VI was only 5.05 per cent of the combined area of the two hooflet means (i.e. the mean hoof area). The average difference between any two claws of the one hoof for all hooves, expressed as a percentage of the mean hoof area of all hooves, was only 2.63 per cent.

It was concluded that in problems of hoof action the differences in area of the two claws of the hoof could be neglected. However, the significant differences found, and relative magnitudes of the hooflet bearing means in

Table VI were suggestive of strong bilateral symmetry in the bearing areas of the hooflets of the animal.

(b) "<u>One cast per Corner" Data</u>

The "one cast per corner" bearing area data are recorded in Appendix F. Age (or breed) class means, and means within age class for left, right, front and rear corners are presented in Table VIII.

Table VIII

Mean Hoof Bearing Area by age (or breed) class for left, right, front, rear and all corners. (units sq. in.) (Group I. "One cast per corner data")

| Corners \ Age class | Mature Friesian | Mature Jersey | 3-year Jersey | 2-year Jersey |
|---|---|---|---|---|
| Left | 16.71 | 12.93 | 12.24 | 11.69 |
| Right | 16.86 | 13.16 | 12.38 | 11.78 |
| Front | 17.07 | 13.39 | 12.44 | 11.82 |
| Rear | 16.50 | 12.70 | 12.18 | 11.65 |
| Standard Error | ±0.42 | ±0.42 | ±0.26 | ±0.26 |
| All Hooves | 16.78 | 13.05 | 12.31 | 11.74 |
| Standard Error | ±0.30 | ±0.30 | ±0.19 | ±0.19 |

Analyses of variance of the mature and immature groups of data are presented in Table IX. All effects were tested against error (1), (the variation of hooves within corners within breeds).

Error (2) was calculated from the duplicate measurements of each cast in order to provide estimates of the repeatability of the Measurement Technique II. The estimates obtained of the standard deviation of the measurement technique are recorded beneath Table IX.

(i) Age and Breed Differences. The Friesian mean bearing area was 3.73 square inches greater than that of the mature Jerseys; in Table IX this breed effect was shown to be highly significant. The 3-year-old Jersey mean bearing area was 0.57 square inches larger than the mean for the 2-year-old Jerseys, and this difference was similarly highly significant (Table IX).

The difference between the mean for mature and the mean for 3-year-old Jerseys was 0.74 square inches. In order to test the significance of this difference the least significant difference was calculated from the following formulae:

$$d = t_{(n-1)} \sqrt{S^2_{\bar{x}_1} + S^2_{\bar{x}_2}}$$

where

$S^2_{\bar{x}_1}$ and $S^2_{\bar{x}_2}$ = the variances of the respective means.

Table IX

Analyses of Variance of Mature Friesian and Jersey, and immature Jersey (3-year-old and 2-year-old) "One cast per corner" bearing area measurements. (10 animals per breed class, one cast per hoof, casts measured in duplicate)

| Source of Variation | d.f. | Mature Friesian & Jersey | | 3 and 2-year-old Jersey | |
|---|---|---|---|---|---|
| | | Mean Square | F | Mean Square | F |
| Between corners | 7 | 82.42948 | | 2.262128 | |
| Ages (or Breeds) | 1 | 558.9772 | 155.42** | 13.2883 | 9.55** |
| Corners | 3 | 5.9117 | 1.64 N.S. | 0.8120 | < 1 |
| Ends | 1 | 15.8886 | 4.42* | 1.8555 | 1.33N.S. |
| Sides | 1 | 1.4823 | < 1 | 0.5487 | <1 |
| Int. x End x Sides | 1 | 0.3629 | < 1 | 0.0316 | <1 |
| Ages x Corners | 3 | 0.0981 | <1 | 0.0369 | <1 |
| Age x End | 1 | 0.1392 | | 0.0888 | |
| Age x Side | 1 | 0.0570 | | 0.0219 | |
| Age x side x end | 1 | 0.096 | | 0.00008 | |
| Within Corners (Error 1) within ages | 72 | 3.5966 | | 1.3914 | |
| Error (2) (Between Measures within Corners) | 80 | 0.00295 | — | 0.0012725 | — |
| Total | 159 | 5.25909 | | 0.73032 | |

(**$p < 0.01$ ; *$p < 0.05$;
N.S. : $p > 0.05$)

Standard deviation of measurement
= ± 0.054 and ± 0.036

n = number of measurement per mean.

The value of d obtained was 0.45 square inches ($p < 0.01$). Thus despite the approximate nature of this test it appeared safe to conclude that the observed difference was highly significant.

(ii) End Differences. In the mature cow group of data in Table IX, the difference between the means for ends was shown to be significant ($p < 0.05$). The front corners mean was 0.57 square inches larger than the rear corners mean in the Friesians and 0.69 square inches larger in the mature Jerseys.

In the immature Jersey group the front hooves were also the larger, by 0.26 square inches in the 3-year-olds, and by 0.17 square inches in the 2-year-olds. These end differences in the immature Jersey group were, however, non significant (Table IX).

(iii) Other Effects. No other effects were significant (Table IX) nor do the means in Table VIII show any marked differences other than those mentioned above.

Because the age (or breed) by corners interaction was non significant, it was deduced that, any pattern of bearing area variation within the four corners of an animal found in one age (or breed) was repeated in a like manner in the other age (or breed) in the same analysis. Thus in the mature group the end difference was seen to be similar in each breed. The difference between sides, which was non significant, was negligible in each breed (Table VIII).

In the immature animals, end and side effects were both non-significant. It was concluded that the differences between the means for each corner were small, since they were not detected by the methods used.

(c) "Duplicate Cast" Data

The original data are recorded in Appendix G. These data were, as noted earlier, divided into four groups (a, b, c and d) for analysis. A hierarchal form of the analysis of variance was applied to each group. The results of these analyses are presented in Table X.

From these analyses the components of variance were calculated and are given in Table XI.

**Table X**

Analyses of Variance of the "duplicate cast" bearing area data. (For data groups a, b, c and d)

| Source of Variation | d.f. | MATURE FRIESIAN & JERSEY | | | | 3-YEAR-OLD & 2-YEAR-OLD JERSEY | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | (a) L.F. - R.R. Group | | (b) R.F. - L.R. Group | | (c) L.F. - R.R. Group | | (d) R.F.-L.R. Group | |
| | | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F |
| Age (or Breed) | 1 | 469.1425 | 45.50** | 179.8801 | 17.60** | 5.6074 | 1.66N.S. | 10.4618 | 2.32N.S. |
| Animals within Ages | 8 | 10.3100 | 5.80** | 10.2183 | 2.31NS | 3.3810 | 5.82** | 4.5026 | 6.91** |
| Corners within Animals | 10 | 1.7782 | 17.39** | 4.4182 | 57.16** | 0.58066 | 9.07** | 0.65190 | 6.88** |
| Casts within Corners | 20 | 0.1022 | 41.23** | 0.0773 | 56.42** | 0.06402 | 62.16** | 0.09479 | 63.41** |
| Repeats within casts | 40 | 0.0025 | | 0.0014 | | 0.00103 | | 0.00149 | |
| Total | 79 | | | | | | | | |

(** $p < 0.01$; * $p < 0.05$; N.S. : $p > 0.05$)

Table XI

The Components of Variance for each analysis group (a,b,c and d) of "duplicate cast" data.
(calculated from Analysis of Variance Table X)

| Source of Variation | d.f. | Expectation of Mean Square | Component | Source of Estimate | | | |
|---|---|---|---|---|---|---|---|
| | | | | (a) L.F. - R.R. | (b) R.F. - L.R. | (c) L.F. - R.R. | (d) R.F. - L.R. |
| Age (or Breed) | 1 | $s_m^2 + 2s_d^2 + 4s_c^2 + 8s_b^2 + 40s_a^2$ | $s_a^2$ | 11.47 | 4.24 | 0.0556 | 0.149 |
| Animals within Ages | 8 | $s_m^2 + 2s_d^2 + 4s_c^2 + 8s_b^2$ | $s_b^2$ | 1.067 | 0.725 | 0.350 | 0.481 |
| Corners within Animals | 10 | $s_m^2 + 2s_d^2 + 4s_c^2$ | $s_c^2$ | 0.419 | 1.08 | 0.129 | 0.139 |
| Casts within corners | 20 | $s_m^2 + 2s_d^2$ | $s_d^2$ | 0.0499 | 0.038 | 0.0315 | 0.0467 |
| Repeats within casts | 40 | $s_m^2$ | $s_m^2$ | 0.0025 | 0.0014 | 0.0010 | 0.0015 |
| Total | 79 | | | | | | |

The standard deviations of casting and measurement techniques were also calculated from Table XI and are shown in Table XII.

Table XII

Standard Deviations of casting and measurement Techniques (sq.in.)

| Source | | Casting $S_d$ | Measurement $S_m$ |
|---|---|---|---|
| Mature Friesian | (a) | 0.223 | 0.0498 |
| and Jersey | (b) | 0.195 | 0.0360 |
| 3 & 2-year-old | (c) | 0.178 | 0.0351 |
| Jersey | (d) | 0.216 | 0.0387 |

These estimates showed that both techniques were of a satisfactory repeatability, and that the measurement technique was of a much higher order of repeatability than the casting technique.

The contribution made by casting to the total variation was small, (Table XI) and that due to measurement negligible, being less than 0.2 per cent in all cases. The component of the variance due to casting was of a similar magnitude in all groups (a, b, c and d). Casting contributed less than 0.6 per cent of the total variation in the mature groups, a and b, where there was a large component due to breed. In the immature Jersey groups, c and d, the age component corresponding to the breed component was small, and the variation due to casting was approximately 6 per cent.

In Table X the high significance of the casts within corners effect in all groups, was attributed to the higher repeatability of the measurement technique compared to the casting technique.

The corners within animals effect was likewise highly significant in all groups. The contribution of the component of variance due to corners was slightly larger in the mature groups, a and b, but there its effect was overshadowed by the large component of the variance due to breed. The corner effect may represent an end effect, side effect or an end side interaction. All that can be deduced from this part of these analyses is that the measurement techniques employed, detected highly significant differences between diagonally opposite hooves within animals. The variation between these hooves made an important contribution to the total variation.

The animals within ages effect was highly significant in the immature groups c and d (Table X) and accounted for the major part of the variation. In the mature Friesian and Jersey groups, a and b, the animals within ages effect was highly significant in a, but non significant in b. Since there were only five animals per breed sub class, such sampling variation was to be expected. The component of variance due to animals within ages, in groups a and b was, however, quite large and of the same magnitude as corners within animals.

The breed effect in the mature Friesian and Jersey groups a and b was highly significant (Table X) and the breed component was the major source of variation (Table XI).

In the immature Jersey groups, c and d, the age effect corresponding to the breed effect was non significant, and its contribution to the variance was of the same order of magnitude as that due to corners within animals.

5. Discussion and Conclusions

The data concerned with the hooflet bearing areas of the Jersey animals showed that the two claws of the hoof were very similar in area. Although differences between hooflet pairs were small, a definite pattern of hooflet size was shown to exist within the animal. In this pattern strong bilateral symmetry was evident. However, the pattern in front hooves was the exact reverse of that in rear hooves. Reference to Sisson (1914) revealed no anatomical features which could account for these front to rear differences.

The difference in area between hooflet pairs was considered too small to be of importance in trampling problems. It was therefore concluded that at the present stage of development of the theory of trampling, further investigation of the relative areas of the claws of the hoof was unwarranted.

The postulate that Friesians, the larger breed, would have larger hoof factors than Jerseys, was supported by the results of both "one cast per corner" and "duplicate" cast data. No information on hoof shape in the mature Friesians was obtained and the use of the 6/20 inch contour in both breeds makes the comparison purely empirical. But a difference in mean bearing area of 3.73 square inches was demonstrated, and the techniques were shown to be of a suitable repeatability for the purpose of making this comparison.

The hypothesis that mature animals would have larger hoof factors than immature animals was, within the Jersey breed, supported by the results of the "one cast per corner" data. The mean bearing area for mature Jerseys was 0.74 square inches larger than that for the 3-year-olds, the mean for which was, in turn, 0.57 square inches larger than the mean for the 2-year-olds. These differences were shown to be statistically significant when the appropriate mean square was tested against the variation within corners within ages. But in the "duplicate cast" data, with only five animals per age sub group, instead of ten, the effect of age in the immature Jerseys, when tested against the variation of animals within ages, was non significant. This non significant result was attributed to the fewer animals per age class and to the different nature of the test applied.

The within cow bearing area relationships were investigated for the purpose of providing information from which to design future sampling procedures. Thus the lack of any evidence of a sides effect in the "one cast per hoof" data is important and may be taken as evidence of bilateral symmetry.

Similarly the significant, though small, difference between front and rear ends in the mature Jersey and Friesian animals, indicates that if there is any pattern of hoof size within mature animals of each breed, then it is a tendency for the front hooves to be larger than the rear. In immature Jerseys although the front hooves were the larger this end difference was non significant. Thus the hypothesis that the front hooves are the larger must be regarded as not proven.

It may be concluded therefore that for the purposes of future sampling of hooves within the mature cow, if two casts per cow were to be taken, then one front and one rear hoof should be moulded at random between sides.

The duplicate cast data was not intended to provide detailed information on within cow bearing area relationships. However, the highly significant corners within animals effect in Table X showed that, with the techniques of measurement employed, highly significant differences were detected between the individual corner means within animals. This cannot be definitely related to any overall side, end, or side by end interaction effect. (In the mature animals the significant corners difference could be in part, a result of the overall difference between the means for end found in the "one cast per corner" data).

The importance of the variation between diagonally opposite corners of the animal is given by the magnitude of the component of the variance due to corners within animals in Table XI. In Table XI individual cow variation, in the absence of the large breed effect, was the major source of variation in bearing area.

Thus it was concluded that in deciding on the number of animals to be used in future experimental work, more information would be obtained by using a larger number of animals and taking fewer measurements per cow, than by using a smaller number of animals and taking more measurements per cow.

The small size of the component of variance due to casting also indicated that better estimates of population parameters would be obtained, by taking only one cast per hoof and hoof casting a greater number of animals, rather than taking more casts per hoof of fewer animals.

The extremely small variation contributed by the measurement technique and its high repeatability, indicated that, provided precautions were taken to prevent misreading of the planimeter, only one measurement per contour line need be taken in future work.

# CHAPTER VI

## HOOF LOADS AND UNIT HOOF LOADS: GROUP I

Simple preliminary trials showed that it was possible to estimate by weighing, the static weight load on the front, or rear hooves, of dairy cattle. The estimates obtained supported the hypothesis that the front hoof load was greater than the rear hoof load. To further test this hypothesis, front end and rear end weights were taken on the Group I animals. The technique used and the results obtained are reported in Section A of this chapter. This is prefaced by a review of the literature upon which certain details of the weighing technique were based.

In Chapter II (Section A) the importance of unit hoof load in problems of hoof action was shown. Accordingly, weights and hoof moulds were taken during the same experimental period, and unit hoof loads were calculated. The results obtained are reported in Section B of this chapter.

### A. HOOF LOADS: GROUP I

1. Objects

(a) To test the technique for estimating the static hoof load on front and rear hooves of the animal, in terms of its accuracy and practical usefulness.

(b) To obtain preliminary information concerning the within cow static hoof loads and the between age (or breed) static hoof loads of the animals of Group I.

(c) To utilise information gained from (a) and (b) above in the design of Part III of the investigation.

2. Review of Literature

No reference could be found to any work describing the estimation of front and rear hoof loads. However, details of technique common to all animal weighing problems were based upon information found in the literature and summarized below.

Data concerning the body weights of some New Zealand Jersey and Friesian cattle were reported by Campbell and Flux (1952). The weights of all classes of Jersey cows (2-year, 3-year, 4-year and older) were shown to change during lactation. There was a decrease in weight for approximately two months after calving, which was more than offset by a much greater increase in weight during the remainder of the lactation period. Mature Friesian animals showed similar weight changes.

Hughes and Harker (1950) showed day to day and also diurnal variation to occur in the weights of grazing bullocks. It was estimated that bullocks increased in weight at a rate of 25 lb. per hour during grazing. Weight variation was related to the grazing habits of the animals, which were in turn influenced by time of sunrise and pasture availability, as determined by season.

More direct evidence, that large day to day and large diurnal variations in the "fill" of the alimentary tract of the ruminant were responsible for corresponding body weight variation, was supplied by the investigations of Tayler (1954).

Hughes and Harker, and Tayler, both quoted evidence showing that this variation due to "fill" was smaller in the early morning than later in the day.

Similarly in America a "Joint Committee Report" (1952) recommended that: "With milk cows, weighings should be made after morning feeding and milking but before watering".

3. Technique of Weighing

Weights were required to provide estimates of hoof load. From the literature quoted above, it was clear that hoof loads would vary throughout the season, from day to day, and during the day. No attempt was made to estimate the extent of these variations. Weighing was, however, carried out at a time when variation would be expected to be at a minimum.

The cows were weighed after milking finished at 7 a.m. It was considered that no more than six animals could be weighed each morning, without causing undue disturbance to the management pattern of the herds. The animals were weighed on an Avery 2 ton weighbridge, accurate to about 1 lb., and equipped with a race leading over the platform. The two parts of the concrete floor of the race, used during weighing, sloped slightly away from the platform of the weighbridge. At balance, the platform of the scales was approximately half an inch lower than the adjacent parts of the race. The slope of the race at each side of the weighing platform was such, that the furthermost part of the race on which the animal stood during weighing, was not more than three quarters of an inch lower than the platform of the scales.

(a) <u>Front End Hoof Load</u>

The animal to be weighed was confined in the race by movable bars so that only the front feet of the animal rested on the scales. When the animal was standing in the "static" position (already defined in Chapter II), the scales were balanced and the front end weight reading obtained. This was taken as an estimate of the static load on the front feet of the animal.

(b) <u>Total Body Weight</u>

To obtain the total body weight, the animal was moved forward on to the scales and weighed in the normal manner.

(c) <u>Rear End Hoof Load</u>

The animal was moved forward again and confined with its rear feet only on the scales. As before the rear end weight was taken as soon as the animal assumed the "static" stance. This weight was taken as an estimate of the static load on the rear feet of the animal.

During weighing, one operator was required to balance and read the scales, while another manoeuvred the animal into what was adjudged to be a "static" stance.

Two complete weighings were made on each animal. With the Jersey groups, the animals of the group to be weighed on any one particular morning were weighed consecutively facing in one direction, then reweighed facing in the other direction. The Friesian group was treated differently, in that each cow was weighed through the race in one direction, and then immediately reweighed through the race in the opposing direction.

4. Results

The original body weight data are presented in Appendix H and the front and rear hoof load data are presented in Appendix I.

(a) Observations on Techniques

In theory, the addition of front and rear hoof loads should equal the total body weight for each animal. This affords an absolute check on the accuracy of the technique used to determine hoof loads. Accordingly, for each age class, mean body weight, and mean front end plus rear end hoof load for first weighings, second weighings and first plus second weighings are given in Table XIII.

From this table, it appeared that the addition of front plus rear hoof loads underestimated the total body

Table XIII

Mean Body Weight and Mean Front End plus Mean Rear End hoofload by age (or breed) class (for first, second, and first and second weighings)

| AGE CLASS | Weighing No. | FRONT + REAR $\bar{x}$ (lb.) | NORMAL WEIGHT $\bar{y}$ (lb.) | $\bar{y} - \bar{x}$ (lb.) |
|---|---|---|---|---|
| Mature Friesian | 1 | 1184.3 | 1201.3 | + 17.0 |
| | 2 | 1184.9 | 1199.7 | + 14.8 |
| | 1 & 2 | 1184.6 | 1200.5 | + 15.9 |
| Mature Jersey | 1 | 861.9 | 866.3 | + 4.4 |
| | 2 | 860.8 | 860.9 | + 0.1 |
| | 1 & 2 | 861.35 | 863.6 | + 2.25 |
| 3 year Jersey | 1 | 719.4 | 724.1 | + 4.7 |
| | 2 | 712.9 | 716.1 | + 3.2 |
| | 1 & 2 | 716.15 | 720.1 | + 3.95 |
| 2 year Jersey | 1 | 679.0 | 672.8 | - 6.2 |
| | 2 | 668.3 | 666.6 | - 1.7 |
| | 1 & 2 | 673.65 | 669.7 | - 3.95 |

weight in heavier animals, and overestimated the weight of smaller animals. This error was less than two per cent of the mean in all cases, and was thus not considered important. This error, if not due to chance errors, could possibly be a result of the slope of the floor of the weighing race. This could cause longer animals to stand with the two feet off the platform at a lower level than the feet on the platform. Shorter animals would conversely stand with the feet on the race at a higher level than those on the platform.

It was concluded that animals should, if possible, be weighed with the feet on and off the scales at nearly the same level. This could be achieved by positioning the animal with more care.

In the Jersey groups in Table XIII the weighing number refers to first and second weighings which were separated by periods of up to one hour. The mean for each weighing number includes weighings in each direction. The lower mean, for all second weighings, was attributed to actual loss of weight due to insensible weight loss and to defaecation and urination.

In the Friesian group, this variation was virtually eliminated by reducing the time interval between repeat weighings to a few minutes. These weighings also enabled a check to be made on "direction of weighing bias". The mean front and rear hoof loads for each direction of weighing are presented in Table XIV.

Table XIV

Mature Friesian mean front and rear hoof loads for each direction of weighing

| Direction of Weighing | Front | Rear |
|---|---|---|
| 1 | 641.2 | 543.1 |
| 2 | 643.1 | 541.8 |

From Table XIV it was concluded that bias due to direction was unimportant. This conclusion was further tested by weighing an inert body at opposite edges of the weighbridge platform. No changes in the weight readings were detectable.

The greatest source of variation in the determinations of hoof load appeared to be the position of the animal. Any deviation in position, away from that of the static stance, produced large variations in the hoof load estimate.

Furthermore, any upset to the animal made balancing of the scales difficult. Thus all recordings were of necessity made with the animal virtually stationary. Excessive handling of the animals consequently increased the error due to position and slowed the rate of weighing.

Thus in the absence of any evidence of a directional error in weighing, it was concluded that future weighings should be made in only one direction over the scales. At the same time, to reduce handling of the animals, and to reduce the time interval between weighings, duplicate weighings could be made without moving the animal more than a few inches away from the first weighing position. Thus a valid estimate of the repeatability of the technique, including weighing errors and errors in positioning the animal, could still be obtained.

(b) Front end and Rear end Static hoof loads

The gross age (or breed) class variances, of the front plus rear hoof load totals for each cow, appeared to be markedly non homogeneous and to be correlated to their respective means. Accordingly the data were transformed to a log scale for the purpose of analysis. Bartlett's test of the homogeneity of variance of the transformed data yielded a corrected Chi square of 0.61 (d.f. = 3), which was non significant. The log data were coded for ease of computation by subtracting 2.0 and multiplying by 1000.

The mean front and rear end hoof loads for each age (or breed) class calculated from both the log and natural scale data are presented in Table XV.

TABLE XV

Mean front end and rear end hoof loads by age (or breed) class from log scale and natural data (lb.)

| AGE CLASS | SCALE | FRONT (F) | REAR (R) | Mean Difference (F - R) | Mean Difference Confidence Limits (95%) | ( F + R) |
|---|---|---|---|---|---|---|
| Mature Friesian | Log.<br>Nat. | 638.9<br>642.2 | 539.4<br>542.4 | 99.5<br>99.8 | -<br>±13.3 | 1178.3<br>1184.6 |
| Mature Jersey | Log.<br>Nat. | 467.1<br>468.8 | 390.6<br>392.6 | 76.5<br>76.2 | -<br>±15.9 | 857.7<br>861.4 |
| 3 year Jersey | Log.<br>Nat. | 391.7<br>392.2 | 321.3<br>322.9 | 70.4<br>70.3 | -<br>±17.1 | 713.0<br>716.1 |
| 2 year Jersey | Log.<br>Nat. | 365.3<br>366.2 | 306.1<br>307.4 | 59.2<br>58.8 | -<br>±10.7 | 671.4<br>673.6 |

TABLE XVII

Analyses of variance of front and rear end hoof loads for each age (or breed) class

| Age (or Breed) Class | | Mature Friesian | | Mature Jersey | | 3-year-old Jersey | | 2-year-old Jersey | |
|---|---|---|---|---|---|---|---|---|---|
| Source | d.f. | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F |
| Animal | 9 | 15808.9 | 45.74** | 6174.11 | 12.48** | 4001.33 | 6.97** | 2944.11 | 13.07** |
| End | 1 19 | 99401.5 | 287.62** | 58140. | 117.51** | 49491. | 86.15** | 34515. | 153.18** |
| Animal xEnd | 9 | 345.6 | 5.39** | 494.78 | 9.77** | 574.44 | 4.82** | 225.33 | 3.19** |
| Measures within End | 20 | 64.15 | | 50.65 | | 119.1 | | 57.60 | |
| Total | 39 | | | | | | | | |

(** $p < 0.01$)

The analysis of variance of the transformed data (Table XVI) showed the difference between the means for breed, and between the means for ends, to be highly significant.

Table XVI

Analysis of Variance of Group I Hoof Load data (using a log transformation, and coding the logged data by subtracting 2.0 and x 1000)

| Source | d.f. | | Mean Square | F |
|---|---|---|---|---|
| Age (or Breed) | 3 | 7 | 483931 | 133.61** |
| End | 1 | | 246412 | 68.03** |
| Age x End | 3 | | 282.7 | < 1 |
| Animals within sub classes | | 72 | 3621.9 | 3.84** |
| Measures within ends | | 80 | 94.26 | |
| Total | | 159 | | |

(** $p < 0.01$)

Each of these effects was tested against the animals within sub classes variation, in the absence of a significant age by end interaction. The end differences within each age (or breed) class are listed in Table XV. It was seen that although there was no evidence of an interaction between age and end on the log scale, these differences when converted to the natural scale were greater in the heavier animals.

From the variation of measures within ends, the standard deviation of the weighing technique was calculated and a value of ± 9.3 lb. obtained.

It was concluded that the front - rear static hoof load differences were such as to make the separate estimation of front and rear hoof loads essential, for accurate estimation of unit hoof load. It was further concluded that the weighing technique used was of sufficient repeatability to be employed for this purpose in future work. The slight modifications mentioned earlier (page 118) should, however, be incorporated into the technique.

To further characterise the front-rear differences for each age class the Analyses of Variance shown in Table XVII were carried out on the natural data. As would be expected, the differences between the means for end (Table XV) were highly significant in all age classes. The animal by end interaction, when tested against the measures within end variation, was also highly significant. However, examination of the mean difference for individual animals showed that the front end was invariably the heavier. The significant end interaction showed the end difference to vary between animals. As a measure of the uniformity of this end difference, confidence limits for the population difference within each age (or breed) class were calculated from the formulae:

$$\text{mean difference} \pm \underset{(9\ d.f.)}{t} \sqrt{\frac{2(\text{Animal x End Mean Square})}{20}}$$

The values obtained were inserted in Table XV.

The standard deviations of the measurement technique for each age (or breed) class were calculated, and the following values obtained:

| | |
|---|---|
| Mature Friesian | ± 8.0 |
| Mature Jersey | ± 7.1 |
| 3-year-old Jersey | ±10.9 |
| 2-year-old Jersey | ± 7.6 |

The technique thus appeared to be of similar accuracy in all groups. The larger mean square in the 3-year-old Jersey group was accounted for by the large discrepancy between the rear end weights (44 lb.) for cow 59 of that group. In the field this cow was noted as being difficult to weigh.

Highly significant differences between the means for age (or breed) were demonstrated in Table XVI. These differences were shown, by the use of the t test on the transformed data, to lie between the means for mature Friesians and mature Jerseys, and between the means for mature Jerseys and 3-year-old Jerseys. The difference between the means for 3-year-old Jerseys and 2-year-old Jerseys although approaching significance (at the five per cent level), was however non significant.

## B: UNIT HOOF LOADS: GROUP I

1. Objects.

(a) To test a method of calculating static unit hoof load, and to obtain preliminary information concerning the between ends within classes, and the between age (or breed) static unit hoof loads of the animals of Group I.

(b) To utilize the information obtained in (a) above in the design of Part III of the investigation.

2. Method of Calculating Static Unit Hoof Load

The static unit load for each end of each cow in the sample was calculated from the following formulae:-

$$\text{Static Unit Load (For end of animal)} = \frac{\text{Total hoof load for end.}}{\text{Total bearing area of end.}}$$

Hoof load data from Section A of this chapter and the "one cast per corner" bearing area data (Chapter V Subsection 4(b) ) were used in these calculations. Calculated in this way, unit load applies only to an animal in the static stance. It was also tacitly assumed that the end load was distributed between the two supporting hooves exactly in proportion to their bearing area. This assumption may or may not be true in the field. Nevertheless, the estimates obtained should be useful approximations to the actual, and quite suitable for comparisons between animals and classes of animals.

3. Results

The calculated unit loads are recorded in Appendix J. The mean unit hoof load for each age (or breed) class, and for

Table XVIII

Mean front end and mean rear end unit hoof loads by age (or breed) class

| AGE CLASS | FRONT (F) | REAR (R) | (F - R) | Confidence Limits 95% | $\frac{(F + R)}{2}$ |
|---|---|---|---|---|---|
| | (p.s.i.) | (p.s.i.) | (p.s.i.) | (p.s.i.) | (p.s.i.) |
| Mature Friesians | 18.827 | 16.623 | 2.204 | ± 1.061 | 17.725 |
| Mature Jerseys | 17.547 | 15.493 | 2.054 | ± 0.624 | 16.520 |
| 3-year Jerseys | 15.826 | 13.278 | 2.548 | ± 0.590 | 14.552 |
| 2-year Jerseys | 15.546 | 13.182 | 2.364 | ± 0.588 | 14.364 |

Table XIX

Analysis of Variance of Mature, 3-year-old and 2-year-old Jersey, Unit hoof load data.

| SOURCE | d.f. | Mean Square | F |
|---|---|---|---|
| Age | 2 } 5 | 28.529 | 20.62** |
| End | 1 } 5 | 80.885 | 58.46** |
| Age x End | 2 } 5 | 0.3112 | <1 |
| Animals within classes | 54 | 1.3836 | |
| Total | 59 | | |

(**p < 0.01)

Table XX

Analyses of Variance of front and rear end unit hoof loads for each age (or breed) class

| Age (or Breed) Class | | MATURE FRIESIAN | | MATURE JERSEY | | 3-YEAR-OLD JERSEY | | 2-YEAR-OLD JERSEY | |
|---|---|---|---|---|---|---|---|---|---|
| Source | d.f. | Mean Square | F | Mean Square | F | Mean Square | F | Mean Square | F |
| Animal | 9 | 10.243 | 4.66* | 1.5885 | 2.08 N.S. | 2.5422 | 3.74* | 2.0526 | 3.04 N.S. |
| End | 1 | 14.301 | 6.50* | 21.101 | 27.68** | 32.462 | 47.74** | 27.945 | 41.35** |
| Animal x End | 9 | 2.199 | | 0.7623 | | 0.6800 | | 0.6758 | |
| Total | 19 | | | | | | | | |

(**p < 0.01; *p < 0.05; N.S.: p>0.05)

front and rear ends within age (or breed) classes, are presented in Table XVIII.

The unit load data represents a set of ratios obtained by dividing hoof load by hoof bearing area. From the information available, it was thought impossible to predict the distribution likely to result when ratios of these two variates were calculated. However, as heterogeneity did not appear to exist in the variances of the Jersey subgroups, and since the range of this data was small, it was considered feasible to apply the analysis of variance technique to the untransformed Jersey data. The variance of the Friesian data was very much greater than the variances of the Jersey groups, and therefore could not be included in the same analysis.

Table XIX gives the results of the analysis of variance of the Jersey data. This analysis showed highly significant differences to exist between the age class means. The application of the t test showed these differences to lie between the mature and immature groups. (The mean difference between mature and 3-year-olds being 1.968 p.s.i.). The difference of only 0.188 p.s.i. between 3-year-olds and 2-year-olds was non significant.

The analysis of variance (Table XIX) also showed highly significant differences to exist between the means for ends. The age by end interaction was non significant, indicating that the differences between ends were repeated in a like manner in each age class. This was further demonstrated by the analyses of variance within each age class, given in Table XX.

The difference between ends was highly significant, and of a similar magnitude ($\div$ 2 p.s.i.) in each age class (Table XVIII). In the mature Friesian group the end difference was only significant at the five per cent level, although the actual difference was of similar magnitude. The end difference, and the population confidence limits for the difference, within each age (or breed) group are given in Table XVIII.

The mean unit hoof load for the mature Friesian group was 1.2 p.s.i. larger than the mean for mature Jerseys. To test the significance of this difference the "Animals within classes" (within ends) variation was calculated for both Friesian and Jersey groups. (Within each breed group, "animals within classes" variation (d.f. = 18). = Total variation (d.f. = 29) minus variation due to ends (d.f.= 1) ). The values obtained were then used in the following form of the t test.

$$t = \bar{x} \Big/ \sqrt{\frac{EMS_1 + EMS_2}{n}}$$

where $\bar{x}$ = the difference between the two means.

$EMS_1$ and $EMS_2$ = the error mean squares, in this case "animals within classes", for each mean.

$n$ = number of measurements in each mean.

The t value obtained ($t = 1.981$) was non significant ($p<0.1; p<0.05$). It was concluded therefore that though the evidence suggested that the mature Friesians exerted a slightly greater static hoof load than the mature Jerseys, the data was not adequate to establish this conclusively.

## C: DISCUSSION AND CONCLUSIONS

It was concluded from these results, that the technique of estimating hoof loads was workable, and capable of giving results of good repeatability. The technique could be improved by slight modifications (page 118). In combination with the bearing area results, the unit hoof load data was calculated, and although a repeatability estimate could not be made, the usefulness of the unit load data was demonstrated in the results obtained from the statistical analysis.

The original hoof load data, and the derived unit load data, were analysed in a like manner. The results were found to follow a similar pattern in each set of data. Unit loads and hoof loads were greater for the front feet in every age (or breed)class. Likewise the means for ages (or breeds) fell into a similar ranking order in each set of data. However the tendency for bearing area to follow the same pattern as hoof load, partly nulified the effect of the large differences in hoof load. Thus the mean unit loads for all ages (or breeds), range only from 14.4 to 17.7 p.s.i. The compensating effect of bearing area is well illustrated in mature Jerseys and Friesians. The mean hoof load for mature Friesians was 38 per cent larger than for mature Jerseys. The mean bearing area was however 28 per cent larger for the Friesians. Thus the unit hoof load was approximately only 7 per cent greater in the Friesian age class (a difference of slightly over 1 p.s.i. which was statistically non significant).

Thus the higher front end mean hoof loads, in each age class, are a result of higher front end hoof loads, incompletely compensated for by slightly larger hoof bearing areas.

From these results, it was concluded, that in designing Part III of the investigation, measurements should be made separately for the front and rear ends of each animal. As it was not possible to estimate separately the hoof loads for left and right hooves, no comparison between sides could be undertaken. An important difference between sides in hoof load, or unit load appeared, on logical grounds, unlikely to exist. Thus one front and one rear hoof of each animal, at random between sides, could be measured. In this way a greater number of animals would be sampled, than if all four hooves were measured.

It was further concluded, that in view of the differences between front and rear ends, and of the differences between age classes, the classification of data into age classes and ends within age classes, should be retained. An examination of the sub class and age class differences, would show which sub classes and classes could be pooled, for the purpose of calculating bulk estimates. In this way also interrelations between factors, should be more apparent. For instance, a clearer picture of the way in which hoof load and bearing area act, in determining unit hoof load, should be obtained. The similtaneous measurement of hoof length and breadth, and enclosed area could also be undertaken, to provide as full a set of information as possible.

Such an investigation based on the findings of Part II is reported in Part III.

For several reasons the comparison between the Jersey and Friesian breeds was not continued further, mainly because it was thought that more useful information would be obtained by measuring all normal classes of the Jersey breed, rather than attempting a breed comparison.

The preliminary results obtained, indicated that the Friesian unit hoof load was only slightly (and non significantly) higher than for the Jerseys. The area directly covered by the Friesian feet was at the same time greater. It was impossible to pursue this comparison further, until estimates of number of footsteps per cow per day were available, for animals of each breed. In any case, until the theory of trampling effects on soil and pasture is elucidated, such comparisons unless strikingly different, are not likely to be conclusive. A first step in the elucidation of such theory, from the animal view-point, appeared to be the measurement of all relevant hoof features for all ages of one breed. Jerseys, the main dairy breed in New Zealand, were the obvious choice for such an investigation.

# PART III

## THE MEASUREMENT OF THE ANIMALS OF GROUP II

# CHAPTER VII

## INTRODUCTION TO PART III

Part III treats with the measurement, and the statistical analysis of measurements, of the bearing area, load, unit load, breadth, length and enclosed area of the hooves of five age classes of Jersey cattle.

In Chapter II, bearing area and hoof load were defined as the determinants of unit hoof load. Unit load and breadth appeared to be the main animal determinants of hoof penetration, and hence of the intensity of the effect of the foot-print on soil and pasture.

Hoof shape could not be defined mathematically, but was recognised as a third factor in problems of hoof penetration, although its exact significance was not known. However, hoof length and hoof breadth should define hoof shape sufficiently to detect any important differences. Finally the enclosed area was postulated to give an estimate of the area affected by the foot-print.

Thus, the measurements were intended to provide estimates of the main factors determining the magnitude of the effect of the foot-print, which is thus regarded as the unit of trampling.

In measuring these hoof factors, the effect of spreading of the toes of the hoof, also mentioned in Chapter II, was experimentally examined.

The objects, source and composition of the animal sample, techniques of hoof casting and toe-spreading, and the treatment of the data, which were similar for each hoof feature, are described in the following sections of this chapter.

The results, of the measurement of bearing area, load and unit load are given in Chapter VIII, and of the measurement of length, breadth and enclosed area in Chapter IX. In these chapters, discussion of results is confined to factors affecting the results, and of interrelations between the results. A summary of the results and conclusions obtained and their relation to trampling problems, is given in Chapter X.

1. Objects

(a) To obtain estimates for each of the following hoof features:-

(i) Bearing area
(ii) Static hoof load
(iii) Static unit hoof load
(iv) Breadth
(v) Length
(vi) Enclosed area

for five age classes, and for front and rear ends within the five age classes of Jersey cattle from the Massey Agricultural College pure-bred Jersey herd.

(b) To statistically evaluate the differences between the means for front and rear ends within age classes, and between the age class means, for each hoof feature.

(c) By applying an artificial toe spreading treatment to test the hypothesis; "Toe spread has a negligible effect on hoof bearing area and hoof length". Further, to obtain an estimate of the possible increase in breadth and enclosed area due to spreading. (By the definition of spreading, hoof breadth and enclosed area must increase).

(d) To obtain estimates of repeatability of the measuring techniques used, in these features unaffected by the spreading treatment.

2. Source and Composition of Sample

Seventy five female animals, comprising five age classes equal in number, were selected at random within age classes from the Massey Agricultural College pure-bred Jersey herd, previously described (page 81). The subsample number was set at fifteen per age class, as the maximum number that could, for practical reasons, be measured. Age composition was as follows:-

| | | |
|---|---|---|
| Mature (over 4 years) | Average age 5½ yrs.: | Range 4-11 yrs. |
| 3-year-olds | .. ..36¾ mths.: | ..35-39 mths. |
| 2-year-olds | .. ..25½ mths.: | ..24-28 mths. |
| 1-year-olds | .. ..13¾ mths.: | ..11-14 mths. |
| Calf | .. .. 4 weeks.: | .. 3-5 weeks. |

All animals 2-year-old or more ("herd cows") had calved in the Spring, and had been lactating for at least three weeks at the time of measurement.

The yearling animals were managed as a separate unit, and derived most of their feed from pasture. The calves were held on pasture, but fed twice daily on whole milk.

Weighing and hoof moulding of the animals were carried out between 30th August and 16th September, 1955. Each animal was hoof moulded immediately after weighing.

3. Hoof Moulding and Casting Techniques

Moulds were made of one front and one rear hoof of each animal, at random between sides. Two moulds and casts were made of each hoof selected. One mould was taken with the hooflets of the hoof in the "toes together" position, the other with the hooflets in the "toes apart" position (defined on page 52). The toes were spread with finger pressure to the maximum possible without causing discomfort to the animal.

The spreading was thus subjective and empirical. It was designed to separate hoof factors into two classes; those unaffected by spreading and those obviously affected. In the latter factors an estimate of the degree of the effect was required.

In making a mould in the "toes together" position the hooflets were held together so that the toes touched or almost touched.

Narrower key way blocks, necessitated by the small size of the hooves of the calves, were used throughout. No other alterations were made to the moulding and casting process as used in Part II.

Casts were also contourlined as previously at the $^{6}/20$ inch contour.

4. Treatment of Data

The data for each of the six hoof features were analysed separately. Firstly, in each case, the sub class means were examined for a treatment effect. If the toe spreading treatment had negligible effect, the two measurements of each hoof (toes together and toes apart casts) were treated as ordinary duplicate measurements, and used to obtain an estimate of the repeatability of the technique.

The methods used in this, and subsequent analysis of the data, is described in (a) below. The aim of these analyses was to specify and evaluate differences between age classes and between ends within age classes. From the information extracted in this way, the results of various hoof features could be compared and evaluated. Graphs were used to aid in this comparison, and to summarize the results. Then finally, it was possible to decide for each feature, which classes (or sub classes) could be combined and the estimates expressed, without undue loss of precision, in a more widely applicable form, by calculating pooled estimates for the combined classes.

In the event of an obvious treatment effect, the data for the "toes together" treatment were dealt with as in (a), except that no estimate of repeatability could be calculated. The "toes apart" data were later treated as described in (b) below.

(a) <u>For Hoof Features showing Negligible Treatment Effect and for the "Toes Together" Data of features showing a Treatment Effect</u>.

Within each age class an analysis of variance of the following form was carried out:

| Source of Variation | d.f. | |
|---|---|---|
| Animal | 14 | |
| End | 1 | 29 |
| Animal x End Interaction | 14 | |
| Measures Within Animal Ends | | 30 |
| Total | | 59 |

The measures within end mean square was used only to calculate the standard deviation of the measurement technique. This estimate of repeatability of measurement would include any extra errors introduced by the spreading treatment.

In the main part of the analysis, the animal by end interaction mean square was used to test the significance of the difference between the means for ends, and between the means for animals, the latter being an incidental test of less importance.

In the tables of means, the end differences for each class were given as front end mean minus rear end mean. (Thus a positive difference indicated that the front mean was the larger.)

The population confidence limits were calculated as follows:-

Population confidence limits.

$$= \text{mean difference} \pm t_{(0.05)} \sqrt{\frac{2\,(A.\ x\ E.I.)}{n}}$$

where:

A. x E.I. = Animal x end interaction mean square and from which the degrees of freedom for t are derived.

n = Number of measurements from which each mean was calculated.

In each hoof feature it was intended to apply the analysis of variance technique to the data for all age classes, and thus implement a test of the age class differences. However, if such tests of significance were to be valid, it was necessary to establish that the error variances of the different age classes were homogeneous. From the results obtained in Part II heterogeneity was anticipated. Thus the "animals within classes" (or strictly "animals within classes within ends") mean square was calculated for each age class as follows:-

| Source of Variation | d.f. |
|---|---|
| Total | 29 |
| Ends | 1 |
| "Animals within classes" | 28 |

Animals within classes was the error variance on which tests of homogeneity were carried out, before combining the data for each age class in the following form of analysis.

| Source of Variation | | d.f. |
|---|---|---|
| Age | 4 | |
| End | 1 | 9 |
| Age x End Interaction | 4 | |
| Animals within classes | | 140 |
| (Total) | | (149) |
| Measures within Ends | | 150 |
| Total | | 299 |

However, as Bartlett's test of homogeneity of variance (Snedecor 1946) invariably indicated heterogeneity to exist, the above form of analysis had usually to be modified, and age classes with divergent variances excluded.

Alternatively, if the relationship of the error variances to the corresponding means for each age class suggested that a transformation of the data was likely to produce homogeniety, the appropriate transformation was carried out and the tests of homogeniety repeated. Then, if homogeniety was not complete, age classes with extreme error variances were dropped from the combined analysis.

In the analysis, the measures within end mean square was used only to calculate the standard deviation of the measurement technique over all classes.

The effects in the main part of the analysis were tested against the animals within classes mean square.

In the event of a significant age effect, differences between individual age class means were tested, by applying the usual form of the t test:

$$t = \bar{\bar{x}} \quad \sqrt{\frac{2(E.M.S.)}{n}}$$

where:

$\bar{x}$ = difference between pair of means.

n = Number of measurements from which each mean was calculated.

E.M.S. = Error mean square (animals within classes) from combined analysis, and from which the appropriate degrees of freedom were derived.

Differences between the mean for any age class not included in the analysis of variance, and any other age class mean, were tested in the following approximate t test for heterogeneous variances.

$$t = \bar{\bar{x}} \quad \sqrt{\frac{E.M.S._1 + E.M.S._2}{n}}$$

Symbols as before, except that:

$E.M.S._1$ and $E.M.S._2$ = the respective error mean squares for each age class.

In the tables of means, significant differences between age class means were indicated, by joining the age classes with a straight line, on which the level of significance was denoted in the usual way.

(b) "Toes Apart" Data for Features Showing a Treatment Effect.

The toes together position was, from observations made during moulding, the normal hooflet position for animals standing on a hard surface. Thus, the toes together estimates were regarded as basic minimal values. The toes apart data were therefore used, in conjunction with the toes together data, to calculate the possible "per cent increase due to spreading" as follows:-

Per cent increase on spreading

$$= \frac{\text{Estimate for hoof with toes apart}}{\text{Estimate for hoof with toes together}} \times \frac{100}{1}$$

The mean increase on spreading for each subclass was calculated, together with the standard error of the mean increase, and included in the tables of means for the toes together data. These estimates provided an indication of the possible error that could be anticipated in measurements based only on the toes together data.

The differences between the mean increase on spreading, for each subclass may, however, be confounded by the subjective nature of the treatment, and its greater facility of application in smaller animals. Little importance can therefore be attached to these differences in treatment response.

<u>Abbreviations Used in Tables</u>

To save space in tables the following abbreviations were used:-

S.E. - Standard error of mean.

S.D. - Standard deviation of sample.

C.L's. - Population confidence limits.

Adj.Class Diff. - Adjacent class difference; denoting the difference between adjacent age class means.

In each case the mean for the older class, minus the mean for the younger class; hence negative values were possible.

The probability level of the results of the statistical tests were denoted by the following convention:

** ; $p < 0.01$: *; $p < 0.05$: (N.S.); $p > 0.05$.

# CHAPTER VIII

## HOOF BEARING AREA: STATIC HOOF LOAD: UNIT STATIC HOOF LOAD

The results of the measurements, and the analysis of measurements of hoof bearing area, static hoof load, and unit static hoof load, are given respectively in sections A,B and C of this chapter. The discussion (Section D) is confined to factors affecting the results.

### A: HOOF BEARING AREA

1. Techniques

Bearing area was measured by the planimeter measurement technique, Technique II, except that in accordance with the conclusions reached in Part II (page 111), only one measurement was made of each cast.

2. Results

The original bearing area data are recorded in Appendix L. Class, and subclass means, are given in Table XXI, and in graphical form in Figure 24.

(a) The Toe Spreading Treatment and the Repeatability of Measurement.

Within subclasses the differences between the treatment means (Table XXI) were negligible. Thus the two measurements for each hoof were treated as ordinary duplicate casts and the within age classes analyses of variance (Table XXII) were carried out. From these the standard deviations for the total measurement technique were calculated and are listed

Table XXI
Mean Bearing Area
(units sq. in.)

| AGE CLASS | FRONT Toe Position T. Mean | FRONT Toe Position S. Mean | REAR Toe Position T. Mean | REAR Toe Position S. Mean | FRONT (F) Mean | REAR (R) Mean | (F - R) Mean | (F - R) C.L's | AGE CLASS TOTAL Mean | AGE CLASS TOTAL S. E. | Adj. class diff. | Results t test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATURE | 11.06 | 11.03 | 11.89 | 11.74 | 11.04 | 11.82 | -0.77 | ±0.70 | 11.43 | ±0.27 | - | |
| | | | | | | | | | | | 0.68 | * |
| 3-YEAR-OLD | 10.44 | 10.30 | 11.14 | 11.12 | 10.37 | 11.13 | -0.76 | ±0.40 | 10.75 | ±0.17 | - | |
| | | | | | | | | | | | 1.27 | ** |
| 2-YEAR-OLD | 9.59 | 9.60 | 9.37 | 9.36 | 9.59 | 9.36 | +0.23 | ±0.53 | 9.48 | ±0.21 | - | |
| | | | | | | | | | | | 2.74 | ** |
| 1-YEAR-OLD | 7.17 | 7.07 | 6.38 | 6.36 | 7.12 | 6.37 | +0.75 | ±0.32 | 6.74 | ±0.12 | - | |
| | | | | | | | | | | | 3.36 | ** |
| CALF | 3.42 | 3.41 | 3.35 | 3.36 | 3.42 | 3.36 | +0.06 | ±0.12 | 3.38 | ±0.04 | - | |

Table XXII
Within Age Class Analyses of Variance of Bearing Area data

| SOURCE OF VARIATION | | d.f. | MATURE M. S. | MATURE F | 3-YEAR-OLD M. S. | 3-YEAR-OLD F | 2-YEAR-OLD M. S. | 2-YEAR-OLD F | 1-YEAR-OLD M. S. | 1-YEAR-OLD F | CALF M. S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Animal | | 14 | 7.0166 | 4.33** | 2.7918 | 5.28** | 4.507 | 5.00** | 1.488 | 4.41** | 0.14316 | 2.90* |
| End | (29) | 1 | 8.947 | 5.52* | 8.770 | 16.59** | 0.7958 | < 1 | 8.452 | 25.06** | 0.03163 | < 1 |
| Animal x End interaction | | 14 | 1.6215 | | 0.5286 | | 0.9022 | | 0.3373 | | 0.04939 | |
| Measures within End | | 30 | 0.06335 | | 0.04918 | | 0.02731 | | 0.06383 | | 0.00687 | |
| Total | | (59) | | | | | | | | | | |
| Standard deviation of measurement (sq.in.) | | = | ±0.25 | | ±0.22 | | ±0.17 | | ±0.25 | | ±0.083 | |
| "Animals within classes" Variation | | = | 4.319 | | 1.660 | | 2.704 | | 0.913 | | 0.0963 | |

beneath Table XXII. The estimates indicate a similar repeatability to that obtained in Part II (page 105). It may be concluded that in each age class the technique of measurement was satisfactory and little altered by the toe spreading treatment.

(b) Differences Between Ends Within Age Classes

The difference between the means for ends, within age classes, are listed in Table XXI (a positive sign indicating the front end mean to be the larger). These results and the results of the analysis of variance (Table XXII) may be summarized as follows:-

| | | |
|---|---|---|
| Mature | difference | significant and negative |
| 3-year-old | .. | highly significant .. .. |
| 2-year-old | .. | non significant and positive |
| 1-year-old | .. | highly significant .. .. |
| Calf | .. | non significant .. .. (and small in magnitude) |

It can only be concluded that the relative bearing areas of front and rear hooves vary between age classes. In general the rear hooves are the larger in 3-year-old animals and older. In 2-year-olds and younger, the front feet tend to be the larger.

The within age class analyses of variance also showed that the differences between the means for animals were highly significant in all age classes, except calves. In the calf age class these differences were only significant at the five per cent level of probability.

(c) Differences Between Age Class Means

The "animals within classes" mean squares, calculated as described in Chapter VII, are listed beneath Table XXII.

Heterogeneity of variance was shown to exist in all combinations of age classes on which an analysis of variance might have been carried out. Thus, as no simple transformation appeared applicable, differences between age class means were tested, using the t test modified for heterogeneous variances.

The difference between the means for mature and 3-year-old groups was significant at the five per cent level. All the remaining differences between adjacent age classes (Table XXI) were highly significant.

3. Discussion: Comparison of Results from Group I and Group II

The age class bearing area means were smaller for the Group II sample than for the corresponding age classes in Group I. The apparent decrease in area was in all cases greater for the front hooves (Tables XXI and VIII). Thus the statistical analyses showed, that in the mature animals of Group I, the front hooves were larger than the rear, while in the mature (and 3-year-old) animals of Group II, the rear hooves were the larger. Further evidence that this was not a freak of sampling was available from a comparison of the bearing areas of the five cows measured in both the Group I and Group II samples (Table XXIII)

Table XXIII

Bearing Area of Mature Cows Measured in Groups I and II.
(Each item is the mean of two measurements of one cast in Group I and of one measurement each of two casts in Group II)

| Cow No. | Hoof | G.I | G.II | (G.I-G.II) |
|---|---|---|---|---|
| | | (Sq.in.) | (Sq.in.) | (Sq.in.) |
| 3 | FL | 15.230 | $11.575^{++}$ | 3.655 |
| | RL | 15.405 | 13.745 | 1.660 |
| 7 | FR | 14.095 | $11.395^{+}$ | 2.700 |
| | RL | 12.615 | $11.875^{+}$ | 0.740 |
| 23 | FR | 12.605 | $9.270^{++}$ | 3.335 |
| | RL | 11.960 | $10.915^{+}$ | 1.045 |
| 53 | FL | 13.300 | $10.160^{++}$ | 3.140 |
| | RR | 12.395 | $11.990^{+}$ | 0.405 |
| 91 | FL | 14.885 | $13.690^{+}$ | 1.195 |
| | RR | 13.700 | $12.990^{+}$ | 0.710 |
| All Cows | Front | 14.023 | 11.218 | 2.805 |
| | Rear | 13.215 | 12.303 | 0.912 |

$^{+}$ Slight heel "erosion".

$^{++}$ Marked heel "erosion".

The same changes in bearing area are apparent as were found in the main sample. The small size of this sample, and the different basis of the measurements, made the data unsuited to statistical treatment. Instead, an individual study was made of the data in conjunction with the hoof casts for each hoof.

In both Group I and Group II, duplicate casts were almost identical in detail. However, casts of hooves moulded in Group I were strikingly different from casts of the same hooves moulded five months later in Group II. Differences were confined to the heels of the hooflets, and described as "heel erosion", to indicate that a loss of the softer elastic tissue forming the heel or bulb of the hooflet had occurred. The remaining surface was calloused or pitted, but hoof wall tissue appeared unaffected. "Heel erosion" occurred only in the hooves of Group II and was more marked in front hooves, where the association with decreased bearing area was, as indicated in Table XXIII, most apparent.

The heel erosion factor appeared to satisfactorily account for the general decrease in bearing area in the older age classes, and for the greater decrease in bearing area of the front hooves. Heel erosion was not apparent in 1-year-olds or calves. Its presence in 2-year-olds and 3-year-olds was observed but not specifically studied.

It was not possible to determine the cause of the heel erosion. When recognised during hoof moulding, heel erosion was not accompanied by any sign of disease or discomfort to the animal, and was thought to be an unimportant chance environmental effect. One possible cause was a softening of the hoof tissues due to wet soil conditions in the winter months, resulting in increased wear at the heel of the hoof. Some factor(s), such as the greater front end hoof load or the manner of placing the front hooves on the ground when walking etc. could then account for the greater erosion in front hooves.

## B: STATIC HOOF LOAD

1. Techniques

The weighing technique described in Chapter VI was used, incorporating the modifications recommended (page 118 and 120). Front end, rear end, and total body weights were taken in duplicate for each animal. The animals were weighed in one direction over the scales. Duplicate weights were taken with only a brief interval, for repositioning the animal, between each. Milking cows were weighed between 7 a.m. and 8 a.m., immediately after milking finished.

Yearlings were collected from pasture at 6.30 a.m. and weighing commenced at 7.30 a.m.

Calves were weighed, to the nearest half pound, on a movable platform scales. A weighing crate, and a wooden platform level with the scales, enabled front and rear weights to be measured in the same manner as for the older cattle. Calves were weighed between 3.30 p.m. and 5 p.m. immediately before their afternoon feed of milk.

2. Results

Body Weights

The normal body weights of the animals of Group II are recorded in Appendix M. and the static hoof load data in Appendix N. The mean body weight, and mean front plus rear hoof loads calculated from those data for each age class are given in Table XXIV.

Table XXV. Mean Static Hoof Loads. (units lb.)

(From natural and log scale data)

| AGE | Scale | FRONT Weighing No. 1 | FRONT Weighing No. 2 | REAR Weighing No. 1 | REAR Weighing No. 2 | FRONT (F) Mean | REAR (R) Mean | (F - R) Mean | (F - R) C.L's. | AGE CLASS TOTAL Mean | AGE CLASS TOTAL S.E. | AGE CLASS TOTAL Adj. Class Diff. | AGE CLASS TOTAL Results t test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATURE | Nat. | 400.1 | 401.1 | 336.0 | 336.3 | 400.6 | 336.1 | 64.5 | ±9.5 | 368.4 | — | | |
| | Log. | | | | | 395.6 | 329.8 | | | 361.2 | ±12 | 23.0 | |
| 3-YEAR-OLD | Nat. | 371.5 | 373.7 | 308.3 | 311.4 | 372.6 | 309.8 | 62.8 | ±8.9 | 341.2 | — | | |
| | Log. | | | | | 371.2 | 308.1 | | | 338.2 | ±6.2 | 32.2 | ** ** |
| 2-YEAR-OLD | Nat. | 335.5 | 334.9 | 283.1 | 283.5 | 335.2 | 283.3 | 51.9 | ±8.3 | 309.3 | — | | |
| | Log. | | | | | 333.1 | 281.1 | | | 306.0 | ±5.6 | 122.4 | |
| 1-YEAR-OLD | Nat. | 205.9 | 209.2 | 164.2 | 163.3 | 207.6 | 163.8 | 43.8 | ±6.0 | 185.7 | — | | ** |
| | Log. | | | | | 207.0 | 162.8 | | | 183.6 | ±3.3 | 151.8 | |
| CALF | Nat. | 38.0 | 38.3 | 26.4 | 26.9 | 38.1 | 26.7 | 11.4 | ±1.0 | 32.4 | — | | ** |
| | Log. | | | | | 38.0 | 26.6 | | | 31.8 | ±0.6 | — | |

(Adj. Class Diff. values and t test results are printed between adjacent age classes, with brackets joining the classes compared.)

Table XXVI.

Within age class Analyses of Variance of static hoof load data.

| SOURCE OF VARIATION | d.f. | | MATURE M. S. | MATURE F | 3-YEAR-OLD M. S. | 3-YEAR-OLD F | 2-YEAR-OLD M. S. | 2-YEAR-OLD F | 1-YEAR-OLD M. S. | 1-YEAR-OLD F | CALF M. S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Animal | (29) | 14 | 17119.0 | 5.82** | 4172.6 | 16.05** | 5289.5 | 23.81** | 930.8 | 7.91** | 25.89 | 7.81** |
| End | | 1 | 62339.0 | 212.1** | 59095.0 | 227.3** | 40456.0 | 182.1** | 28777.0 | 244.5** | 1966.5 | 593.4** |
| Animal x End interaction | | 14 | 293.9 | | 260.0 | | 222.2 | | 117.7 | | 3.314 | |
| Measures within End | 30 | | 21.67 | | 22.93 | | 21.40 | | 16.40 | | 0.9127 | |
| Total | 59 | | | | | | | | | | | |
| Standard deviation of measurement (lb.) | | | ±4.7 | | ±4.8 | | ±4.6 | | ±4.0 | | ±0.96 | |

Table XXIV

Mean Front plus Rear and Normal Body Weight by Age Classes.

| Age Class | Front + Rear (x) | Normal Weight (y) | Difference (y-x) |
|---|---|---|---|
| | (lbs.) | (lbs.) | (lbs.) |
| Mature | 736.7 | 742.0 | + 5.3 |
| 3-year-old | 682.4 | 684.0 | + 1.6 |
| 2-year-old | 618.5 | 620.8 | + 2.3 |
| 1-year-old | 371.3 | 371.9 | + 0.6 |
| Calf | 64.8 | 64.4 | - 0.4 |

Within age classes, the differences between the means from each source indicate only negligible bias in the technique used to measure hoof loads, when used as a method of estimating total body weight.

Front and Rear End Static Hoof Loads

Age class and subclass means, from the static hoof load data in Appendix N, are given in Table XXV, and in graphical form in figure 22.

(a) Repeatability of Measurement Technique

The means for first and second weighings, within subclasses (Table XXV), show little sign of any bias in favour of either first or second weighings. From the within age class analyses of variance (Table XXVI), the standard deviation of the measurement technique for each age class was calculated. The values obtained (listed beneath Table XXVI) reflect the difficulty of maintaining the animal in the "static" stance during weighing. The indicated repeatability is nevertheless higher than that obtained in Part II (page 124), probably as a result of eliminating the time interval between repeat weighings. In the calf age class, the lighter scales gave a higher repeatability, though in relation to the mean this repeatability was slightly lower than in other classes.

(b) Differences Between Ends Within Ages

Within each age class, the mean load on the front hooves was highly significantly greater than that for the rear (Tables XXV and XXVI). As would be expected, the end difference was greater in the older (and heavier) age classes.

The within age class analyses of variance (Table XXVI) also indicated that there were highly significant differences between the means for animals in each age class.

(c) Differences Between Age Class Means

The "animals within classes" variation was calculated for each age class as described in Chapter VII. The heterogeneity of these variances was such, that the data was transformed to logarithms so that the 3-year-old, 2-year-old, 1-year-old and calf age classes could be combined in the analysis of variance in Table XXVII. (Bartlett's test of homogeneity of variance, for this grouping, gave a chi-square value of 4.68; d.f.= 3 which was non significant). The mature class (log. scale error variance = 0.01282) could not be included in this analysis.

Age class and subclass mean hoof loads derived from the logarithm scale data are given in Table XXV.

Table XXVII

Analysis of Variance of Static Hoof Load Data for 3-year-old, 2-year-old, 1-year-old and Calf Age Classes (data transformed to logarithms.)

| Source of Variation | d. f. | | M. S. | F. |
|---|---|---|---|---|
| Age | 3 | 7 | 13.610 | 3594.9** |
| End | 1 | | 0.6440 | 170.1** |
| Age x End Interaction | 3 | | 0.02695 | 7.12** |
| Animals within Classes | | 112 | 0.003786 | |
| (Total) | | (119) | | |
| Measures within Ends | | 120 | 0.00009363 | |
| Total | | 239 | | |

Standard deviation of measurement = +3.53 / -3.45

The standard deviation of the measurement technique (recorded beneath Table XXVII) summarizes the repeatability of the two weighing techniques over the four age classes.

In the main part of the combined analysis, all effects were highly significant. The highly significant age by end interaction indicated that the relative magnitude of the front and rear end means, on the logarithm scale varied from class to class. On the natural scale the differences between the ends (Table XXV) were obviously greater in the heavier age classes. The significant end effect indicated that the bulk means for ends (front = 176.6; rear = 139.1) were highly significantly different.

From these results, and from the results of the within age classes analyses, it seems well established that the front hooves of the Jerseys support a greater hoof load than the rear hooves, and that this end difference is greater in heavier classes.

There were also shown to be highly significant differences between the age class means. The use of the t test showed that there were highly significant differences between all age class means in the combined analysis. In addition the use of the t test, modified for heterogeneous variances, showed that the difference between the means for mature and 3-year-old classes was not significant. However the difference between the means for mature and 2-year-old classes was highly significant.

## C: UNIT STATIC HOOF LOAD

### 1. Method of Calculation

Two independent estimates of static unit hoof load ("unit load") were calculated for each hoof measured. This was possible, because all hoof load and bearing area estimates were made in duplicate. The following formula was used:-
For any hoof x, at end y.

$$\text{Unit Load} = \frac{\text{Hoof Load (for end y)}}{\text{Bearing Area (of hoof x)}} \div 2$$

It is assumed that the end load is distributed equally between left and right hooves. This is probably a close approximation for static stance, and is unlikely to produce a bias in the estimates, although variation would probably be reduced.

Table XXVIII

Mean Static Unit Hoof Load (units p.s.i.)

| AGE CLASS | FRONT (F) Mean | REAR (R) Mean | (F - R) Mean | (F - R) C.L's. | AGE CLASS TOTAL Mean | AGE CLASS TOTAL S.E. | AGE CLASS TOTAL Adj. Class Diff. | AGE CLASS TOTAL Results t test |
|---|---|---|---|---|---|---|---|---|
| MATURE | 18.30 | 14.21 | 4.09 | ±1.35 | 16.25 | ±0.42 | – 0.26 | |
| 3-YEAR-OLD | 18.05 | 13.94 | 4.10 | ±0.85 | 15.99 | ±0.30 | – 0.41 | |
| 2-YEAR-OLD | 17.60 | 15.22 | 2.38 | ±1.01 | 16.41 | ±0.30 | – 2.59 | ** |
| 1-YEAR-OLD | 14.70 | 12.93 | 1.78 | ±1.00 | 13.82 | ±0.30 | – 9.01 | ** |
| CALF | 5.59 | 4.02 | 1.56 | ±0.19 | 4.80 | ±0.06 | – | |

Table XXIX

Within Age Class Analyses of Variance of Static Unit Hoof Load Data.

| SOURCE OF VARIATION | d.f. | | MATURE M. S. | MATURE F | 3-YEAR-OLD M. S. | 3-YEAR-OLD F | 2-YEAR-OLD M. S. | 2-YEAR-OLD F | 1-YEAR-OLD M. S. | 1-YEAR-OLD F | CALF M. S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Animal | | 14 | 62.99 | 2.67* | 20.97 | 2.23 N.S. | 45.29 | 3.38* | 27.71 | 2.10 N.S. | 1.351 | 2.79* |
| End | (29) | 1 | 1004.3 | 42.54** | 1009.2 | 107.4** | 338.91 | 25.31** | 189.07 | 14.35** | 146.6 | 303.1** |
| Animal x End interaction | | 14 | 23.61 | | 9.399 | | 13.39 | | 13.18 | | 0.4836 | |
| Measures within End | 30 | | 0.5490 | | 1.039 | | 0.6122 | | 1.431 | | 0.1585 | |
| Total | (59) | | | | | | | | | | | |

Standard deviation of measurement (p.s.i.) = ±0.37 (Mature), ±0.51 (3-year-old), ±0.39 (2-year-old), ±0.60 (1-year-old), ±0.20 (Calf)

In the unit loads recorded in Appendix O, the division by 2 was omitted. The statistical analyses were carried out on this coded data, but all means presented were decoded.

2. Results

The Mean unit loads for age classes and subclasses are given in Table XXVIII and in graphical form in figure 23.

(a) Repeatability of Measurement

The standard deviations of the measurement technique, calculated from the within ages analyses of variance (Table XXIX), provide estimates of the repeatability of the measurement technique. Although errors from two sources contribute to the errors of measurement, the technique appeared satisfactory for the purposes required.

(b) Differences Between Ends Within Ages

Within each age class, the mean front end unit hoof load was highly significantly greater than the mean rear end unit load (Tables XXVIII and XXIX). The end differences were greater in the older age classes.

The within age class analyses of variance also showed that only in the mature, 2-year-old and calf age classes, were the differences between the means for animals significant ($p < 0.05$).

(c) Analysis of Combined Age Class Data

The "animals within classes" mean square was calculated for each age class. These variances were heterogeneous and no simple transformation appeared to be applicable. Thus, only the data for 3-year-old, 2-year-old, and 1-year-old classes were combined in the analysis of variance in Table XXX.

Table XXX

Analysis of Variance of Static Unit Hoof Load Data for 3-year-old, 2-year-old and 1-year-old Age Classes.

| Source of Variation | d. f. | | M. S. | F. |
|---|---|---|---|---|
| Age | 2 | 5 | 464.5 | 21.45** |
| End | 1 | | 1362.2 | 62.90** |
| Age x End Interaction | 2 | | 87.46 | 4.04* |
| Animals within Classes | 84 | | 21.66 | |
| (Total) | (89) | | | |

Bartlett's test of the homogeneity of the error variances for this grouping gave a chi-square of 3.18 (d.f.= 2) which was non significant. Data for the mature class (error variance = 43.30) and for the calf age class (error variance =0.9172) were not included in this analysis.

The significant interaction in Table XXX indicated, that the ratio of the end means within age classes varied from age class to age class in the analysis. In Table XXVIII the end difference was seen to increase steadily from 1-year-old to 2-year-old to 3-year-old classes. The bulk means for end were also shown to be highly significantly different (front = 16.78 ; rear = 14.03)

The combined analysis also showed that the differences between the age class means were highly significant. The use of the t test showed that, while the difference between 2-year-olds and 3-year-olds was non significant, all other comparisons between the classes in the analysis were highly significant.

The application of the t test modified for heterogeneous variance, showed that the differences between calf and 1-year-old, and between mature and 1-year-old classes, were highly significant. However, the differences between mature and 3-year-old, and mature and 2-year-old classes were non significant.

Thus the means for age classes comprising herd cows did not differ significantly. However the unit load for 1-year-olds was highly significantly smaller than for these age classes, but by less than 2.6 p.s.i. in all comparisons. The unit load for calves was highly significantly smaller again, being only 4.8 p.s.i.

It was thus apparent that pooling the data for 2-year-old, 3-year-old and mature classes, to provide an estimate for "herd cows", would summarize part of the results in a practically more useful and widely applicable form. The mean unit load for the new "herd cows" was 16.2 p.s.i. (S.D. = $\pm$ 2.6; number of cows in sample = 45; 4 determinations per cow). The range for this sample was 11.6 - 23.7 p.s.i.

## D: DISCUSSION

Bearing area and hoof load were considered important in trampling problems, as the joint determinants of unit hoof load (Chapter IIA). Thus, evidence indicating whether or not the unit load results were typical, is of importance in evaluating the results.

Three points may be examined:

1. The estimates obtained for hoof bearing area.

2. The estimates obtained for hoof load.

3. The proportionality between bearing area and hoof load.

1. Hoof Bearing Area

The bearing area results for Group II were lower than the corresponding estimates for Group I. The decrease was attributed to a heel erosion factor observed in herd cows of Group II and specifically studied in mature cows (Section A.3.). This may or may not have been a regular seasonal change.

2. Hoof Load.

The animals of Group II were weighed during that portion of the lactational season, at which Campbell and Flux (1952) found the body weights of lactating Jersey animals to be the lowest. Thus for herd cows the mean body weights obtained were lower than the corresponding means for Group I. Further, the actual estimates obtained for all classes of Group II were in the vicinity of ten per cent lower than the corresponding means reported by Campbell and Flux. Altogether this suggests that the body weight estimates obtained in Group II were, if anything, lower than usual. Furthermore, an increase in body weight and hence in hoof load, could be expected to occur in all age classes as the season progressed. In the immature groups this would be a result of normal growth. However, growth would also be expected to produce a compensating, or partly compensating, increase in bearing area.

3. The Proportionality Between Bearing Area and Hoof Load.

In the mature animals of Group II, the smaller hoof load accompanied by the smaller bearing area, yielded a unit hoof load estimate similar to that obtained for Group I. In 2-year-olds and 3-year-olds the decrease in bearing area more than compensated for the smaller loadings, so that unit load estimates were almost 2 p.s.i. greater for Group II. The apparent compensating action, if due to heel erosion coinciding with a normal seasonal reduction in body weight, appeared accidental; but both changes could be seasonal in occurrence.

Between the age classes of Group II a constant proportionality between hoof load and bearing area appeared to be reached at the 2-year-old class, and maintained in older age classes. In younger classes there was clearly no linear proportionality between load and bearing area. Weight increased more rapidly than bearing area, particularly between calves and 1-year-olds, resulting in a rapid increase in unit hoof load.

Between ends within age classes the front hooves were shown consistently to support heavier hoof loads than the rear hooves, probably because the front feet have to support the head and neck as well as the front portion of the body.

The unit loads were, at the same time, consistently greater for the front hooves. Although by no means conclusive, the bearing area measurements suggest that the front hooves were proportioned to partly, but not completely, compensate for the greater load. The mature and 3-year-old classes of Group II were direct exceptions. This could be attributed to greater heel erosion in the front hooves; probably an environmental, rather than an inherent hoof size feature.

More conclusive was the evidence obtained from the measurement of breadth (see later). Breadth, defined by the hard hoof wall, was unaffected by heel erosion, and proved to be virtually independent of contour height. The results showed that front hooves were broader than the rear in all classes, significantly so in 2-year-olds and older. This implied that the basic structure of the front hooves was proportioned to support the larger load. This did not come to full expression in the 2-year-olds and older animals of Group II, due to greater heel erosion in the front hooves, probably an environmental effect.

It is interesting to note that the results obtained by Kelly (page 55) are in general agreement with the above. (presumably heel erosion was absent in Kelly's animals)

Other causes of variation in unit load may be postulated. Changes in rumen "fill", pregnancy and degree of fatness or condition of the animal are further factors that might influence unit load. It appears therefore that the estimates of variation obtained will be underestimates. However there is a good chance that the multiplicity of factors involved will, on the average, cancel one another out. Thus, the estimates obtained of mean unit load may be fairly typical of the average for all seasons. Thus the corresponding estimates from Group I and Group II, did not show a very large seasonal change.

# CHAPTER IX

## HOOF LENGTH : HOOF BREADTH : ENCLOSED AREA OF THE HOOF.

The measurements obtained of hoof length, hoof breadth, and enclosed area, and the statistical analysis of the measurements, form the subject of sections A, B and C of this Chapter. In Section D the main differences between the age class variances for each set of hoof measurements are summarized. The discussion ( Section E) is confined to factors affecting the results, and to relationships between the results.

### A: HOOF LENGTH.

#### 1. Techniques

Hoof length was measured with the hoof cast levelled in the measuring board. Two straight edges were used to demarcate front and rear terminal lines, as defined on page 52. The distance between the mid points of the terminal lines was measured with friction callipers, to the nearest one tenth of an inch.

#### 2. Results

The original hoof length data are recorded in Appendix P. Class and subclass means are presented in Table XXXI, and in graphical form in Figure 25.

Table XXXI

Mean Hoof Length (in.)

| AGE CLASS | Scale | FRONT Toe Position T. | FRONT Toe Position S. | REAR Toe Position T. | REAR Toe Position S. | FRONT Mean (F) | REAR Mean (R) | (F - R) Mean | (F - R) C.L's | AGE CLASS TOTAL Mean | S. E. | Adj. class diff. | Results t test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MATURE | Nat. | 4.01 | 4.11 | 4.27 | 4.31 | 4.06 | 4.29 | -0.23 | ±0.17 | 4.18 | – | – | |
| | Log. | | | | | 4.05 | 4.28 | | | 4.16 | ±0.04 | 0.09 | |
| 3-YEAR-OLD | Nat. | 3.91 | 3.95 | 4.18 | 4.26 | 3.93 | 4.22 | -0.29 | ±0.12 | 4.08 | – | – | |
| | Log. | | | | | 3.93 | 4.22 | | | 4.07 | ±0.04 | 0.28 | ** |
| 2-YEAR-OLD | Nat. | 3.76 | 3.83 | 3.79 | 3.81 | 3.80 | 3.80 | 0.00 | ±0.10 | 3.80 | – | – | |
| | Log. | | | | | 3.79 | 3.79 | | | 3.79 | ±0.04 | 0.52 | ** |
| 1-YEAR-OLD | Nat. | 3.36 | 3.37 | 3.16 | 3.21 | 3.36 | 3.18 | +0.18 | ±0.07 | 3.27 | – | – | |
| | Log. | | | | | 3.36 | 3.17 | | | 3.26 | ±0.03 | 0.97 | ** |
| CALF | Nat. | 2.31 | 2.33 | 2.28 | 2.29 | 2.32 | 2.28 | +0.04 | ±0.04 | 2.30 | – | – | |
| | Log. | | | | | 2.31 | 2.28 | | | 2.30 | ±0.02 | | |

Table XXXII

Within Age Class Analyses of Variance of Hoof Length data

| SOURCE OF VARIATION | d.f. | MATURE M.S. | MATURE F | 3-YEAR-OLD M.S. | 3-YEAR-OLD F | 2-YEAR-OLD M.S. | 2-YEAR-OLD F | 1-YEAR-OLD M.S. | 1-YEAR-OLD F | CALF M.S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Animal | 14 | 0.2050 | 2.10 (N.S.) | 0.1373 | 3.14* | 0.1744 | 5.28** | 0.08945 | 5.03** | 0.02036 | 3.61* |
| End | (29) 1 | 0.7935 | 8.14* | 1.2326 | 28.18** | 0.0001 | $<1$ (N.S.) | 0.4860 | 27.32** | 0.01667 | 2.98 (N.S.) |
| Animal x End interaction | 14 | 0.09743 | | 0.04374 | | 0.03304 | | 0.01779 | | 0.005593 | |
| Measures within End | 30 | 0.01283 | | 0.00800 | | 0.004833 | | 0.0090 | | 0.0020 | |
| Total | (59) | | | | | | | | | | |
| Standard deviation of measurement. (in.) | | ±0.113 | | ±0.089 | | ±0.070 | | ±0.095 | | ±0.045 | |

(a) The Toe Spreading Treatment and Repeatability of Measurement.

The spreading treatment appeared to produce a negligible increase (<0.1 in.) in mean hoof length in each subclass (Table XXXI). This effect, even if statistically significant, was of no practical importance. Despite its inclusion in the statistical analysis as part of the errors of measurement, the standard deviation of the measurement technique within age classes (listed beneath Table XXXII) indicated a high repeatability.

(b) Differences Between Ends Within Age Classes.

The differences between the means for end within age classes are listed in Table XXXI, a positive sign indicating that the front end mean is the larger. The results of the tests of significance of this end difference, from the within age class analyses of variance Table XXXII, and the direction of the difference, may be summarized as follows:

| | | |
|---|---|---|
| Mature | difference | significant and negative |
| 3-year-old | .. | highly significant and negative |
| 2-year-old | .. | equal to Zero |
| 1-year-old | .. | highly significant and positive |
| Calf | .. | non significant and positive (but small in magnitude) |

A decrease in length of the front hooves relative to the rear was apparent in 2-year-olds and older classes (see Figure 25). All differences were small in relation to the age class means.

Significance of the differences between the means for animals was established in the 2-year-old and 1-year-old classes ($p < 0.01$), and in 3-year-old and calf classes ($p < 0.05$). In the mature class these differences were non significant.

(c) Analysis of Combined Age Class Data

The error variances ("animals within classes") for each age class were heterogeneous and appeared to be proportional to the respective age class means. The data were accordingly transformed to logarithms. The mature, 3-year-old, 2-year-old and 1-year-old age classes could then be included in the analysis of variance given in Table XXXIII. (Bartlett's test of homogeneity of the error variances for this grouping gave a chi-square value of 3.79; d.f. = 3; which was non significant). The calf age class (error variance = 0.0004930; on the logarithm scale) could not be included in this analysis.

TABLE XXXIII.

Analysis of Variance of Length Data for mature, 3-year-old, 2-year-old and 1-year-old Age Classes (data transformed to logarithms).

| Source of Variation | d. f. | | M. S. | F. |
|---|---|---|---|---|
| Age | 3 | 7 | 0.1352 | 104.3** |
| End | 1 | | 0.003913 | $3.01^{N.S.}$ |
| Age x End Interaction | 3 | | 0.009484 | 7.31** |
| Animals within Classes | 112 | | 0.001298 | |
| Total | 119 | | | |
| Measures within Ends | 120 | | 0.000115 | |
| Total | 239 | | | |

Standard deviation of measurement (in.) = + 0.095
- 0.093

The means for age classes and ends within age classes, calculated from the log scale data are included in Table XXXI. These estimates differ only very slightly from the arithmetical means.

From the combined analysis of variance (Table XXXIII) the pooled estimate of the standard deviation of the measurement technique was;

$$\begin{matrix} + 0.095 \\ - 0.093 \end{matrix}$$

In the combined analysis the bulk means for age did not differ significantly. The age by end interaction was highly significant, reflecting the change in relative magnitude of front and rear ends in the different age classes, seen previously from the within age class analyses.

There were also shown to be highly significant differences between the means for age classes. Use of the t test showed that, while the mean for mature animals did not differ significantly from 3-year-olds, all other differences were highly significant. Use of the t test modified for heterogeneous variances showed the mean for calves to be highly significantly different from that for 1-year-olds.

Although the mean for 2-year-olds was highly significantly different from 3-year-olds and mature animals, the differences were small ($< 0.4$ in.), thus the mean and standard deviation for the herd cows was calculated. The mean value for this grouping was 4.02 in.; S.D. = $\pm$ 0.31 and the range = 3.3 - 4.8.

## B: HOOF BREADTH.

1. Techniques

Hoof breadth was measured by gauging, at approximately right angles to the axis of the hoof, the maximum breadth across the twin bearing areas of the hoof. A pair of friction callipers were used.

2. Results : Toes Together Data

The original measurements of hoof breadth are recorded in Appendix Q. Since the toe spreading treatment produced an obvious increase in breadth, only the toes together data was subjected to the usual statistical analysis. From this data, the means for age classes, and ends within age classes are given in Table XXXIV and in graphical form in figure 26.

Table XXXIV

Mean Hoof Breadth and per cent increase due to Spreading

| AGE CLASS | FRONT Mean (F) | FRONT Toes Spread % Increase Mean | FRONT Toes Spread % Increase S. E. | REAR Mean (R) | REAR Toes Spread % Increase Mean | REAR Toes Spread % Increase S. E. | (F - R) Mean | (F - R) C.L's (5%) | AGE CLASS TOTAL Mean | AGE CLASS TOTAL S. E. | AGE CLASS TOTAL Adj. class diff. | AGE CLASS TOTAL Result t test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | in. | % | ± % | in. | % | ± % | in. | in. | in. | ± in. | in. | |
| MATURE | 3.78 | 13.5 | 1.47 | 3.64 | 11.5 | 1.31 | 0.14 | ±0.11 | 3.71 | 0.048 | - 0.08 | ** |
| 3-YEAR-OLD | 3.75 | 12.0 | 0.76 | 3.51 | 15.1 | 0.97 | 0.24 | ±0.08 | 3.63 | 0.027 | - 0.20 | ** |
| 2-YEAR-OLD | 3.57 | 13.3 | 0.70 | 3.30 | 14.5 | 1.26 | 0.27 | ±0.08 | 3.43 | 0.030 | - 0.52 | ** |
| 1-YEAR-OLD | 2.94 | 15.7 | 1.01 | 2.88 | 12.8 | 1.33 | 0.06 | ±0.09 | 2.91 | 0.026 | - 0.96 | ** |
| CALF | 1.97 | 17.6 | 1.25 | 1.92 | 18.7 | 1.74 | 0.05 | ±0.05 | 1.95 | 0.021 | - | |

Table XXXV

Within Age Classes Analyses of Variance of "Toes Together" Hoof Breadth data.

| SOURCE OF VARIATION | d.f. | MATURE M. S. | MATURE F | 3-YEAR-OLD M. S. | 3-YEAR-OLD F | 2-YEAR-OLD M. S. | 2-YEAR-OLD F | 1-YEAR-OLD M. S. | 1-YEAR-OLD F | CALF M. S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | (29) | | | | | | | | | | |
| Animal | 14 | 0.1143 | 5.37** | 0.03136 | 2.61* | 0.04407 | 3.94** | 0.02871 | 2.26(N.S.) | 0.02176 | 4.43** |
| End | 1 | 0.147 | 6.91* | 0.432 | 36.00** | 0.5333 | 47.66** | 0.0270 | 2.12(N.S.) | 0.0213 | 4.34(N.S.) |
| Animal x End interaction | 14 | 0.02128 | | 0.01200 | | 0.01119 | | 0.01271 | | 0.004907 | |

(a) Differences Between Ends Within Age Classes

Within each age class the mean breadth of the front hooves was consistently greater than for the rear. In the younger classes the difference was small ( ≑ 0.05 in.) and statistically non significant (Table XXXV). In 2-year-olds and older, the difference was again small (< 0.3 in), but significant at $p < 0.01$ for 2-year-olds and 3-year-olds, and at $p < 0.05$ for matures.

Differences between the means for animals within classes were significant in mature, 2-year-old, and calf age classes ($p < 0.01$) and in the 3-year-old class ($p < 0.05$). In 1-year-olds however, these differences were non significant.

(b) Analysis of Combined Age Class Data

The variation due to "animals within classes" for 3-year-old, 2-year-old, 1-year-old and calf classes were homogeneous and these age classes were included in the combined analysis of variance Table XXXVI. (Bartlett's test gave a chi-square of 3.68; d.f. = 3: N.S.) The mature group (error variance = 0.0678) could not be included in this analysis.

TABLE XXXVI

Analysis of Variance of Hoof Breadth Data for 3-year-old, 2-year-old, 1-year-old and calf Age Classes.

| Source of Variation | d. f. | | M. S. | F. |
|---|---|---|---|---|
| Age | 3 | 7 | 16.964 | 813.3** |
| End | 1 | | 0.7207 | 34.59** |
| Age x End Interaction | 3 | | 0.09763 | 4.69** |
| Animals within Classes | 112 | | 0.02083 | |
| Total | 119 | | | |

In the analysis the age by end interaction was highly significant, reflecting the variation in the differences between front and rear ends within age classes. However, as would be expected from the within age class analyses, the bulk mean for the front end was highly significantly larger than the mean for the rear. (Front = 3.06; rear = 2.90). The difference in breadth was, however, very slight, and only of interest as the only linear or area measurement to show a consistent end difference.

The combined analysis Table XXXVI also showed there were highly significant differences between the age class means. The use of the t test showed that all age class means were highly significantly different. The t test modified for heterogeneous variances showed further, that the difference of 0.28 inches between 2-year-olds and mature age class means, was highly significant. The negligible difference of 0.08 inches between matures and 3-year-olds was non significant.

For the purposes of relating breadth measurements to trampling, the differences between the 2-year-olds, 3-year-olds and mature animals obviously do not warrant division into separate classes. The bulk mean for "herd cows" was 3.59; S.D. $\pm$ 0.25; range = 3.1 - 4.3.

### 3. Results: Toes Apart Data

From the toes together and toes apart data the "per cent increase on spreading" was calculated for each hoof as described on page 140 The mean per cent increase for subclasses, and the standard error of the mean, are given in Table XXXIV.

The treatment produced an increase in breadth of 12 - 15 per cent in all age classes except calves, where the increase was approximately 18 per cent. It can be concluded that the treatment was effective in increasing the breadth, but due to the subjective nature of the treatment, little importance can be attached to minor differences in response.

C: ENCLOSED AREA OF THE HOOF.

1. Techniques

One measurement of the enclosed area of each hoof cast was made in the same fashion as for bearing area. Front and rear terminal lines of the cast were demarcated by two straight edges, so that enclosed area could be accurately traced with the planimeter.

2. Results "Toes Together" Data

The original enclosed area data are recorded in Appendix R. Since there was an obvious treatment effect, only the "toes together" data were subjected to the usual analysis described below.

The means calculated from the "toes together" data, for age classes, and ends within age classes are given in Table XXXVII, and in graphical form in figure 27.

## Table XXXVII

Mean Enclosed Area and per cent increase due to Spreading

| AGE CLASS | Scale | FRONT Mean (F) | FRONT Toes Spread % Increase Mean | FRONT Toes Spread % Increase S. E. | REAR Mean (R) | REAR Toes Spread % Increase Mean | REAR Toes Spread % Increase S. E. | (F - R) Mean | (F - R) C.L's. (5%) | AGE CLASS TOTAL Mean | AGE CLASS TOTAL S. E. | AGE CLASS TOTAL Adj. class diff. | AGE CLASS TOTAL Result t test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | sq.in. | % | % | sq.in. | % | % | sq.in. | sq.in. | sq.in. | sq.in. | sq.in. | |
| MATURE | Nat. | 13.88 | 12.63 | ±0.84 | 13.98 | 12.37 | ±1.11 | -0.09 | ±0.67 | 13.93 | – | – | |
| | Log. | 13.79 | | | 13.93 | | | | | 13.86 | ±0.22 | | |
| | | | | | | | | | | | | 0.74 | * |
| 3-YEAR-OLD | Nat. | 13.10 | 13.13 | ±1.54 | 13.24 | 17.34 | ±1.04 | -0.14 | ±0.50 | 13.17 | – | – | |
| | Log. | 13.05 | | | 13.20 | | | | | 13.12 | ±0.21 | | |
| | | | | | | | | | | | | 1.63 | ** |
| 2-YEAR-OLD | Nat. | 11.89 | 15.61 | ±1.08 | 11.20 | 16.08 | ±1.24 | +0.69 | ±0.46 | 11.55 | – | – | |
| | Log. | 11.84 | | | 11.16 | | | | | 11.50 | ±0.18 | | |
| | | | | | | | | | | | | 3.22 | ** |
| 1-YEAR-OLD | Nat. | 8.56 | 19.38 | ±1.42 | 8.06 | 17.77 | ±2.63 | +0.50 | ±0.32 | 8.31 | – | – | |
| | Log. | 8.52 | | | 8.04 | | | | | 8.28 | ±0.13 | | |
| | | | | | | | | | | | | 4.30 | ** |
| CALF | Nat. | 4.01 | 20.28 | ±1.26 | 3.96 | 19.74 | ±1.84 | +0.06 | ±0.17 | 3.99 | – | – | |
| | Log. | 4.00 | | | 3.95 | | | | | 3.98 | ±0.06 | | |

## Table XXXVIII

Within Age Class Analyses of Variance of Enclosed Area data

| SOURCE OF VARIATION | d.f. | MATURE M. S. | MATURE F | 3-YEAR-OLD M. S. | 3-YEAR-OLD F | 2-YEAR-OLD M. S. | 2-YEAR-OLD F | 1-YEAR-OLD M. S. | 1-YEAR-OLD F | CALF M. S. | CALF F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | (29) | | | | | | | | | | |
| Animal | 14 | 3.793 | 5.17** | 1.692 | 4.16** | 1.884 | 5.46** | 0.7324 | 4.34** | 0.1110 | 2.24(N.S.) |
| End | 1 | 0.0644 | $<1$(N.S.) | 0.1388 | $<1$(N.S.) | 3.536 | 10.26** | 1.8401 | 10.91** | 0.0224 | $<1$(N.S.) |
| Animal x End interaction | 14 | 0.7337 | | 0.4065 | | 0.3447 | | 0.1687 | | 0.04946 | |

(a) Differences Between Ends Within Age Classes

The differences between the means for ends within ages were small, and only of interest because of the similar pattern to that found in bearing area and length. The direction of the differences and the tests of significance (Tables XXXVII ahd XXXVIII) may be summarized as follows:

| | | |
|---|---|---|
| Mature | difference | non significant and negative |
| 3-year-old | .. | .. .. .. .. |
| 2-year-old | .. | highly significant and positive |
| 1-year-old | .. | .. .. .. .. |
| Calf | .. | non significant and positive (but small in magnitude) |

The within age class analyses also showed that there were highly significant differences between the means for animals in all age classes except calves. In this also there was a similarity to the bearing area results.

(b) Analysis of Combined Age Class Data

The "animals within classes" mean square was calculated for each age class. These variances were heterogeneous, but the relationship to the means was such,that transforming the data to logarithms appeared likely to reduce the heterogeneity. Bartlett's test of the homogeneity of the error variances of the transformed data gave a non significant chi-square value of 5.8(d.f. = 4). All age classes could thus be included in the analysis of variance Table XXXIX.

Class and subclass means derived from the transformed data given in Table XXXVII, differed only slightly from the arithmetical means.

TABLE XXXIX

Analysis of Variance of Enclosed Area Data for All Age Classes.

| Source of Variation | d. f. | | M. S. | F. |
|---|---|---|---|---|
| Age | 4 | | 1.4974 | 1071.1** N.S. |
| End | 1 | 9 | 0.003408 | 2.44 N.S. |
| Age x End Interaction | 4 | | 0.001718 | 1.23 |
| Animals within ages | 140 | | 0.001398 | |
| Total | 149 | | | |

In the combined age class analysis the effects of end, and of the age by end interaction, were both non significant, reflecting the small magnitude of the ends within subclass differences already mentioned.

The analysis also showed that there were highly significant differences between the age class means. The t test was used to show that all differences between these means were significant ($p < 0.05$ for the difference between mature and 3-year-olds, and $p < 0.01$ in all other comparisons).

Although the differences between the 2-year-olds, 3-year-olds and mature age classes were significant, the actual differences were sufficiently small to make the pooling of these age classes feasible. The estimate obtained for the mean of this pooled "herd cow" class was 12.9 sq. in. (S.D. = $\pm$ 1.6; range = 9.4 - 17.0).

### D: SUMMARY: DIFFERENCES BETWEEN THE AGE CLASS VARIANCES FOR ALL HOOF FEATURES

The patterns formed by the error variances (animals within classes) for each age class were, in general, similar for each hoof feature. The variance for mature animals was invariably the largest, generally markedly so. The age range of 4 - 11 years could account for the large variability.

The 3-year-old, 2-year-old and 1-year-old classes form an intermediate group of variances in some cases homogeneous, and/or showing proportionality to the respective means.

The variances for the calf age class were invariably the smallest. Apparently the variation accompanying the small mean values was small also. The variation in ages was small; the range being only 3-5 weeks. Again environmental wear factors, operating for an average of four weeks at a mean unit hoof loading of 4 p.s.i., could not be expected to produce as much variation as in older animals.

### E: DISCUSSION

#### 1. Length and Breadth

Figures 25 and 26 summarize the estimates obtained for length and breadth. The graphs of the age class means are similar in form. The intervals between adjacent classes decrease from the largest, between calves and 1-year-olds, to the smallest between 3-year-olds and matures.

However the graphs of the subclass means (Figures 25. and 26.) form contrasting patterns. On the other hand, the pattern of the end differences for hoof length corresponds closely to that found in bearing area (Figure 24.). The results of the tests of significance summarized on pages 144 and 163 for length and bearing area are also almost identical. This, and the nature of the heel erosion factor, suggested that the length of the front hooves was reduced by heel erosion, while breadth was unaffected.

The breadth of the hoof would not be expected to vary due to wear, since breadth is defined by the tough and rigid hoof wall tissue, which at the sides of the hoof is approaching the perpendicular. Again, since the maximum breadth occurred almost at ground level, the contour height of measurement had virtually no effect on the breadth. Thus, breadth measured with the toes of the hoof together, is probably the best measure of the size of the structural framework of the hoof.

As measured by breadth, the front hooves were slightly larger than the rear. In 1-year-olds and calves, however, this difference was very small and non significant.

2. Breadth, Enclosed Area and the Spreading Treatment

Breadth and enclosed area were the only hoof features affected by the toe spreading treatment. The mechanism is obvious. The practical significance is less clear. It was found that the toes could be easily spread on the raised hoof. However in most cases, as the hoof penetrated the wax, considerable pressure was required to keep the toes spread, especially with larger animals. Thus it is very likely that in the older and heavier animals the toes were not spread to the maximum at termination of penetration. At termination of penetration toe position was fairly stable.

Against this, is the argument that the wax should approximate to a moist plastic soil; thus if pressure was applied to keep the toes apart, the amount of spread likely to occur in the field was probably exceeded. Little importance is therefore attached to the differences in subclass response. Most important were the findings that bearing area (and hence unit load) and length were unaffected. The increases in breadth and enclosed area are taken to mean that true estimates of these factors can only be obtained under field conditions. Such estimates may be larger by as much as 10-20 per cent.

The toes together treatment was not completely effective. In some hooves it was impossible to obtain a mould without slight spreading occurring. Spreading to approximately $\frac{1}{8}$ inch at the toes was not considered a disadvantage, particularly if it appeared to be natural for the hoof. A spread of $\frac{1}{4}$ inch or more was considered excessive, and a fresh attempt was made to obtain a mould with, if possible, less spread.

3. <u>Hoof Shape</u>

Hoof shape can be partially defined by the ratio of breadth to length. The ratios $\frac{\text{Mean Breadth}}{\text{Mean Length}} \times \frac{100}{1}$ for each subclass are given below in order, for each age class from calf to mature classes.

| | | | | | |
|---|---|---|---|---|---|
| Front. | 84.9; | 87.5; | 94.0; | 95.4; | 93.1. |
| Rear. | 84.3; | 90.6; | 86.8; | 83.2; | 84.8. |

The ratios indicated only minor shape changes in rear hooves over the five age classes studied. The relative shortening of the front feet in the older ages appeared to be due to the heel erosion factor. The practical significance of this change, of approximately ten per cent units, is probably small.

However any investigation of hoof shape would obviously have to deal with front and rear hooves separately, and also assess the full nature and frequency of the erosion factor.

4. Bearing Area and Enclosed Area

The graphs for bearing area and enclosed area were generally similar (Figures 24 and 27). The enclosed area included the cleft between hooflets, and was consequently approximately twenty per cent larger than bearing area in all classes and subclasses. Within classes, the differences between the end means for enclosed area were consistent with the presence of a slight heel erosion effect, parallel to, but less marked than that observed in bearing area.

5. Possible Correlations Between Hoof Features

From the results, and on logical grounds, it seemed likely that the bearing area and enclosed area of the hoof could be predicted from direct linear measurements of the hoof. Since area represents a length squared, some function of (length multiplied by breadth), appears a logical choice.

Field experience suggested that breadth could be measured directly on the hoof. This would be a measurement sensitive to hoof size, but insensitive to contour level or heel erosion. However length, from the results just presented, would be sensitive to these changes.

It appeared feasible to measure length directly, by first contourlining the heels of each hooflet, and then measuring the length of each hooflet individually.

Similarly, once the ratio of the load distribution between the front and rear hooves is known for all seasons, then hoof load could be predicted from body weight. However in this, and in other instances, where either prediction equations or correlations between factors could be developed, the uses to which the results could be put do not appear to justify the work involved.

Other more profitable lines of research, following from these results, are mentioned in the final discussion (Chapter X).

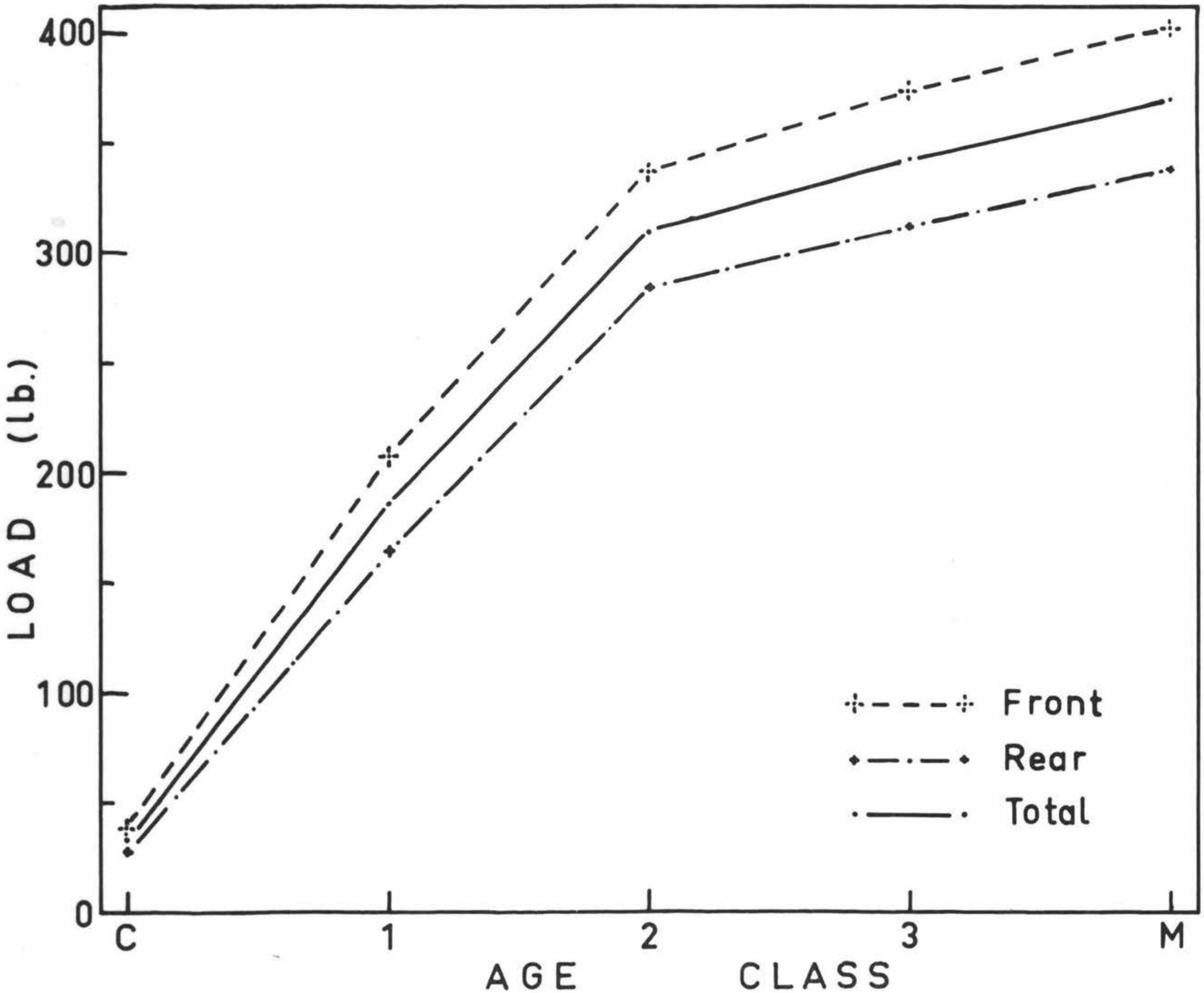



Fig. 22.— Static hoof load.

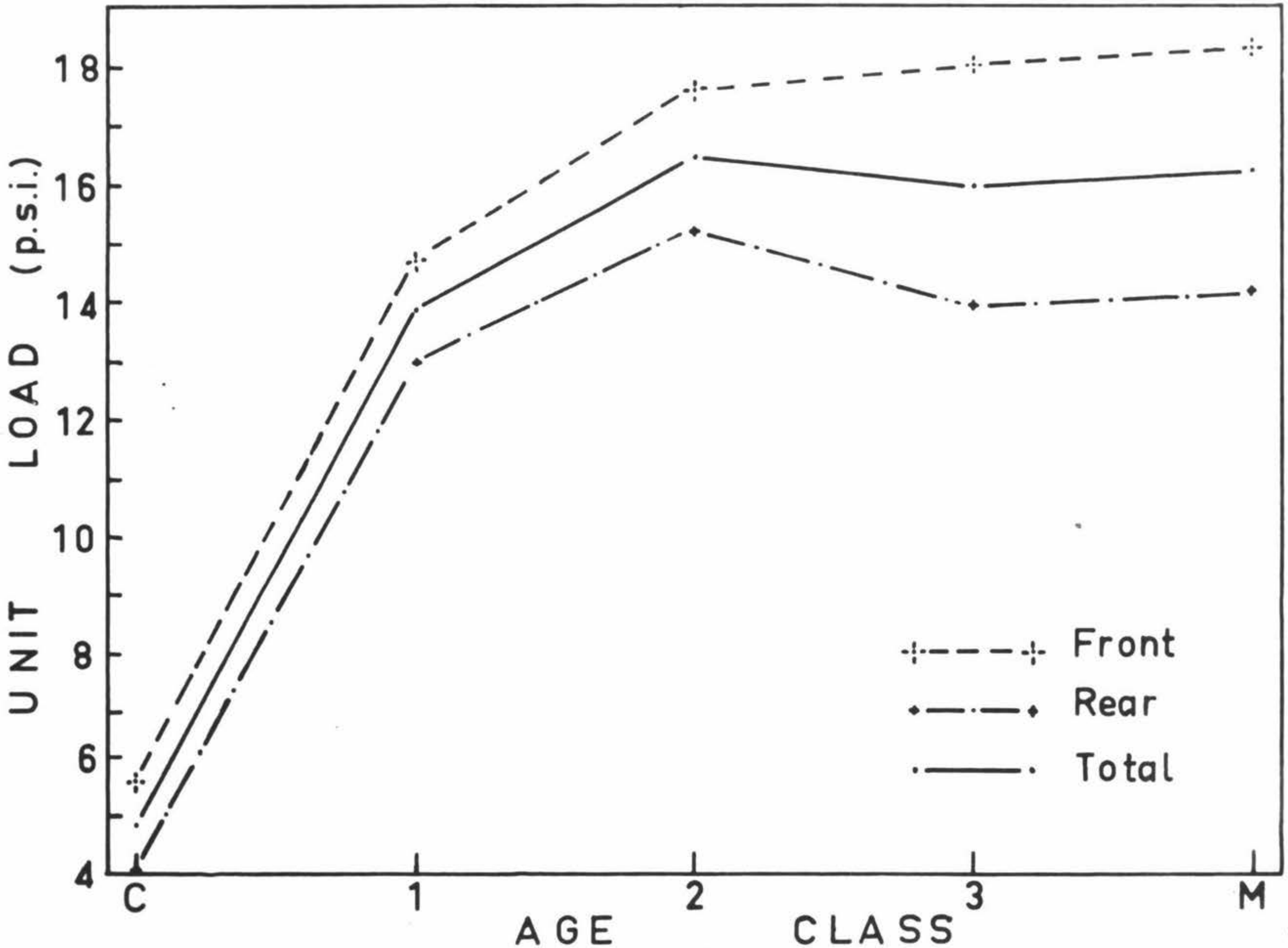


Fig. 23.— Static unit hoof load.


Fig. 24.– Bearing area.

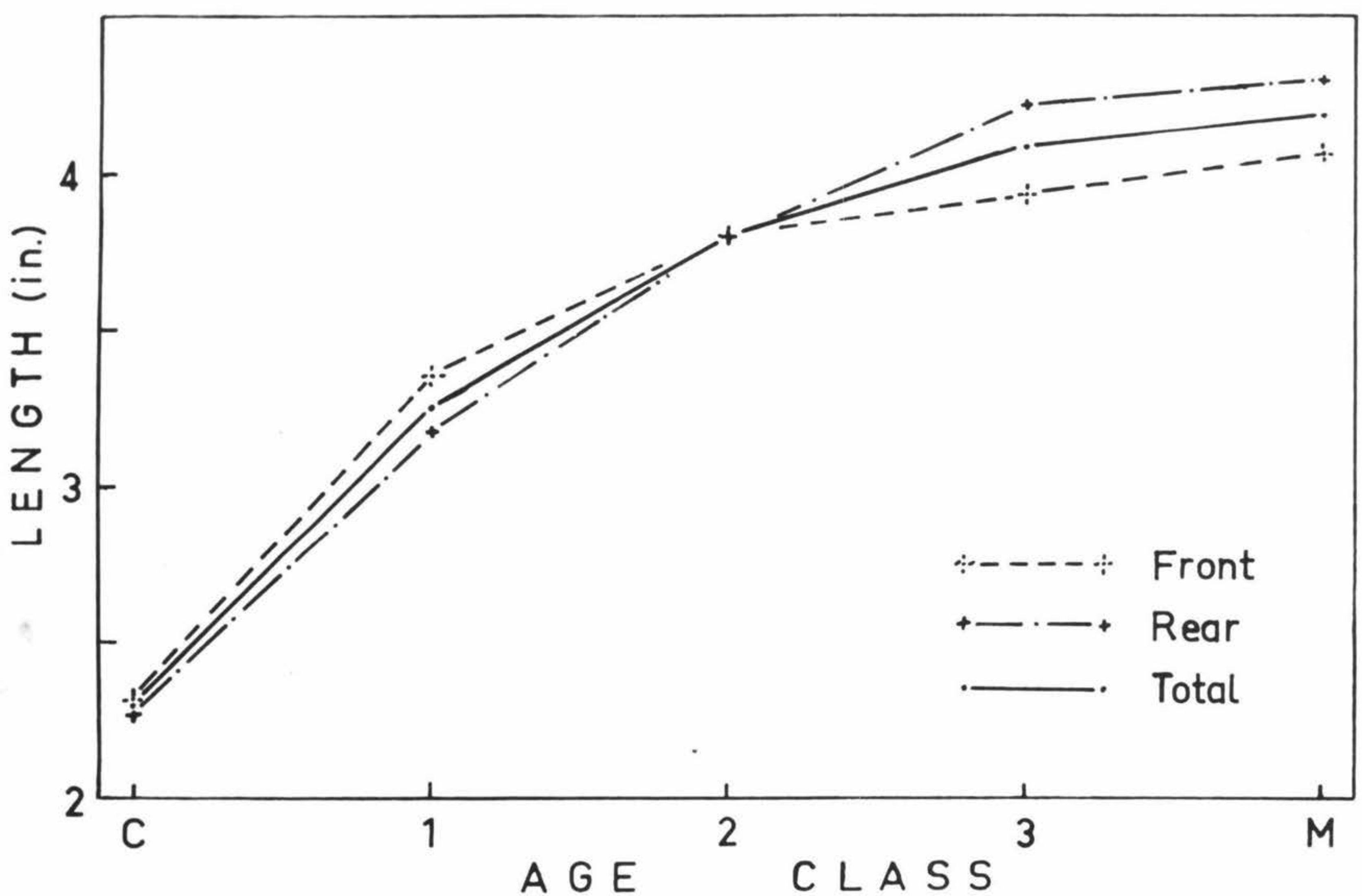



Fig. 25.—Length of hooves.

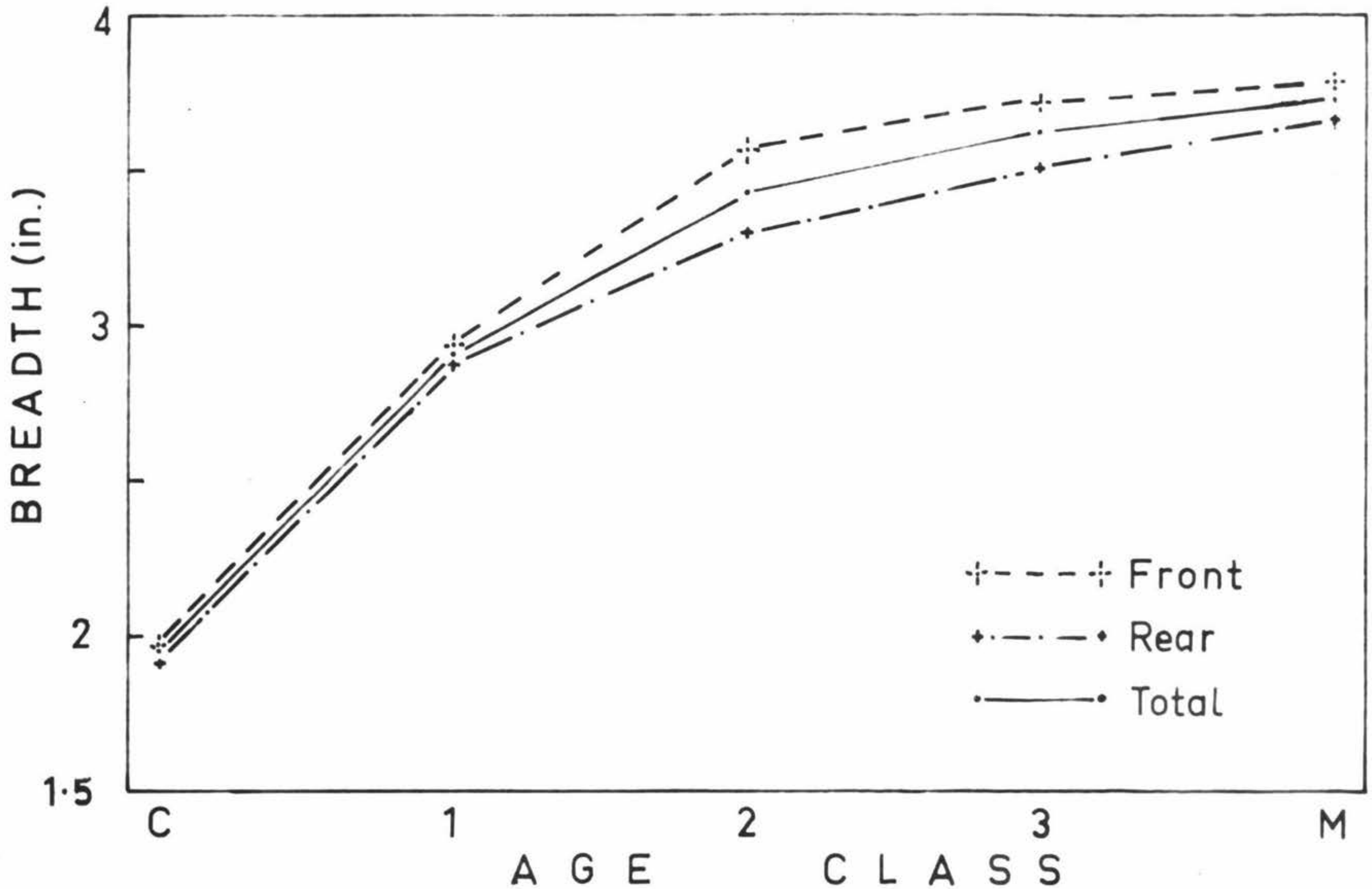



Fig. 26.— **Breadth of hooves.**

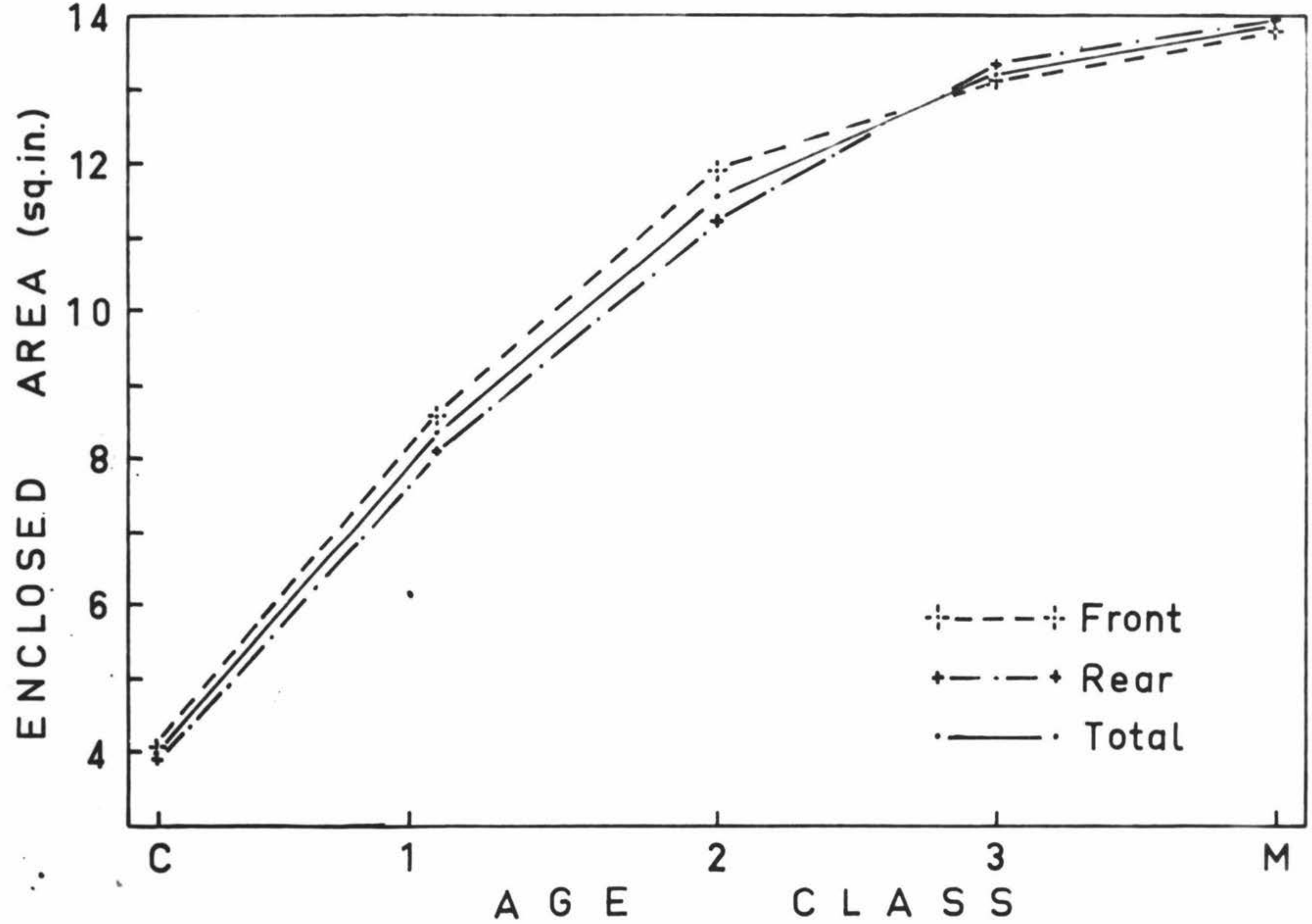


Fig. 27. — Enclosed area of hooves.

# CHAPTER X

## SUMMARY OF FINDINGS: DISCUSSION: FINAL SUMMARY

### A: SUMMARY OF FINDINGS

From Part I

1. A method of measuring hoof bearing area and enclosed area was developed. This involved hoof moulding, casting, contouring and subsequent planimeter measurement of hoof area from a hoof cast.

From Part II. The measurement of the animals of Group I, comprising 2-year-old, 3-year-old and mature Jerseys, and mature Friesians.

2. The total hoof casting technique and the planimeter measurement technique, were each shown to be highly repeatable when used to measure the hoof bearing areas of the animals of Group I. (In Part III this was confirmed over five age classes of Jerseys, from calves to mature animals, and also when extended to the measurement of hoof length. Enclosed area and breadth were also successfully measured, though no repeatability estimate was obtained).

3. A weighing technique was used to estimate the front and rear end hoof loads of the animals of Group I. The technique was practicable and of a satisfactory repeatability. (In Part III this technique was employed to estimate the hoof loads for five age classes of Jerseys. Slight modifications increased the repeatability).

4. The hoof bearing area of the 2-year-old, 3-year-old and mature Jerseys of Group I was shown to increase markedly from the zero bearing area at the 1/20 inch contour to the 4/20 inch contour. Thereafter the increase was steady and smaller

to the 7/20 inch contour level. This was attributed to the concave shape of many hooves, and the sloping bulb or heel of all hooflets. From this, and other considerations, the 6/20 inch contour was fixed as the most suitable level for hoof measurement.

5. The hooflet bearing areas of the 2-year-old, 3-year-old and mature Jerseys of Group I were measured. The differences between medial and lateral hooflets of the hoof were small, but were symmetrical between sides of the animal. It was concluded that the hooflets of the hoof could be regarded as identical in trampling problems.

6. The hoof bearing area, static hoof load and static unit hoof load were measured for the Group I animals. The bearing area data showed no evidence of a difference between left and right sides, but showed some evidence that the bearing area of the front hooves was larger than the rear. Hoof loads and unit hoof loads were greater for the front hooves than for the rear. These findings were used to design the sampling method employed in Part III.

7. The comparison between mature Friesians and mature Jerseys showed that both hoof bearing area and hoof load were greater in the Friesians. The net result was a non significant breed difference in unit hoof load, that for the Friesians being greater by only 1 p.s.i.

From Part III. The measurement of the animals of Group II; comprising calf, 1-year-old, 2-year-old, 3-year-old and mature age classes of Jerseys.

8. The differences between 2-year-olds, 3-year-olds and mature age classes, as measured by mean unit hoof load, hoof length, breadth, and enclosed area, were small. These age classes were therefore combined, and pooled estimates calculated, for the new "herd cow" class. In this way, the main results for the hoof features important in trampling problems, are summarized in Table XL.

Table XL

Summary of Estimates of Means of Hoof Features Important in Trampling for the Three Main Classes of Jersey Cattle.

| CLASS | No. in Sample | No. of Measurements | UNIT LOAD (p.s.i.) | LENGTH (in.) | No. of Measurements | BREADTH (in.) | ENCLOSED AREA (sq.in) |
|---|---|---|---|---|---|---|---|
| HERD COWS | 45 | 180 | 16.2 | 4.02 | 90 | 3.59 | 12.88 |
| (S.D.) | | | ±2.6 | ±0.31 | | ±0.25 | ±1.6 |
| (Range) | | | 11,6-23.7 | 3.3-4.8 | | 3.1-4.3 | 9.4-17.0 |
| YEARLINGS | 15 | 60 | 13.8 | 3.27 | 30 | 2.91 | 8.31 |
| (S.D.) | | | ±1.8 | ±0.20 | | ±0.14 | ±0.71 |
| (Range) | | | 10.2-18.2 | 2.9-3.7 | | 2.5-3.1 | 7.10-9.86 |
| CALVES | 15 | 60 | 4.8 | 2.30 | 30 | 1.95 | 3.98 |
| (S.D.) | | | ±0.9 | ±0.09 | | ±0.12 | ±0.28 |
| (Range) | | | 3.34-6.38 | 2.1-2.4 | | 1.7-2.1 | 3.48-4.54 |

9. Hoof Bearing Area, Enclosed Area, Length and Breadth

Details of estimates for class and subclass means for hoof bearing area, enclosed area, length and breadth, are presented in the text in the corresponding tables of means. From these estimates and the statistical analyses of the measurements for each of the above hoof dimensions, the following results were obtained.

(i) The Age Class Means for each of the above hoof dimensions increased by steadily decreasing increments between age classes, from calves to mature animals. All adjacent class differences were statistically highly significant, except the difference between 3-year-olds and matures. This difference for bearing area and enclosed area was significant at the five per cent level, but was not significant for length and breadth.

(ii) The Differences Between Means for Ends Within Age Classes were in all instances too small to warrant separate consideration in trampling problems. In-consistencies in these results, and in the bearing area results for Part II and Part III, were explained by heel erosion in the hooves of the mature animals. This probably occurred also in the 3-year-olds and 2-year-olds of Group II, but not in the 1-year-olds or calves. This was most marked in front hooves. The only important effect, from the point of view of trampling problems, as treated in this thesis, was the resultant effect on unit hoof load (see later).

(iii) The Toe Spreading Treatment. The postulate that "toe spread has a negligible effect on hoof bearing area and hoof length" was confirmed. A toe spreading treatment increased hoof length and enclosed area by from 10 to 20 per cent in all subclasses.

Due to the artificial nature of the spreading treatment, no importance could be attached to the differences in subclass response.

(iv) Hoof Shape, as measured by the ratio of mean breadth to mean length within subclasses, showed only small changes, which indicated a relative shortening of the front hooves of herd cows. This was probably attributable to heel erosion. In the light of present knowledge, it was thought that this could be regarded as a minor change, until further evidence to the contrary was available.

10. Hoof Load

The estimates of class and subclass means for hoof load are presented in the text (Table XXV). The main findings from the analysis of the hoof load results may be summarized as follows:-

(i) The Age Class Means for hoof load increased ten fold from calves to mature animals. The increase was greatest between calves and 1-year-olds. Thereafter the increase between adjacent classes became progressively smaller. Thus the difference between 3-year-old and mature classes was small and statistically non significant. All other adjacent class differences were statistically highly significant. As treated in this thesis, these, and other differences in hoof load, were considered important only in their effect on unit hoof load.

(ii) The Differences Between the Means for Ends Within Age Classes were highly significant in all age classes. The load on the front hooves being greater than that on the rear. The extra load on the front hooves was 11 lb. in calves, increasing at a slower rate than mean hoof load to 64 lb. in mature animals. Thus the relative difference between front and rear hoof loads was greatest in calves and smaller in more mature animals.

11. Unit Hoof Load.

The estimates of unit hoof load were regarded as the summation of the effects of hoof load and hoof bearing area. The class and subclass mean unit hoof loads are presented in Table XXVIII and in summarized form in Table XL. The main features of these results may be summarized as follows:-

(i) The Age Class Means for unit hoof load form a distinctive pattern (Figure 23). Mean unit hoof load increased rapidly from 4.8 p.s.i. for calves to 13.8 p.s.i. for 1-year-olds, and to a maximum of 16.4 p.s.i. for 2-year-olds. Differences between these age class means were clearly highly significant, despite the approximate nature of certain of the statistical tests, due to the heterogeneous age class error variances. The mean unit loads for 2-year-olds, 3-year-olds and mature classes were not significantly different and were approximately constant, with a mean for the three classes ("herd cows") of 16.2 p.s.i.

(ii) The Differences Between the Means for Ends Within Age Classes were highly significant in every age class. The front end unit hoof load was in every age class greater than that for the rear. The difference was greatest (over 4 p.s.i.) in 3-year-olds and mature animals. This difference appeared to be due in part to the greater heel erosion in front hooves, although in Group 1, when no heel erosion was noted, the unit load on the front hooves was still significantly greater than that for the rear (approximately by 2 p.s.i. ) While this difference is noted, the practical utility of a pooled estimate for herd cows outweighed the greater precision obtainable by calculating separate estimates for subclasses. The mean hoof load for herd cows was therefore calculated. The relation of this and the estimates for other hoof factors (Table XL) to trampling, is discussed further in Section B.

12. A comparison of the results from Part II and Part III, the evidence of heel erosion and the probable effects of normal growth on hoof features, all serve to emphasize that the estimates obtained are susceptible to change. A review of literature dealing with variation in body weights, likewise indicated that hoof loads and hence unit hoof load, were likewise liable to seasonal changes and minor fluctuations. Thus, the estimates obtained can only be claimed to apply to the selected population, for the period during which the measurements were taken. Judgment must be used in applying the results to other populations or periods.

## B: DISCUSSION OF SUMMARIZED RESULTS IN RELATION TO TRAMPLING

The relative magnitude of the hoof load and hoof breadth estimates for each class in Table XL are illustrated in Figure 28. The hoof cross-sections were drawn for illustrative purposes only. They were, however, based on the following information from results already presented:

a. Depth of penetration = 6/20 inch. b. Hooflets equal in size (page 98) c. Width between hooflets at the 6/20 inch contour for each age class = $\frac{\text{Mean enclosed area} - \text{Mean bearing area}}{\text{Mean hoof length}}$

(Herd cows = 0.58 in.; 1-year-old=0.48 in.; calves=0.26 in.)

This was only an approximate method of estimation which, however, since the variation in length was small, should be sufficiently accurate for illustrative purposes.
d. The curvature of the bearing surfaces was based on the data in Table V. (Page 86). Hooflet width at any contour was made proportional to the bearing area at that contour for the Jersey animals of Group I. Calf and 1-year-old hooflet sections were scaled down versions of this. The hoof sections illustrate effectual rather than actual cross-sections.

In the diagram, the relative lengths of the unit load vectors emphasize the very small unit load of the calf age class. The calf hoof would be stable on any soil with an ultimate bearing capacity of 4.8 p.s.i. or greater. The 1-year-old hoof would not be stable unless the ultimate bearing capacity was greater than 13.8 p.s.i. Similarly the mature hoof would not be stable unless the ultimate bearing capacity exceeded 16.2 p.s.i. Furthermore, on such a soil, the penetration of the 1-year-old and calf hooves would be less than the six twentieths of an inch shown in the diagram.

The effect of the difference between mean front and rear unit hoof load, would be to make the threshold at which hoof penetration occurred indefinite. Because of this and other sources of variation in unit load, the threshold ultimate bearing capacity at which hoof penetration, due to mass sheer failure of the soil, was negligible, would be higher than the ultimate bearing capacities cited above, for each age class.

In the event of sheer failure of the soil as treated on page 46, soil factors would mainly decide the depth of hoof penetration. However, the hoof with the heavier unit load would have a greater potential for penetration, and thus soil damage, than the less heavily loaded hoof. In the three age classes dealt with, heavier unit loads are carried by broader and longer hooves, affecting larger areas.

Similarly the potential volume of soil likely to be compressed, by virtue of the heavier unit hoof load and larger hoof of the herd cows, is very much greater than for either 1-year-olds or calves. This may be illustrated by considering the hemispheres of soil, of diameter equal to hoof breadth, beneath the hoof sections in Figure 28. These volumes are obviously those most likely to suffer, due to either soil sheering failure or soil compression. The volumes of the hemispheres in order, from herd cows to calves, are approximately 12, 6.5, and 2, $in.^3$..

In instances where trampling, as measured by the number of foot prints, is intensive enough to completely cover any area, breadth is likely to be of importance only in determining the depth of zones of soil compression. From the literature studied (Chapter I), it appeared almost certain that the depth of such zones of compression would be some linear function of breadth (provided soil mechanical theory for idealized masses can be modified to apply to surface soils).

In deciding whether or not the static unit loads as measured are likely to cause soil compression, the following information from the review of literature is relevant:-

a. In many instances tractor tyres were shown to cause soil compaction (Fountaine and Payne (1952)) (Page 19). (Tractor tyres are seldom inflated to more than 15 p.s.i.. Water ballast and the elasticity of the tyre wall could increase the vertical unit load only to about 18 or 19 p.s.i.).
b. Day and Holmgren (1952) found that complete closure of inter-aggregate spaces could be produced in certain sieved soil aggregates, at certain moisture contents, by pressures of 21 p.s.i. or less (Page 30).

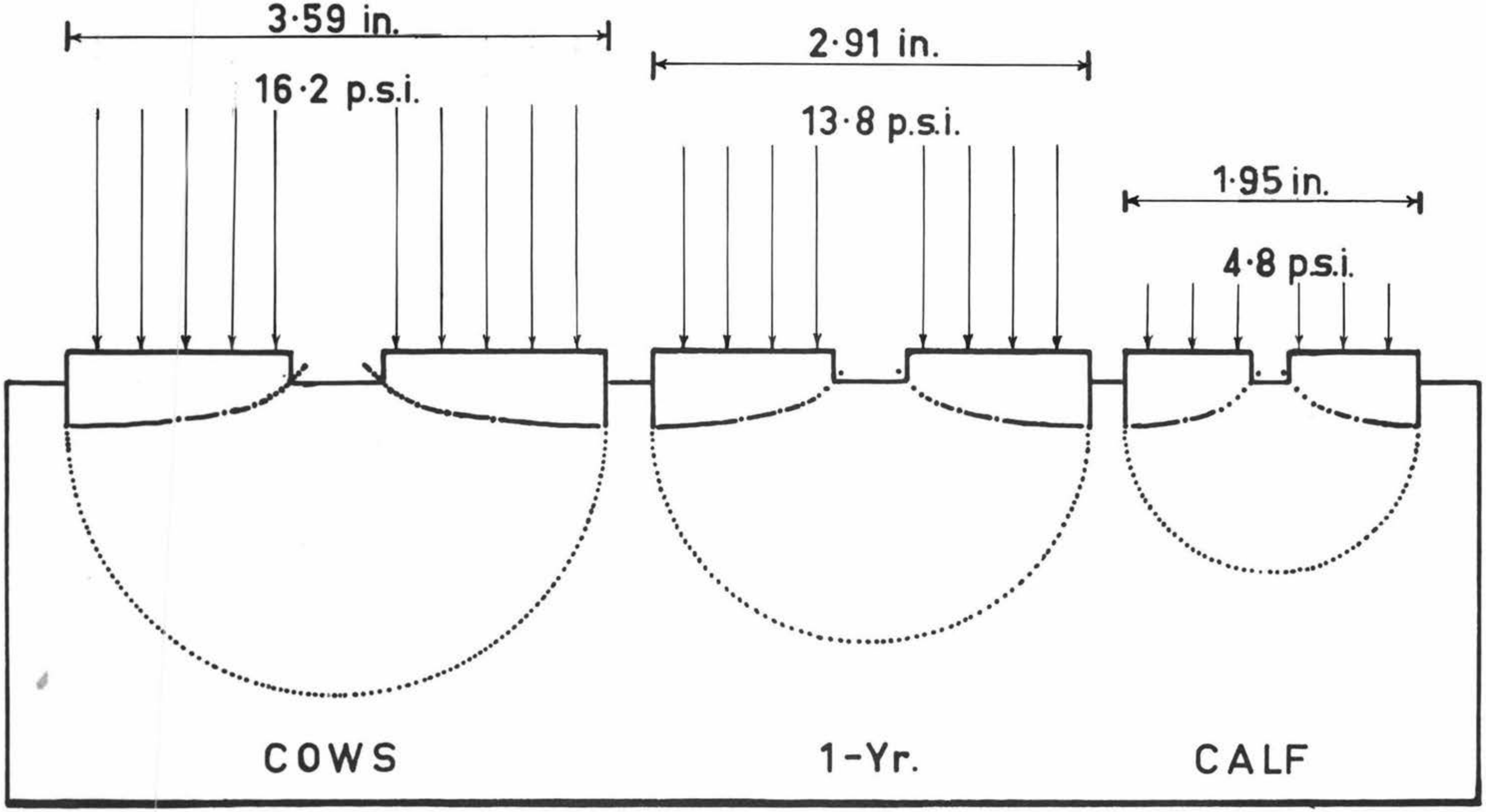



Fig. 28.–Diagram of hoof action using estimates of hoof factors (full size).

From these and other work reviewed on pages 16-36, it appeared that under certain conditions, especially for plastic soils with moisture contents in the plastic range, soil compaction could be caused by the mature cows and probably 1-year-olds also. It was doubtful whether calves could produce compaction, as distinct from surface puddling. For the dynamic case, when transient unit loads would be expected to be approximately double the magnitude of the static loads, soil compression again seems likely, at least for matures and 1-year-olds.

Overseas investigations (see pages 20-23) suggested that prolonged grazing produced a zone of soil compaction at or near the soil surface, and extending several inches into the profile. If the gleyed layer observed in the "winter" paddock at Massey Agricultural College (see page 24) was, as seems likely, a layer of compacted soil, its thickness was approximately equal to the breadth of the hooves of the herd cow Jerseys of Group II. The thickness of this layer contrasts with the gleyed layer, approximately half an inch thick, produced by sheep trampling on a nearby area of the same soil type (Edmonds (1956) ) (see page 25). There is clearly opportunity for further research to measure hoof factors in sheep, and in elucidating the determinants and physical laws governing the distribution of stress and sheer failure zones for the hooves of sheep and cattle.

In work of this nature the investigator, dealing with a foundation the size of an animal's foot, is in the advantageous position of being able to excavate all soil likely to show signs of change. In engineering, the inaccessability of the zones of stress beneath large structures has been a severe handicap in testing the theory of soil mechanics.

Further work towards solving the problems involved in hoof action could be devoted to defining in full the shape of the average hoof, for the various classes of animals. Data of this nature could be used to produce an artificial hoof. The way would then be open to conduct experiments in which the reaction of the soil beneath the loaded hoof could be examined, without the cumbersome animal and consequent unmanageable hoof loadings being involved.

At the same time, artificial trampling treatments, which bear a known relationship to natural trampling, could be employed in plot experiments of convenient size, to determine the effect of the various trampling factors on pasture production.

In this type of work and in artificial hoof loading experiments, the estimates of hoof features, especially those for unit hoof load, could be used to help solve some of the problems involved in trampling, and eventually to ascertain its true role in the complex ecology of animals, pastures and soils.

# FINAL SUMMARY

Literature relevant to trampling and the animal pasture complex was reviewed. From this, and the soil mechanics of hoof action, six hoof features - bearing area, load, unit load, length, breadth and enclosed area - were defined as the main determinants of the effect of trampling on soils and pastures.

Hoof dimensions were defined in terms of contour lines corresponding to various depths of hoof penetration on a horizontal surface.

Hooves were moulded in a plastic wax, and subsequent measurements of hoof dimensions made on contourlined plaster of paris hoof casts. Front and rear end hoof loads were determined by a weighing technique. Unit hoof load was calculated from hoof load and bearing area.

Hoof bearing area, hoof load, and unit hoof load were determined for forty animals, comprising two, three and over four-year-old Jerseys, and over four-year-old Friesians, in late March and early April. Bearing area was found to increase at higher contour levels (corresponding to deeper hoof penetration). The rate of increase was lower above the 4/20 inch contour, and the 6/20 inch contour was fixed as the most suitable contour at which to measure hoof dimensions. The bearing area of medial and lateral hooflets differed only slightly. It was not possible to demonstrate a difference between left and right hooves in hoof bearing area. There was some evidence of a difference between front and rear hooves, especially in load and unit load, both of which were greater for the front hooves.

Friesians and Jerseys differed little in unit load, the load and bearing area both being greater in the Friesians.

From the end of August to mid September the six hoof features were measured on seventy five Jerseys, comprising five classes; calves, one, two, three and over four-year-olds. A hooflet toe spreading treatment had negligible effect on bearing area and hoof length, but increased breadth and enclosed area by 10-20 per cent. The small differences between front and rear ends in bearing area, length and enclosed area, were inconsistent between age classes, due to a heel erosion factor more marked in the front hooves of older classes, and not present in the first group measured. As measured by breadth (unaffected by the heel erosion) the front hooves were the larger. Front end hoof loads and unit loads were greater than the rear.

For each hoof dimension the age class means increased, by steadily decreasing increments, from calves to mature animals. Load increased similarly, the relative increase being greater. Unit load increased rapidly from a very small value for calves to a maximum at 2-year-olds, thereafter being virtually constant.

It was possible to summarize part of the results by calculating pooled estimates for herd cows (two, three and over four-year-olds). The summarized results were presented in a diagram of hoof action and their relation to trampling problems was discussed.

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# APPENDICES

## SIX HOOF FEATURES OF DAIRY CATTLE

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

# LIST OF APPENDICES

## APPENDIX

# A P P E N D I X   A

## PLASTER OF PARIS SHRINKAGE TEST

Object: To examine the linear accuracy of a wax moulding and casting technique.

Materials: The moulds were made in a plaque of the wax used for hoof moulding. Plaster of Paris as used in hoof casting was used to make the casts. All measurements were taken with the same steel rule graduated in $^{1}/_{32}$ inch.

Method: Three wax moulds 12 x $1\frac{1}{2}$ x $\frac{3}{4}$ inch were made and in the floor of each mould three impressions were made of the edge of a sheet of glass approximately 11 $^{27}/_{32}$ inch long. A plaster bar was cast in each mould. Bars (1), (2) and (3) were each cast from different plaster of Paris slurries, described as of "stiff", "medium", and "liquid" consistencies respectively. The "stiff" slurry would hardly flow, and the "liquid" slurry contained so much water that it would hardly set satisfactorily. The "medium" was of approximately the consistency used throughout the hoof casting work.

Results

The measurements made of the lengths of the glass sheet and of the casts of the impressions of the glass are presented in Table I. All measurements are in $^{1}/_{32}$ inch and coded by subtracting 11 inches.

Table I

Linear Measurements of Plaster Casts (units $^1/_{32}$ in. - 11 in.)

Length of Glass Sheet

| Measurement No. | 1 | 2 | 3 |
|---|---|---|---|
| | 26.8 | 26.8 | 26.8 |

Length of Impressions of Glass Sheet

Thirty six hours after casting

| On Bar No. | 1 | 2 | 3 |
|---|---|---|---|
| Impression No. | | | |
| a | 27.5 | 27.0 | 26.5 |
| b | 27.0 | 26.9 | 27.5 |
| c | 27.0 | 26.0 | 27.0 |

Sixty hours after casting

| On Bar No. | 1 | 2 | 3 |
|---|---|---|---|
| Impression No. | | | |
| a | 27.5 | 27.0 | 26.8 |
| b | 27.0 | 27.0 | 27.0 |
| c | 27.0 | 26.4 | 27.0 |

Discussion

The measurements obtained show little evidence of any shrinkage or contraction either during casting or after setting. All discrepancies could be accounted for by experimental error in measurement. The corners of the glass sheet were sharper than the corners of the casts of the sheet. Hence measurements of the plaster bars were less repeatable.

Errors could also be introduced by distortion of the moulding wax when making impressions of the glass sheet.

Conclusions

It was therefore concluded that errors due to shrinkage or expansion of the plaster of Paris either during casting or for sixty hours after casting were negligible.

If shrinkage or expansion occurred during setting then it probably acted in a vertical direction acting on the free surface of the plaster of Paris mixture.

## APPENDIX B

**Pilot Trial: Measurements of bearing area and enclosed area (sq. in.)**
**(Cow No. 83 - 10 Casts Left Front Hoof)**

**Bearing Areas**

| Cast No. | Measurement No. a | b | c |
|---|---|---|---|
| 1 | 11.47 | 11.54 | 11.51 |
| 2 | 10.99 | 11.08 | 11.25 |
| 3 | 11.36 | 11.26 | 11.29 |
| 4 | 11.46 | 11.51 | 11.52 |
| 5 | 11.63 | 11.63 | 11.68 |
| 6 | 11.27 | 11.26 | 11.15 |
| 7 | 11.29 | 11.40 | 11.50 |
| 8 | 11.44 | 11.50 | 11.65 |
| 9 | 11.67 | 11.76 | 12.00 |
| 10 | 11.53 | 11.63 | 11.60 |

**Enclosed Areas**

| Cast No. | Measurement No. a | b | c |
|---|---|---|---|
| 1 | 13.50 | 13.45 | 13.20 |
| 2 | 12.73 | 13.84 | 12.63 |
| 3 | 13.10 | 12.90 | 13.50 |
| 4 | 13.30 | 13.30 | 12.99 |
| 5 | 13.78 | 13.79 | 13.62 |
| 6 | 13.88 | 13.82 | 13.79 |
| 7 | 13.45 | 13.38 | 13.37 |
| 8 | 13.70 | 13.76 | 13.60 |
| 9 | 13.93 | 14.18 | 14.09 |
| 10 | 12.61 | 13.04 | 12.64 |

# APPENDIX C

**Vertical height of Waterline contours on thirty random hooves drawn one per cow from Group I Animals. All hooves dipped in dye solution 3/20" deep, and Waterline contour height measured in 1/20" units to nearest half unit.**

| TWO YEAR OLDS | Heel | Side | THREE YEAR OLDS | Heel | Side | MATURE | Heel | Side |
|---|---|---|---|---|---|---|---|---|
| 24 LR L | 5.5 | 5 | 43 LR | 5 | 5 | 36 RL | 5 | 5 |
| R | 5 | 5 | | 5.5 | 5 | | 5.5 | 5 |
| 42 RR | 5 | 5 | 17 LF | 5 | 5 | 7 LR | 5.5 | 5 |
| | 5 | 4.5 | | 5.5 | 5 | | 5.5 | 5 |
| 28 LR | 5 | 4.5 | 13 LR | 5.5 | 5 | 23 LF | 5 | 5 |
| | 5 | 4 | | 5.5 | 5 | | 6 | 4.5 |
| 56 LF | 5 | 5 | 12 LR | 5 | 5 | 3 LF | 5 | 5 |
| | 5 | 4 | | 5 | 5 | | 5 | 5 |
| 98 RR | 5 | 4.5 | 37 LF | 5 | 5 | 87 RF | 5 | 5 |
| | 5 | 4 | | 5.5 | 5 | | 5.5 | 4.5 |
| 61 RR | 5 | 5 | 49 RR | 5 | 5 | 91 LR | 5 | 5 |
| | 5 | 4.5 | | 5 | 5 | | 5.5 | 5 |
| 8 RF | 5 | 5 | 54 RR | 5 | 5 | 53 RF | 5 | 4 |
| | 5 | 5 | | 5.5 | 5 | | 5 | 5 |
| 86 LR | 5 | 4 | 59 RF | 5 | 5.5 | 73 RF | 5.5 | 5 |
| | 5 | 5 | | 5.5 | 5 | | 5.5 | 5 |
| 110 LF | 5 | 5 | 64 RF | 5 | 4 | 25 LR | 5.5 | 4.5 |
| | 5 | 5 | | 5 | 4.5 | | 5.5 | 5 |
| 75 RR | 5 | 5 | 60 FL | 5 | 4 | 18 LF | 5 | 5 |
| | 5 | 4.5 | | 5 | 4 | | 5 | 5 |

APPENDIX D

Mean Bearing area measured at seven contour levels on a sub sample of thirty Jersey hoof casts from Group I. (units, sq. in.)

| Cow No. | Corner | Contour Level 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | | | | MATURE JERSEYS | | | | |
| 87 | RF | 6.155 | 10.025 | 11.4[illegible] | 12.525 | 13.185 | 13.870 | 14.255 |
| 91 | LR | 5.715 | 9.010 | 10.99[illegible] | 11.935 | 12.6[illegible]0 | 13.180 | 13.670 |
| 3 | LF | 5.355 | 7.985 | 11.93[illegible] | 13.555 | 14.440 | 15.230 | 15.900 |
| 18 | LF | 2.760 | 5.650 | 10.3[illegible] | 12.065 | 12.465 | 12.975 | 13.475 |
| 73 | RF | 4.870 | 8.785 | 12.11[illegible] | 13.345 | 14.185 | 14.600 | 15.065 |
| 36 | LR | 4.295 | 6.825 | 8.15[illegible] | 9.060 | 9.790 | 10.325 | 10.750 |
| 7 | LR | 4.565 | 8.090 | 10.485 | 11.480 | 12.205 | 12.615 | 12.995 |
| 25 | LR | 6.035 | 9.295 | 10.96[illegible] | 12.[illegible] | 12.695 | 13.105 | 13.605 |
| 53 | RF | 7.175 | 9.635 | 11.1[illegible] | 11.930 | 12.445 | 12.950 | 13.370 |
| 23 | LF | 3.180 | 5.775 | 8.555 | 10.285 | 11.215 | 11.815 | 12.280 |
| | | | | 3-YEAR-OLD JERSEYS | | | | |
| 43 | LR | 7.330 | 9.015 | 10.1[illegible] | 10.465 | 10.925 | 11.290 | 11.740 |
| 12 | RR | 6.665 | 9.945 | 11.440 | 12.200 | 12.850 | 13.325 | 1[illegible].72[illegible] |
| 49 | RR | 8.780 | 10.150 | 10.[illegible] | 11.425 | 11.905 | 12.30[illegible] | 12.645 |
| 54 | RR | 5.755 | 9.025 | 10.[illegible] | 10.735 | 11.360 | 11.73[illegible] | 12.240 |
| 37 | LF | 4.110 | 7.500 | 9.075 | 11.160 | 12.[illegible] | 12.570 | 13.[illegible] |
| 13 | L[illegible] | 7.655 | 9.550 | 10.55[illegible] | 11.415 | 11.010 | 12.465 | 12.765 |
| 64 | RF | 5.710 | 9.250 | 11.[illegible] | 11.905 | 12.435 | 12.960 | 13.540 |
| 59 | RF | 6.430 | 9.150 | 11.[illegible]1 | 11.940 | 12.630 | 13.080 | 13.445 |
| 60 | LF | 7.640 | 10.300 | 11.57[illegible] | 12.200 | 12.670 | 13.245 | 13.690 |
| 17 | LF | 5.850 | 8.125 | 9.3[illegible] | 10.050 | 10.560 | 10.940 | 11.365 |
| | | | | 2-YEAR-OLD JERSEYS | | | | |
| 98 | RR | 7.850 | 9.680 | 10.530 | 11.155 | 11.750 | 12.110 | 12.475 |
| 56 | LF | 7.185 | 9.420 | 10.505 | 11.395 | 11.955 | 12.390 | 12.810 |
| 75 | RR | 5.425 | 7.805 | 8.95[illegible] | 9.740 | 10.250 | 10.690 | 11.260 |
| 24 | LR | 7.540 | 9.155 | 10.1[illegible] | 10.690 | 11.070 | 11.405 | 11.715 |
| 28 | LR | 5.995 | 9.125 | 10.175 | 10.745 | 11.195 | 11.520 | 11.815 |
| 110 | LF | 3.985 | 5.625 | 7.51[illegible] | 8.690 | 9.270 | 9.800 | 10.260 |
| 42 | RR | 6.070 | 8.495 | 9.720 | 10.720 | 11.250 | 11.670 | 12.020 |
| 8 | RF | 6.850 | 8.845 | 9.995 | 10.585 | 11.140 | 11.510 | 11.990 |
| 61 | RR | 7.965 | 9.855 | 10.970 | 11.525 | 12.170 | 12.575 | 12.910 |
| 86 | LR | 7.295 | 9.395 | 10.205 | 10.965 | 11.465 | 11.925 | 12.395 |

## APPENDIX E

Hooflet Bearing Areas (sq.in.)
(Each item is the mean of two measurements of one cast)

| Cow No. | FRONT Left Lateral | FRONT Left Medial | FRONT Right Medial | FRONT Right Lateral | REAR Left Lateral | REAR Left Medial | REAR Right Medial | REAR Right Lateral |
|---|---|---|---|---|---|---|---|---|
| **MATURE JERSEY** | | | | | | | | |
| 3 | 7.445 | 7.785 | 7.895 | 6.945 | 7.200 | 8.205 | 7.590 | 7.730 |
| 7 | 6.825 | 7.045 | 6.970 | 7.125 | 6.295 | 6.320 | 6.630 | 6.765 |
| 18 | 6.290 | 6.500 | 7.310 | 6.360 | 6.345 | 5.730 | 6.170 | 6.625 |
| 23 | 5.775 | 6.040 | 6.570 | 6.035 | 6.080 | 5.880 | 5.605 | 5.665 |
| 25 | 5.785 | 6.625 | 6.870 | 5.860 | 7.545 | 5.560 | 6.035 | 6.860 |
| 36 | 5.195 | 5.395 | 5.735 | 5.275 | 5.490 | 4.835 | 4.670 | 5.060 |
| 53 | 6.550 | 6.750 | 7.240 | 6.115 | 6.530 | 5.730 | 5.770 | 6.625 |
| 73 | 6.770 | 6.415 | 7.540 | 7.060 | 6.485 | 6.775 | 6.675 | 6.420 |
| 87 | 6.460 | 7.495 | 7.635 | 6.240 | 6.780 | 6.080 | 5.695 | 7.150 |
| 91 | 7.690 | 7.195 | 7.550 | 7.445 | 6.630 | 6.085 | 7.300 | 6.400 |
| **3 YEAR-OLD JERSEY** | | | | | | | | |
| 12 | 6.730 | 6.155 | 6.515 | 7.065 | 6.710 | 6.400 | 6.515 | 6.570 |
| 13 | 7.030 | 6.555 | 7.200 | 7.015 | 6.775 | 5.690 | 6.590 | 6.580 |
| 17 | 5.525 | 5.415 | 5.555 | 5.635 | 6.355 | 5.495 | 5.370 | 6.460 |
| 37 | 6.235 | 6.335 | 6.755 | 6.290 | 6.090 | 5.700 | 5.935 | 5.965 |
| 43 | 5.225 | 5.470 | 5.825 | 5.310 | 5.730 | 6.170 | 5.550 | 4.980 |
| 49 | 5.725 | 5.975 | 5.775 | 5.675 | 6.110 | 5.680 | 6.295 | 5.890 |
| 59 | 6.110 | 6.800 | 6.560 | 6.520 | 6.015 | 5.355 | 5.365 | 6.480 |
| 54 | 5.825 | 6.460 | 6.005 | 5.870 | 6.205 | 5.725 | 5.475 | 6.260 |
| 60 | 6.655 | 6.590 | 6.400 | 5.735 | 5.995 | 5.875 | 6.310 | 6.720 |
| 64 | 6.410 | 6.660 | 6.685 | 6.605 | 6.460 | 6.430 | 6.470 | 6.785 |
| **2 YEAR-OLD JERSEY** | | | | | | | | |
| 8 | 6.575 | 5.780 | 5.765 | 5.865 | 5.730 | 5.660 | 5.440 | 6.075 |
| 24 | 6.090 | 5.965 | 5.915 | 5.935 | 6.455 | 5.325 | 5.700 | 5.880 |
| 28 | 5.925 | 6.345 | 6.265 | 6.435 | 5.860 | 5.725 | 5.305 | 5.820 |
| 42 | 5.360 | 6.165 | 6.005 | 5.575 | 6.045 | 5.360 | 5.490 | 6.180 |
| 56 | 5.910 | 6.315 | 6.565 | 6.195 | 5.985 | 5.985 | 5.810 | 6.290 |
| 61 | 6.015 | 6.315 | 6.160 | 6.280 | 6.455 | 5.890 | 5.720 | 6.700 |
| 75 | 5.170 | 6.200 | 5.715 | 5.400 | 5.710 | 5.700 | 5.030 | 6.190 |
| 86 | 6.235 | 6.695 | 6.715 | 5.995 | 6.185 | 5.740 | 6.340 | 6.365 |
| 98 | 5.760 | 5.250 | 6.095 | 5.755 | 6.170 | 5.825 | 5.775 | 6.250 |
| 110 | 5.125 | 4.675 | 5.160 | 4.705 | 5.270 | 4.775 | 5.145 | 5.620 |

## APPENDIX F

"One cast per corner" Bearing Area Measurements (sq.in.) Group I

### MATURE FRIESIAN

| Cow No. | FRONT Left 1 | FRONT Left 2 | FRONT Right 1 | FRONT Right 2 | REAR Left 1 | REAR Left 2 | REAR Right 1 | REAR Right 2 |
|---|---|---|---|---|---|---|---|---|
| 131 | 18.00 | 18.03 | 17.53 | 17.54 | 16.84 | 16.98 | 15.92 | 15.92 |
| 135 | 18.04 | 17.88 | 17.44 | 17.33 | 19.09 | 19.13 | 19.83 | 19.74 |
| 144 | 16.09 | 16.10 | 16.47 | 16.30 | 16.38 | 16.47 | 16.32 | 16.28 |
| 146 | 17.43 | 17.32 | 17.79 | 17.74 | 15.79 | 15.79 | 14.56 | 14.54 |
| 154 | 16.81 | 16.84 | 17.68 | 17.66 | 18.76 | 18.80 | 19.91 | 20.11 |
| 164 | 16.17 | 16.22 | 17.52 | 17.50 | 14.30 | 14.30 | 15.19 | 15.36 |
| 165 | 16.68 | 16.85 | 16.61 | 16.60 | 15.27 | 15.25 | 14.90 | 14.95 |
| 168 | 17.25 | 17.31 | 17.03 | 17.08 | 16.24 | 16.37 | 16.55 | 16.56 |
| 170 | 15.28 | 15.39 | 15.89 | 15.96 | 15.13 | 15.19 | 15.48 | 15.29 |
| 171 | 17.81 | 17.88 | 17.90 | 17.83 | 16.38 | 16.42 | 16.81 | 16.83 |

### 3-YEAR-OLD JERSEY

| Cow No. | FRONT Left 1 | FRONT Left 2 | FRONT Right 1 | FRONT Right 2 | REAR Left 1 | REAR Left 2 | REAR Right 1 | REAR Right 2 |
|---|---|---|---|---|---|---|---|---|
| 12 | 12.93 | 12.84 | 13.62 | 13.54 | 13.14 | 13.08 | 13.18 | 13.19 |
| 13 | 13.58 | 13.59 | 14.25 | 14.18 | 12.43 | 12.50 | 13.16 | 13.18 |
| 17 | 10.96 | 10.92 | 11.16 | 11.22 | 11.87 | 11.83 | 11.80 | 11.86 |
| 37 | 12.52 | 12.62 | 13.08 | 13.01 | 11.81 | 11.77 | 11.88 | 11.92 |
| 43 | 10.71 | 10.68 | 11.10 | 11.17 | 11.89 | 11.91 | 10.51 | 10.55 |
| 49 | 11.71 | 11.69 | 11.43 | 11.47 | 11.82 | 11.76 | 12.18 | 12.19 |
| 59 | 12.92 | 12.90 | 13.10 | 13.06 | 11.38 | 11.36 | 11.83 | 11.86 |
| 54 | 12.30 | 12.27 | 11.90 | 11.85 | 11.96 | 11.90 | 11.71 | 11.76 |
| 60 | 13.25 | 13.24 | 12.15 | 12.12 | 11.91 | 11.83 | 12.89 | 13.08 |
| 64 | 13.06 | 13.08 | 13.26 | 13.32 | 12.92 | 12.86 | 12.22 | 13.29 |

### MATURE JERSEY

| Cow No. | FRONT Left 1 | FRONT Left 2 | FRONT Right 1 | FRONT Right 2 | REAR Left 1 | REAR Left 2 | REAR Right 1 | REAR Right 2 |
|---|---|---|---|---|---|---|---|---|
| 3 | 15.30 | 15.16 | 14.83 | 14.85 | 15.40 | 15.41 | 15.35 | 15.29 |
| 7 | 13.82 | 13.92 | 14.09 | 14.10 | 12.61 | 12.62 | 13.40 | 13.39 |
| 18 | 12.83 | 12.75 | 13.64 | 13.70 | 12.07 | 12.08 | 12.79 | 12.80 |
| 23 | 11.75 | 11.88 | 12.61 | 12.60 | 11.97 | 11.95 | 11.33 | 11.21 |
| 25 | 12.44 | 12.38 | 12.72 | 12.74 | 13.08 | 13.13 | 12.91 | 12.88 |
| 36 | 10.55 | 10.63 | 11.02 | 11.00 | 10.33 | 10.32 | 9.71 | 9.75 |
| 53 | 13.32 | 13.28 | 13.29 | 13.42 | 12.30 | 12.22 | 12.36 | 12.43 |
| 73 | 13.19 | 13.18 | 14.63 | 14.57 | 13.28 | 13.24 | 13.05 | 13.14 |
| 87 | 13.93 | 13.98 | 13.88 | 13.87 | 12.90 | 12.82 | 12.85 | 12.84 |
| 91 | 14.89 | 14.88 | 14.98 | 15.01 | 12.68 | 12.75 | 13.68 | 13.72 |

### 2-YEAR-OLD JERSEY

| Cow No. | FRONT Left 1 | FRONT Left 2 | FRONT Right 1 | FRONT Right 2 | REAR Left 1 | REAR Left 2 | REAR Right 1 | REAR Right 2 |
|---|---|---|---|---|---|---|---|---|
| 8 | 12.37 | 12.34 | 11.60 | 11.66 | 11.42 | 11.36 | 11.48 | 11.55 |
| 24 | 12.07 | 12.04 | 11.84 | 11.86 | 11.79 | 11.77 | 11.55 | 11.61 |
| 28 | 12.31 | 12.23 | 12.69 | 12.71 | 11.57 | 11.60 | 11.14 | 11.11 |
| 42 | 11.51 | 11.54 | 11.54 | 11.62 | 11.39 | 11.42 | 11.70 | 11.64 |
| 56 | 12.24 | 12.21 | 12.73 | 12.79 | 11.96 | 11.98 | 12.07 | 12.13 |
| 61 | 12.33 | 12.33 | 12.45 | 12.43 | 12.33 | 12.36 | 12.42 | 12.42 |
| 75 | 11.35 | 11.39 | 11.15 | 11.16 | 11.53 | 11.43 | 11.21 | 11.23 |
| 86 | 12.94 | 12.92 | 12.67 | 12.75 | 11.88 | 11.97 | 12.73 | 12.68 |
| 98 | 11.03 | 10.99 | 11.82 | 11.88 | 12.02 | 11.97 | 12.01 | 12.04 |
| 110 | 9.81 | 9.79 | 9.87 | 9.86 | 10.06 | 10.03 | 10.74 | 10.79 |

APPENDIX G

"Duplicate Cast" Bearing Area Measurements (sq. in.)

MATURE FRIESIAN (LF-RR)

| Corner | Cast No. | Measurement No. | 131 | 135 | 144 | 168 | 171 |
|---|---|---|---|---|---|---|---|
| Left Front | a | 1 | 18.00 | 18.04 | 16.09 | 17.25 | 17.81 |
| | | 2 | 18.03 | 17.88 | 16.10 | 17.31 | 17.88 |
| | b | 1 | 18.04 | 17.95 | 16.11 | 17.63 | 17.84 |
| | | 2 | 17.93 | 17.80 | 16.09 | 17.66 | 17.83 |
| Right Rear | a | 1 | 15.92 | 19.83 | 16.32 | 16.55 | 16.81 |
| | | 2 | 15.92 | 19.74 | 16.28 | 16.56 | 16.83 |
| | b | 1 | 16.46 | 19.40 | 15.94 | 17.53 | 16.79 |
| | | 2 | 16.49 | 19.46 | 15.94 | 17.36 | 16.90 |

(RF-LR)

| Cow Number | | | 146 | 154 | 164 | 165 | 170 |
|---|---|---|---|---|---|---|---|
| Right Front | a | 1 | 17.79 | 17.68 | 17.52 | 16.61 | 15.89 |
| | | 2 | 17.74 | 17.66 | 17.50 | 16.60 | 15.96 |
| | b | 1 | 17.87 | 18.32 | 17.13 | 16.12 | 15.95 |
| | | 2 | 17.83 | 18.26 | 17.19 | 16.17 | 15.82 |
| Left Rear | a | 1 | 15.79 | 18.76 | 14.30 | 15.27 | 15.13 |
| | | 2 | 15.79 | 18.80 | 14.30 | 15.25 | 15.19 |
| | b | 1 | 15.85 | 18.70 | 14.40 | 14.98 | 15.34 |
| | | 2 | 15.80 | 18.71 | 14.46 | 14.97 | 15.43 |

MATURE JERSEY (LF-RR)

| Cow Number | 7 | 18 | 25 | 36 | 73 |
|---|---|---|---|---|---|
| | 13.82 | 12.83 | 12.44 | 10.55 | 13.19 |
| | 13.92 | 12.75 | 12.38 | 10.63 | 13.18 |
| | 13.64 | 13.00 | 12.54 | 10.81 | 13.27 |
| | 13.60 | 12.95 | 12.65 | 10.78 | 13.23 |
| | 13.40 | 12.79 | 12.91 | 9.71 | 13.05 |
| | 13.39 | 12.80 | 12.88 | 9.75 | 13.14 |
| | 13.14 | 12.69 | 13.14 | 9.69 | 12.60 |
| | 13.22 | 12.65 | 13.11 | 9.77 | 12.58 |

(RF-LR)

| Cow Number | 3 | 23 | 53 | 87 | 91 |
|---|---|---|---|---|---|
| | 14.83 | 12.61 | 13.29 | 13.88 | 14.98 |
| | 14.85 | 12.60 | 13.42 | 13.87 | 15.01 |
| | 14.41 | 12.45 | 12.95 | 13.88 | 14.81 |
| | 14.48 | 12.47 | 12.95 | 13.86 | 14.82 |
| | 15.40 | 11.97 | 12.30 | 12.90 | 12.68 |
| | 15.41 | 11.95 | 12.22 | 12.82 | 12.75 |
| | 15.64 | 12.10 | 12.30 | 12.83 | 13.20 |
| | 15.67 | 12.02 | 12.27 | 12.86 | 13.16 |

3 YEAR-OLD JERSEY (LF-RR)

| Cow Number | | | 12 | 13 | 49 | 59 | 54 |
|---|---|---|---|---|---|---|---|
| Left Front | a | 1 | 12.93 | 13.58 | 11.71 | 12.92 | 12.30 |
| | | 2 | 12.84 | 13.59 | 11.69 | 12.90 | 12.27 |
| | b | 1 | 12.81 | 13.43 | 11.73 | 12.53 | 12.04 |
| | | 2 | 12.86 | 13.43 | 11.67 | 12.50 | 11.98 |
| Right Rear | a | 1 | 13.18 | 13.16 | 12.18 | 11.83 | 11.71 |
| | | 2 | 13.19 | 13.18 | 12.19 | 11.86 | 11.76 |
| | b | 1 | 13.34 | 12.74 | 12.35 | 11.90 | 11.70 |
| | | 2 | 13.31 | 12.82 | 12.25 | 11.95 | 11.76 |

(RF-LR)

| Cow Number | | | 17 | 37 | 43 | 60 | 64 |
|---|---|---|---|---|---|---|---|
| Right Front | a | 1 | 11.16 | 13.08 | 11.10 | 12.15 | 13.26 |
| | | 2 | 11.22 | 13.01 | 11.17 | 12.12 | 13.32 |
| | b | 1 | 11.24 | 12.89 | 11.23 | 12.13 | 12.96 |
| | | 2 | 11.23 | 12.87 | 11.27 | 12.20 | 12.96 |
| Left Rear | a | 1 | 11.87 | 11.81 | 11.89 | 11.91 | 12.92 |
| | | 2 | 11.83 | 11.77 | 11.91 | 11.83 | 12.86 |
| | b | 1 | 11.67 | 12.05 | 11.27 | 12.79 | 13.07 |
| | | 2 | 11.57 | 12.06 | 11.31 | 12.73 | 13.01 |

2 YEAR-OLD JERSEY (LF-RR)

| Cow Number | 56 | 61 | 75 | 86 | 98 |
|---|---|---|---|---|---|
| | 12.24 | 12.33 | 11.35 | 12.94 | 11.03 |
| | 12.21 | 12.33 | 11.39 | 12.92 | 10.99 |
| | 12.38 | 12.17 | 10.91 | 12.77 | 11.05 |
| | 12.40 | 12.18 | 10.85 | 12.76 | 11.14 |
| | 12.07 | 12.42 | 11.21 | 12.73 | 12.01 |
| | 12.13 | 12.42 | 11.23 | 12.68 | 12.04 |
| | 11.65 | 12.56 | 10.66 | 12.73 | 12.11 |
| | 11.68 | 12.59 | 10.72 | 12.80 | 12.11 |

(RF-LR)

| Cow Number | 8 | 24 | 28 | 42 | 110 |
|---|---|---|---|---|---|
| | 11.60 | 11.84 | 12.69 | 11.54 | 9.87 |
| | 11.66 | 11.86 | 12.71 | 11.62 | 9.86 |
| | 11.54 | 11.58 | 13.02 | 11.59 | 10.17 |
| | 11.48 | 11.71 | 12.92 | 11.57 | 10.12 |
| | 11.42 | 11.79 | 11.57 | 11.39 | 10.06 |
| | 11.36 | 11.77 | 11.60 | 11.42 | 10.03 |
| | 11.53 | 11.42 | 11.48 | 11.65 | 10.14 |
| | 11.51 | 11.39 | 11.56 | 11.65 | 10.08 |

# APPENDIX H

## NORMAL BODY WEIGHTS GROUP I (Units; lb.)

| Mature Friesian | | | 3 year-old Jersey | | |
|---|---|---|---|---|---|
| | Weighing No. | | | Weighing No. | |
| Cow No. | 1 | 2 | Cow No. | 1 | 2 |
| 131 | 1390 | 1391 | 12 | 741 | 733 |
| 135 | 1186 | 1187 | 13 | 643 | 647 |
| 144 | 1350 | 1350 | 17 | 687 | 680 |
| 146 | 1281 | 1277 | 37 | 729 | 723 |
| 154 | 1073 | 1072 | 43 | 599 | 595 |
| 164 | 1299 | 1300 | 49 | 733 | 711 |
| 165 | 1237 | 1228 | 54 | 719 | 706 |
| 168 | 1152 | 1149 | 59 | 794 | 784 |
| 170 | 997 | 997 | 60 | 757 | 754 |
| 171 | 1048 | 1046 | 64 | 839 | 828 |

| Mature Jersey | | | 2 year-old Jersey | | |
|---|---|---|---|---|---|
| 3 | 960 | 953 | 8 | 653 | 645 |
| 7 | 884 | 882 | 24 | 693 | 690 |
| 18 | 859 | 853 | 28 | 598 | 598 |
| 23 | 828 | 822 | 42 | 671 | 665 |
| 25 | 878 | 871 | 56 | 750 | 738 |
| 36 | 713 | 713 | 61 | 671 | 671 |
| 53 | 810 | 799 | 75 | 604 | 598 |
| 73 | 848 | 840 | 86 | 752 | 746 |
| 87 | 973 | 971 | 98 | 685 | 670 |
| 91 | 910 | 905 | 110 | 651 | 645 |

# APPENDIX I

## Hoof Load (lb.) Group I

**MATURE JERSEYS**

| | FRONT | | REAR | | TOTAL | |
|---|---|---|---|---|---|---|
| Weighing No. | 1 | 2 | 1 | 2 | 1 | 2 |
| Cow No. 3 | 534 | 516 | 434 | 422 | 960 | 953 |
| 7 | 479 | 491 | 392 | 391 | 884 | 882 |
| 18 | 477 | 485 | 354 | 368 | 859 | 853 |
| 23 | 446 | 450 | 373 | 368 | 828 | 822 |
| 25 | 473 | 475 | 409 | 402 | 878 | 871 |
| 36 | 394 | 379 | 311 | 330 | 713 | 713 |
| 53 | 445 | 439 | 364 | 362 | 810 | 799 |
| 73 | 437 | 450 | 401 | 395 | 848 | 840 |
| 87 | 525 | 518 | 468 | 456 | 973 | 971 |
| 91 | 480 | 483 | 423 | 428 | 910 | 905 |

**3 YEAR-OLD JERSEYS**

| | FRONT | | REAR | | TOTAL | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 1 | 2 | 1 | 2 |
| Cow No. 12 | 414 | 425 | 311 | 305 | 741 | 733 |
| 13 | 374 | 372 | 276 | 275 | 643 | 647 |
| 17 | 365 | 383 | 322 | 304 | 687 | 680 |
| 37 | 408 | 399 | 336 | 328 | 729 | 723 |
| 43 | 318 | 328 | 274 | 266 | 599 | 595 |
| 49 | 403 | 389 | 335 | 320 | 733 | 711 |
| 54 | 369 | 361 | 346 | 332 | 719 | 706 |
| 59 | 418 | 412 | 332 | 376 | 794 | 784 |
| 60 | 412 | 410 | 360 | 329 | 757 | 754 |
| 64 | 453 | 452 | 368 | 363 | 839 | 828 |

**MATURE FRIESIANS**

| | | | | | | |
|---|---|---|---|---|---|---|
| 131 | 720 | 731 | 634 | 626 | 1390 | 1391 |
| 135 | 628 | 612 | 554 | 548 | 1186 | 1187 |
| 144 | 719 | 719 | 580 | 584 | 1350 | 1350 |
| 146 | 684 | 686 | 591 | 593 | 1281 | 1277 |
| 154 | 581 | 584 | 484 | 480 | 1073 | 1072 |
| 164 | 692 | 701 | 570 | 602 | 1299 | 1300 |
| 165 | 674 | 673 | 580 | 555 | 1237 | 1228 |
| 168 | 619 | 612 | 510 | 514 | 1152 | 1149 |
| 170 | 526 | 537 | 457 | 452 | 997 | 997 |
| 171 | 569 | 576 | 471 | 464 | 1048 | 1046 |

**2 YEAR-OLD JERSEYS**

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | 352 | 348 | 318 | 308 | 653 | 645 |
| 24 | 391 | 380 | 316 | 322 | 693 | 690 |
| 28 | 340 | 337 | 260 | 263 | 598 | 598 |
| 42 | 351 | 360 | 316 | 300 | 671 | 665 |
| 56 | 401 | 399 | 348 | 333 | 750 | 738 |
| 61 | 381 | 367 | 307 | 309 | 671 | 671 |
| 75 | 328 | 314 | 268 | 272 | 604 | 598 |
| 86 | 398 | 401 | 364 | 351 | 752 | 746 |
| 98 | 384 | 368 | 330 | 308 | 685 | 670 |
| 110 | 364 | 360 | 273 | 283 | 651 | 645 |

# APPENDIX J

Unit Hoof Loads (p.s.i.) Group I
(Cows in same order from the top of each column as for hoof load data Appendix I)

| MATURE JERSEYS FRONT | MATURE JERSEYS REAR | 3-YEAR-OLD JERSEYS FRONT | 3-YEAR-OLD JERSEYS REAR |
|---|---|---|---|
| 17.459 | 13.930 | 15.851 | 11.713 |
| 17.343 | 15.052 | 13.417 | 10.747 |
| 18.178 | 14.515 | 16.900 | 13.218 |
| 18.346 | 15.949 | 15.752 | 14.014 |
| 18.854 | 15.596 | 14.796 | 12.037 |
| 17.894 | 15.981 | 17.106 | 13.660 |
| 16.582 | 14.723 | 15.108 | 14.325 |
| 15.962 | 15.101 | 15.968 | 15.249 |
| 18.739 | 17.973 | 16.194 | 13.835 |
| 16.114 | 16.108 | 17.166 | 13.980 |

| MATURE FRIESIANS | | 2-YEAR-OLD JERSEYS | |
|---|---|---|---|
| 20.408 | 19.190 | 14.592 | 13.665 |
| 17.541 | 14.166 | 16.126 | 13.656 |
| 22.137 | 17.785 | 13.556 | 11.515 |
| 19.493 | 19.512 | 15.386 | 13.348 |
| 16.886 | 12.426 | 16.010 | 14.146 |
| 20.665 | 19.814 | 15.099 | 12.437 |
| 20.183 | 18.801 | 14.251 | 11.894 |
| 17.926 | 15.581 | 15.581 | 14.515 |
| 17.003 | 14.880 | 16.448 | 13.281 |
| 16.032 | 14.073 | 18.408 | 13.359 |

# APPENDIX K.

## Herd Test Numbers or Ear-marks
## of the Animals of Group II

Measurements and data for the animals of Group II is presented in the order given below -

| MATURE | 3-YEAR-OLD | 2-YEAR-OLD | 1-YEAR-OLD | CALF |
|---|---|---|---|---|
| Test No. | Test No. | Test No. | E. M. | E. M. |
| 3 | 11 | 2 | 28 | 39 |
| 7 | 44 | 9 | 38 | 41 |
| 13 | 46 | 15 | 71 | 45 |
| 17 | 56 | 21 | 74 | 48 |
| 23 | 61 | 25 | 83 | 50 |
| 31 | 68 | 30 | 95 | 52 |
| 43 | 75 | 36 | 107 | 53 |
| 49 | 83 | 47 | 112 | 55 |
| 53 | 84 | 52 | 120 | 67 |
| 54 | 86 | 60 | 138 | 81 |
| 59 | 90 | 62 | 144 | 82 |
| 88 | 98 | 71 | 145 | 83 |
| 91 | 99 | 73 | 164 | 110 |
| 95 | 106 | 87 | 180 | 113 |
| 107 | 110 | 63 | 197 | 112 |

# APPENDIX L

Bearing Areas (Sq. in.) Group II

(Measurement No. 1 = Cast 1. Toes Together; 2 = Cast 2. Toes apart)

## MATURE

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 11.48 | 11.67 | 13.78 | 13.71 |
| 11.54 | 11.25 | 11.75 | 12.00 |
| 10.93 | 11.14 | 11.54 | 11.67 |
| 9.40 | 8.68 | 11.35 | 11.12 |
| 9.21 | 9.33 | 11.07 | 10.76 |
| 13.16 | 13.23 | 11.93 | 11.64 |
| 8.89 | 8.87 | 11.04 | 10.67 |
| 9.26 | 9.06 | 10.99 | 10.74 |
| 10.23 | 10.09 | 12.20 | 11.78 |
| 8.92 | 9.03 | 10.11 | 9.94 |
| 12.08 | 12.20 | 11.13 | 11.27 |
| 12.16 | 13.24 | 11.69 | 11.38 |
| 13.86 | 13.52 | 12.77 | 13.21 |
| 11.50 | 11.16 | 12.32 | 11.62 |
| 13.24 | 12.94 | 14.60 | 14.66 |

## 3 YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 10.97 | 10.85 | 11.93 | 11.81 |
| 10.10 | 10.31 | 11.15 | 10.75 |
| 9.78 | 10.03 | 11.12 | 11.56 |
| 10.41 | 10.60 | 11.54 | 11.64 |
| 10.44 | 10.25 | 11.87 | 11.71 |
| 9.26 | 8.58 | 9.67 | 9.90 |
| 10.56 | 10.79 | 10.95 | 10.91 |
| 11.98 | 11.87 | 11.48 | 11.78 |
| 11.14 | 10.95 | 11.98 | 11.24 |
| 11.93 | 11.55 | 11.79 | 12.26 |
| 10.55 | 10.34 | 11.11 | 10.86 |
| 9.04 | 8.63 | 10.36 | 10.55 |
| 10.81 | 10.43 | 12.19 | 12.29 |
| 10.98 | 11.01 | 11.28 | 9.85 |
| 8.57 | 8.26 | 9.75 | 9.73 |

## 2 YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 7.38 | 7.49 | 6.79 | 6.83 |
| 9.92 | 10.30 | 9.50 | 9.20 |
| 8.60 | 8.85 | 8.44 | 8.03 |
| 8.57 | 8.79 | 7.95 | 7.94 |
| 10.22 | 9.79 | 9.86 | 9.96 |
| 11.19 | 10.96 | 9.54 | 9.45 |
| 9.59 | 9.43 | 9.16 | 9.23 |
| 9.71 | 10.10 | 10.22 | 10.01 |
| 11.84 | 12.03 | 11.27 | 11.15 |
| 9.49 | 9.52 | 9.61 | 9.89 |
| 10.00 | 10.01 | 8.98 | 9.03 |
| 9.46 | 9.32 | 9.05 | 8.71 |
| 8.52 | 8.43 | 9.64 | 9.71 |
| 9.76 | 9.53 | 11.09 | 12.27 |
| 9.60 | 9.28 | 8.88 | 8.92 |

## 1 YEAR-OLD

| | | | |
|---|---|---|---|
| 5.95 | 5.59 | 5.63 | 5.17 |
| 7.52 | 7.56 | 6.90 | 7.46 |
| 7.85 | 7.43 | 6.65 | 6.51 |
| 6.79 | 6.62 | 6.06 | 6.02 |
| 6.82 | 6.21 | 6.73 | 6.26 |
| 7.04 | 7.18 | 6.08 | 6.26 |
| 6.51 | 6.30 | 5.88 | 6.27 |
| 8.02 | 8.36 | 6.39 | 6.33 |
| 7.63 | 7.09 | 6.69 | 6.20 |
| 7.90 | 7.84 | 7.67 | 7.62 |
| 7.56 | 7.47 | 5.70 | 5.61 |
| 7.00 | 6.91 | 6.59 | 6.23 |
| 7.69 | 8.06 | 6.97 | 8.01 |
| 7.17 | 7.24 | 5.75 | 5.75 |
| 6.09 | 6.18 | 5.96 | 5.71 |

## CALF

| | | | |
|---|---|---|---|
| 3.58 | 3.49 | 3.61 | 3.63 |
| 3.43 | 3.25 | 3.37 | 3.41 |
| 3.45 | 3.56 | 3.38 | 3.32 |
| 3.73 | 3.84 | 3.45 | 3.53 |
| 3.06 | 3.20 | 3.10 | 3.15 |
| 3.65 | 3.48 | 3.69 | 3.66 |
| 3.48 | 3.46 | 3.23 | 3.25 |
| 3.47 | 3.53 | 3.61 | 3.72 |
| 3.26 | 3.15 | 3.33 | 3.22 |
| 3.79 | 3.67 | 3.38 | 3.47 |
| 3.19 | 3.28 | 3.54 | 3.46 |
| 3.05 | 3.27 | 3.45 | 3.36 |
| 3.22 | 3.19 | 2.99 | 2.75 |
| 3.63 | 3.57 | 3.13 | 3.32 |
| 3.33 | 3.18 | 3.00 | 3.17 |

APPENDIX M

Normal Body Weights (lb.) Group II

(1 = 1st weighing; 2 = 2nd weighing)

| MATURE | | 3-YEAR-OLD | | 2-YEAR OLD | |
|---|---|---|---|---|---|
| 1 | 2 | 1 | 2 | 1 | 2 |
| 844 | 843 | 790 | 789 | 494 | 493 |
| 846 | 845 | 655 | 655 | 596 | 597 |
| 548 | 548 | 696 | 696 | 572 | 571 |
| 614 | 613 | 620 | 620 | 668 | 668 |
| 777 | 777 | 678 | 679 | 690 | 690 |
| 990 | 991 | 622 | 622 | 674 | 675 |
| 576 | 576 | 584 | 583 | 594 | 595 |
| 616 | 618 | 779 | 779 | 683 | 682 |
| 751 | 750 | 750 | 751 | 649 | 650 |
| 621 | 621 | 735 | 735 | 573 | 572 |
| 696 | 696 | 668 | 668 | 600 | 597 |
| 826 | 828 | 627 | 629 | 502 | 500 |
| 822 | 822 | 713 | 715 | 652 | 653 |
| 710 | 713 | 739 | 739 | 770 | 770 |
| 892 | 891 | 603 | 602 | 594 | 594 |

| YEARLING | | CALF | |
|---|---|---|---|
| 322 | 323 | 64.0 | 65.0 |
| 365 | 367 | 55.5 | 55.0 |
| 417 | 418 | 71.0 | 71.0 |
| 338 | 338 | 74.0 | 74.0 |
| 394 | 395 | 59.0 | 59.0 |
| 383 | 384 | 65.0 | 64.5 |
| 352 | 353 | 63.5 | 63.5 |
| 382 | 383 | 72.0 | 72.0 |
| 320 | 321 | 63.0 | 63.0 |
| 389 | 389 | 68.0 | 68.0 |
| 401 | 399 | 57.0 | 56.0 |
| 389 | 390 | 60.5 | 60.5 |
| 385 | 386 | 63.0 | 63.0 |
| 346 | 348 | 68.5 | 68.5 |
| 389 | 390 | 63.0 | 63.0 |

APPENDIX N.

Static Hoof Loads (lb.) Group II

(1 = 1st weighing; 2 = 2nd weighing)

| MATURE | | | | 3-YEAR-OLD | | | | 2-YEAR-OLD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FRONT | | REAR | | FRONT | | REAR | | FRONT | | REAR | |
| 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 451 | 448 | 384 | 376 | 420 | 418 | 362 | 368 | 267 | 275 | 224 | 229 |
| 464 | 469 | 381 | 389 | 368 | 372 | 284 | 282 | 316 | 310 | 272 | 276 |
| 310 | 306 | 228 | 225 | 384 | 384 | 312 | 310 | 302 | 308 | 268 | 272 |
| 346 | 346 | 276 | 280 | 340 | 336 | 270 | 272 | 368 | 371 | 296 | 294 |
| 436 | 436 | 353 | 346 | 374 | 374 | 302 | 308 | 372 | 366 | 314 | 328 |
| 508 | 516 | 474 | 466 | 332 | 334 | 294 | 299 | 352 | 343 | 320 | 322 |
| 323 | 319 | 248 | 256 | 319 | 322 | 253 | 262 | 314 | 320 | 272 | 268 |
| 334 | 336 | 276 | 269 | 434 | 420 | 336 | 344 | 363 | 370 | 315 | 311 |
| 408 | 400 | 330 | 334 | 397 | 395 | 347 | 360 | 360 | 352 | 291 | 288 |
| 324 | 323 | 284 | 284 | 384 | 394 | 354 | 356 | 319 | 318 | 263 | 250 |
| 366 | 359 | 331 | 329 | 362 | 368 | 297 | 301 | 336 | 332 | 258 | 256 |
| 426 | 444 | 380 | 372 | 341 | 355 | 289 | 279 | 276 | 270 | 220 | 234 |
| 448 | 456 | 370 | 376 | 392 | 403 | 322 | 316 | 364 | 356 | 292 | 290 |
| 389 | 387 | 305 | 314 | 393 | 395 | 334 | 341 | 403 | 408 | 368 | 362 |
| 468 | 472 | 420 | 428 | 332 | 336 | 268 | 273 | 321 | 325 | 274 | 272 |

| 1-YEAR-OLD | | | | CALF | | | |
|---|---|---|---|---|---|---|---|
| 184 | 183 | 140 | 128 | 39.0 | 37.0 | 25.0 | 27.0 |
| 201 | 205 | 164 | 155 | 34.0 | 37.0 | 23.0 | 25.0 |
| 212 | 224 | 186 | 184 | 44.0 | 43.0 | 31.0 | 30.0 |
| 192 | 196 | 148 | 152 | 43.0 | 45.5 | 29.5 | 30.5 |
| 224 | 228 | 170 | 174 | 35.0 | 36.0 | 25.0 | 25.0 |
| 216 | 211 | 162 | 160 | 37.5 | 36.5 | 28.5 | 29.0 |
| 204 | 206 | 144 | 148 | 37.5 | 36.5 | 27.5 | 28.5 |
| 212 | 216 | 161 | 164 | 42.0 | 41.0 | 28.0 | 30.0 |
| 180 | 181 | 136 | 137 | 37.0 | 37.0 | 27.0 | 27.0 |
| 208 | 222 | 184 | 176 | 39.0 | 39.0 | 26.0 | 27.0 |
| 212 | 212 | 187 | 192 | 33.0 | 34.0 | 24.0 | 22.0 |
| 220 | 224 | 174 | 172 | 36.0 | 36.0 | 23.0 | 24.0 |
| 214 | 210 | 184 | 188 | 36.0 | 37.0 | 28.0 | 27.0 |
| 188 | 192 | 155 | 148 | 40.0 | 40.5 | 27.0 | 26.0 |
| 222 | 228 | 168 | 172 | 37.0 | 38.0 | 24.0 | 26.0 |

APPENDIX O.

Static Unit Hoof Loads (p.s.i.) Group II

(Each item coded by multiplying by 2)

MATURE

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 39.28 | 38.39 | 27.87 | 27.42 |
| 40.21 | 41.69 | 32.43 | 32.42 |
| 28.36 | 27.47 | 19.76 | 19.28 |
| 36.80 | 39.86 | 24.32 | 25.18 |
| 47.33 | 46.73 | 31.89 | 32.16 |
| 38.60 | 39.00 | 39.73 | 40.03 |
| 36.33 | 35.96 | 22.46 | 23.99 |
| 36.06 | 37.08 | 25.11 | 25.05 |
| 39.88 | 39.64 | 27.05 | 28.35 |
| 36.32 | 35.76 | 28.09 | 28.57 |
| 30.30 | 29.43 | 29.74 | 29.19 |
| 35.03 | 33.53 | 32.51 | 32.69 |
| 34.84 | 33.73 | 28.97 | 28.46 |
| 33.83 | 34.68 | 24.76 | 27.02 |
| 35.35 | 36.48 | 28.77 | 29.20 |

3-YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 38.29 | 38.52 | 30.60 | 31.16 |
| 36.44 | 36.08 | 25.47 | 26.23 |
| 39.26 | 38.28 | 28.06 | 26.82 |
| 32.66 | 31.70 | 23.40 | 23.37 |
| 35.82 | 36.49 | 25.44 | 26.30 |
| 35.85 | 38.93 | 30.40 | 30.20 |
| 30.21 | 29.84 | 23.10 | 24.01 |
| 36.23 | 35.38 | 29.27 | 29.20 |
| 35.64 | 36.07 | 28.96 | 32.03 |
| 32.19 | 34.11 | 30.02 | 29.04 |
| 34.31 | 35.59 | 26.73 | 27.72 |
| 37.72 | 41.14 | 27.90 | 26.45 |
| 36.26 | 38.64 | 26.42 | 25.71 |
| 35.79 | 35.88 | 32.49 | 34.62 |
| 38.74 | 40.68 | 27.49 | 28.06 |

2-YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 36.18 | 36.72 | 32.99 | 33.52 |
| 31.85 | 30.10 | 28.63 | 30.00 |
| 35.12 | 34.80 | 31.75 | 33.87 |
| 42.94 | 42.21 | 37.23 | 37.03 |
| 36.40 | 36.64 | 31.85 | 32.93 |
| 31.46 | 31.30 | 33.54 | 34.07 |
| 32.74 | 33.93 | 29.69 | 29.04 |
| 37.38 | 36.63 | 30.82 | 31.07 |
| 30.41 | 29.26 | 25.82 | 25.83 |
| 33.61 | 33.40 | 27.37 | 25.28 |
| 33.60 | 33.17 | 28.73 | 28.35 |
| 29.36 | 28.96 | 24.31 | 26.87 |
| 42.72 | 42.23 | 30.29 | 29.87 |
| 41.29 | 42.81 | 31.48 | 29.50 |
| 33.44 | 35.02 | 30.86 | 30.49 |

1-YEAR-OLD

| | | | |
|---|---|---|---|
| 30.92 | 32.72 | 24.86 | 24.75 |
| 26.72 | 27.11 | 23.76 | 20.77 |
| 27.00 | 30.14 | 27.96 | 28.26 |
| 28.27 | 29.60 | 24.42 | 25.24 |
| 32.84 | 36.71 | 25.26 | 27.79 |
| 30.68 | 29.38 | 26.64 | 25.55 |
| 31.33 | 32.69 | 24.48 | 23.60 |
| 26.43 | 25.83 | 25.19 | 25.90 |
| 23.59 | 25.53 | 20.33 | 22.10 |
| 26.32 | 28.31 | 23.98 | 23.09 |
| 28.04 | 28.38 | 32.81 | 34.22 |
| 31.42 | 32.41 | 26.40 | 27.60 |
| 27.82 | 26.05 | 26.39 | 23.47 |
| 26.22 | 26.51 | 26.95 | 25.73 |
| 36.45 | 36.89 | 28.18 | 30.12 |

CALF

| | | | |
|---|---|---|---|
| 10.89 | 10.60 | 6.92 | 7.44 |
| 9.91 | 11.38 | 6.82 | 7.33 |
| 12.75 | 12.08 | 9.17 | 9.04 |
| 11.53 | 11.85 | 8.55 | 8.64 |
| 11.44 | 11.25 | 8.06 | 7.94 |
| 10.27 | 10.49 | 7.72 | 7.92 |
| 10.77 | 10.55 | 8.51 | 8.77 |
| 12.10 | 11.61 | 7.76 | 8.06 |
| 11.35 | 11.75 | 8.11 | 8.38 |
| 10.29 | 10.63 | 7.69 | 7.78 |
| 10.34 | 10.36 | 6.78 | 8.36 |
| 11.80 | 11.01 | 6.67 | 7.14 |
| 11.18 | 11.60 | 9.36 | 9.82 |
| 11.02 | 11.34 | 8.63 | 7.83 |
| 11.11 | 11.95 | 8.00 | 8.20 |

# APPENDIX P

## Hoof Lengths (units - in.) Group II

| MATURE | | | | 3 YEAR-OLD | | | | 2 YEAR-OLD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FRONT | | REAR | | FRONT | | REAR | | FRONT | | REAR | |
| 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 4.1 | 4.2 | 4.5 | 4.6 | 3.8 | 4.1 | 4.5 | 4.5 | 3.5 | 3.4 | 3.3 | 3.3 |
| 4.0 | 4.1 | 4.2 | 4.3 | 4.2 | 4.1 | 4.3 | 4.4 | 3.7 | 3.9 | 3.7 | 3.6 |
| 4.2 | 4.4 | 4.3 | 4.5 | 3.9 | 4.0 | 4.2 | 4.3 | 3.6 | 3.7 | 3.7 | 3.7 |
| 3.8 | 3.5 | 4.1 | 4.2 | 3.9 | 4.0 | 4.3 | 4.3 | 3.6 | 3.7 | 3.6 | 3.7 |
| 3.6 | 3.7 | 4.1 | 4.1 | 4.0 | 4.0 | 4.3 | 4.3 | 3.9 | 3.8 | 3.9 | 4.0 |
| 4.3 | 4.5 | 4.2 | 4.2 | 3.7 | 3.7 | 4.1 | 4.2 | 4.3 | 4.4 | 3.9 | 3.9 |
| 3.7 | 3.7 | 4.1 | 4.1 | 3.8 | 4.1 | 4.0 | 4.1 | 3.7 | 3.9 | 3.8 | 3.8 |
| 3.2 | 3.7 | 4.1 | 4.3 | 4.3 | 4.3 | 4.2 | 4.5 | 3.8 | 4.0 | 3.9 | 3.9 |
| 3.8 | 4.0 | 4.5 | 4.4 | 4.2 | 4.2 | 4.5 | 4.4 | 4.0 | 4.1 | 4.0 | 4.0 |
| 3.9 | 3.8 | 4.2 | 4.2 | 4.3 | 4.2 | 4.2 | 4.3 | 3.8 | 3.9 | 3.7 | 3.9 |
| 4.2 | 4.4 | 4.0 | 4.2 | 3.7 | 3.7 | 4.0 | 4.0 | 3.7 | 3.7 | 3.7 | 3.6 |
| 4.3 | 4.5 | 4.4 | 4.3 | 3.6 | 3.6 | 4.0 | 4.0 | 3.9 | 3.8 | 3.8 | 3.8 |
| 4.6 | 4.6 | 4.3 | 4.4 | 3.9 | 3.8 | 4.3 | 4.5 | 3.4 | 3.5 | 3.9 | 3.9 |
| 4.2 | 4.2 | 4.2 | 4.2 | 3.9 | 4.0 | 3.8 | 3.9 | 4.0 | 4.1 | 4.2 | 4.3 |
| 4.3 | 4.3 | 4.8 | 4.7 | 3.5 | 3.7 | 4.0 | 4.2 | 3.7 | 3.7 | 3.8 | 3.3 |

1 YEAR-OLD

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.2 | 3.2 | 3.0 | 3.0 | 2.3 | 2.3 | 2.3 | 2.2 |
| 3.5 | 3.5 | 3.4 | 3.5 | 2.3 | 2.3 | 2.3 | 2.3 |
| 3.5 | 3.5 | 3.3 | 3.1 | 2.4 | 2.4 | 2.3 | 2.3 |
| 3.2 | 3.1 | 3.0 | 3.0 | 2.4 | 2.4 | 2.5 | 2.4 |
| 3.4 | 3.2 | 3.2 | 3.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| 3.2 | 3.3 | 3.2 | 3.2 | 2.4 | 2.4 | 2.4 | 2.4 |
| 3.2 | 3.2 | 3.0 | 3.2 | 2.4 | 2.4 | 2.2 | 2.4 |
| 3.6 | 3.7 | 3.3 | 3.4 | 2.3 | 2.4 | 2.3 | 2.3 |
| 3.4 | 3.3 | 3.2 | 3.1 | 2.1 | 2.2 | 2.2 | 2.2 |
| 3.5 | 3.6 | 3.3 | 3.4 | 2.4 | 2.4 | 2.3 | 2.3 |
| 3.5 | 3.4 | 3.0 | 2.9 | 2.2 | 2.2 | 2.2 | 2.3 |
| 3.3 | 3.1 | 3.1 | 3.1 | 2.2 | 2.3 | 2.4 | 2.3 |
| 3.5 | 3.6 | 3.3 | 3.7 | 2.3 | 2.3 | 2.2 | 2.2 |
| 3.3 | 3.5 | 3.0 | 3.1 | 2.4 | 2.4 | 2.2 | 2.3 |
| 3.1 | 3.3 | 3.1 | 3.2 | 2.3 | 2.3 | 2.2 | 2.2 |

# APPENDIX Q

Breadth (units in.) Group II

| MATURE | | | | 3 YEAR-OLD | | | | 2 YEAR-OLD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FRONT | | REAR | | FRONT | | REAR | | FRONT | | REAR | |
| 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 3.8 | 4.3 | 4.0 | 4.2 | 3.7 | 4.4 | 3.8 | 4.1 | 3.3 | 3.9 | 3.2 | 3.5 |
| 3.8 | 4.1 | 3.4 | 3.6 | 3.6 | 4.2 | 3.5 | 4.0 | 3.5 | 4.0 | 3.3 | 3.7 |
| 3.6 | 4.0 | 3.4 | 3.8 | 3.7 | 4.3 | 3.4 | 3.9 | 3.4 | 3.9 | 3.0 | 3.7 |
| 3.7 | 4.2 | 3.6 | 4.0 | 3.8 | 4.3 | 3.5 | 4.1 | 3.7 | 4.1 | 3.2 | 3.9 |
| 3.6 | 4.1 | 3.5 | 4.0 | 3.9 | 4.2 | 3.6 | 4.3 | 3.5 | 3.9 | 3.1 | 3.6 |
| 4.3 | 4.9 | 3.9 | 4.5 | 3.4 | 3.9 | 3.3 | 4.0 | 3.7 | 4.1 | 3.4 | 3.6 |
| 3.5 | 4.0 | 3.5 | 3.8 | 3.8 | 4.1 | 3.4 | 3.9 | 3.5 | 3.9 | 3.3 | 3.8 |
| 3.1 | 4.1 | 3.4 | 4.2 | 3.8 | 4.2 | 3.5 | 4.0 | 3.5 | 4.0 | 3.3 | 3.8 |
| 3.8 | 4.1 | 3.7 | 4.1 | 3.9 | 4.5 | 3.5 | 4.1 | 3.9 | 4.4 | 3.6 | 4.0 |
| 3.6 | 4.1 | 3.3 | 3.8 | 3.8 | 4.1 | 3.6 | 4.0 | 3.5 | 3.8 | 3.4 | 4.0 |
| 3.9 | 4.5 | 3.6 | 4.2 | 3.8 | 4.2 | 3.5 | 4.0 | 3.5 | 4.1 | 3.3 | 3.8 |
| 4.0 | 4.5 | 3.7 | 4.2 | 3.6 | 4.0 | 3.5 | 4.1 | 3.6 | 4.0 | 3.1 | 3.7 |
| 4.1 | 4.5 | 3.8 | 4.1 | 4.0 | 4.4 | 3.7 | 4.0 | 3.5 | 4.1 | 3.3 | 3.8 |
| 3.8 | 4.2 | 3.8 | 4.0 | 3.9 | 4.1 | 3.4 | 4.0 | 3.7 | 4.2 | 3.7 | 4.0 |
| 4.1 | 4.6 | 4.0 | 4.3 | 3.5 | 4.0 | 3.4 | 4.0 | 3.7 | 4.2 | 3.3 | 3.7 |

| 1 YEAR-OLD | | | | CALF | | | |
|---|---|---|---|---|---|---|---|
| 2.8 | 3.3 | 2.7 | 3.0 | 2.0 | 2.2 | 1.9 | 2.2 |
| 3.1 | 3.6 | 3.0 | 3.5 | 2.0 | 2.2 | 2.0 | 2.2 |
| 3.1 | 3.7 | 2.8 | 3.2 | 1.9 | 2.3 | 1.9 | 2.2 |
| 2.7 | 3.0 | 2.9 | 3.0 | 2.0 | 2.3 | 1.8 | 2.3 |
| 2.9 | 3.4 | 3.1 | 3.3 | 1.8 | 2.1 | 1.8 | 2.2 |
| 2.8 | 3.4 | 2.5 | 2.9 | 2.0 | 2.2 | 1.9 | 2.2 |
| 3.0 | 3.3 | 2.9 | 3.3 | 1.8 | 2.2 | 1.8 | 2.2 |
| 3.0 | 3.6 | 2.7 | 3.4 | 2.0 | 2.4 | 2.1 | 2.4 |
| 2.8 | 3.4 | 2.9 | 3.3 | 2.1 | 2.5 | 2.2 | 2.4 |
| 3.1 | 3.4 | 3.1 | 3.5 | 2.1 | 2.6 | 1.9 | 2.4 |
| 3.0 | 3.4 | 2.9 | 3.3 | 2.0 | 2.3 | 2.0 | 2.5 |
| 3.0 | 3.4 | 3.0 | 3.4 | 2.0 | 2.4 | 2.0 | 2.3 |
| 3.0 | 3.5 | 3.0 | 3.4 | 1.9 | 2.2 | 1.7 | 2.2 |
| 2.9 | 3.3 | 2.9 | 3.2 | 1.9 | 2.3 | 1.8 | 2.2 |
| 2.9 | 3.3 | 2.8 | 3.0 | 2.1 | 2.6 | 2.0 | 2.2 |

# APPENDIX R

## Enclosed Areas (Sq. in.) Group II

(Measurement No. 1 = Cast 1. Toes Together; 2 = Cast 2. Toes apart)

### MATURE

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 14.64 | 16.36 | 15.79 | 17.56 |
| 13.25 | 14.86 | 13.17 | 14.10 |
| 13.27 | 14.96 | 13.17 | 15.42 |
| 12.11 | 13.07 | 13.24 | 15.46 |
| 11.73 | 13.53 | 12.93 | 15.08 |
| 16.95 | 19.23 | 15.12 | 17.27 |
| 11.49 | 13.86 | 12.74 | 13.82 |
| [illegible] | 14.11 | 12.86 | 15.28 |
| 13.23 | 14.19 | 14.65 | 15.59 |
| 12.67 | 14.42 | 12.84 | [illegible] |
| 14.84 | 16.92 | 13.05 | 15.34 |
| 15.19 | 18.05 | 14.42 | 16.16 |
| 16.68 | 17.89 | 14.63 | 15.72 |
| 14.32 | 15.87 | 14.29 | 15.41 |
| 15.57 | 18.02 | 16.73 | 18.56 |

### 3 YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 13.92 | 15.22 | [illegible] | 16.80 |
| 13.75 | 15.20 | [illegible] | 15.70 |
| 12.20 | 15.20 | [illegible] | 14.30 |
| 13.09 | 15.64 | [illegible] | 15.82 |
| 13.50 | 15.78 | [illegible] | 16.73 |
| 11.55 | 12.81 | [illegible] | 14.90 |
| 12.69 | 14.91 | [illegible] | 14.49 |
| 14.63 | 15.96 | [illegible] | 16.19 |
| 14.21 | 17.03 | [illegible] | 15.80 |
| 14.60 | 15.05 | [illegible] | 15.93 |
| 12.72 | 14.19 | [illegible] | 14.77 |
| 11.71 | 13.13 | [illegible] | 15.56 |
| 14.13 | 14.96 | [illegible] | 16.19 |
| 13.44 | 14.30 | [illegible] | 14.18 |
| 11.24 | 12.65 | [illegible] | 14.68 |

### 2 YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 9.90 | 11.93 | 9.43 | 10.40 |
| 11.09 | 13.57 | 10.53 | 12.26 |
| 10.80 | 12.95 | [illegible] | 11.96 |
| 11.66 | 13.55 | 10.50 | 12.99 |
| 12.14 | 13.33 | 11.10 | 13.20 |
| 13.09 | [illegible] | 11.93 | 12.67 |
| 11.55 | 13.43 | [illegible] | 12.96 |
| 11.70 | 13.65 | 11.68 | 12.89 |
| 13.72 | 15.43 | 12.41 | 14.93 |
| 11.44 | 12.67 | [illegible] | 13.48 |
| 11.75 | 13.55 | 10.60 | 12.07 |
| 12.60 | 13.47 | 10.40 | 12.62 |
| 10.84 | 12.67 | 11.28 | 13.30 |
| [illegible] | 15.05 | 13.65 | 15.75 |
| 12.30 | 14.19 | 11.53 | 12.88 |

### 1 YEAR-OLD

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| [illegible] | 9.10 | 7.57 | [illegible] |
| 9.10 | 11.31 | 8.30 | 11.58 |
| 9.52 | 11.64 | 8.05 | 9.37 |
| 7.43 | 8.47 | 7.69 | 8.67 |
| 8.47 | 9.50 | 8.76 | 9.10 |
| 7.88 | 10.36 | 7.10 | 8.19 |
| 8.08 | 9.61 | 7.80 | 9.84 |
| 9.40 | 10.71 | 7.91 | 10.13 |
| 8.24 | 9.78 | 8.07 | 9.12 |
| 9.86 | 11.02 | 9.35 | 9.86 |
| 8.80 | 10.49 | 7.75 | 8.78 |
| 8.51 | 9.75 | 8.35 | 9.87 |
| 9.29 | 11.09 | 8.70 | 11.65 |
| 8.43 | 10.43 | 7.61 | 9.11 |
| 8.05 | 9.76 | 7.90 | 8.89 |

### CALF

| FRONT 1 | FRONT 2 | REAR 1 | REAR 2 |
|---|---|---|---|
| 4.16 | 4.60 | 4.15 | 4.48 |
| 3.81 | 4.47 | [illegible] | 4.33 |
| 4.10 | 5.10 | [illegible] | 4.57 |
| 4.26 | 5.12 | [illegible] | 5.10 |
| 3.61 | 4.21 | [illegible] | 4.44 |
| 4.23 | 4.73 | [illegible] | 4.80 |
| 3.83 | 4.80 | 3.58 | 4.57 |
| 4.13 | 5.14 | 4.44 | 5.22 |
| 3.88 | 4.73 | 4.18 | 4.87 |
| 4.54 | 5.35 | 3.35 | 5.10 |
| 3.77 | 4.74 | 3.97 | 5.05 |
| 3.89 | 4.80 | 4.42 | 4.84 |
| 3.60 | 4.52 | 3.48 | 4.32 |
| 4.10 | 4.82 | 3.76 | 4.60 |
| 4.28 | 5.20 | 3.38 | 4.62 |