A STUDY OF KEMP VARIATION IN THE FLEECES OF CHEVIOT EWES

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I INTRODUCTION

The Cheviot and its crosses are becoming increasingly important as a hill country sheep in New Zealand. The popularity of the breed is based primarily on its fertility, mothering ability and hardiness. However, its wool, which is regarded as a by-product of minor importance under the English farming system, is of greater economic value to the New Zealand farmer.

The fleece of the Cheviot has been criticised by people connected with the wool trade for certain faults. Naturally, such faults lower the value of the fleece. Thus, if the return per sheep is to be maximised the fleece type would need to be improved provided that such fleece improvement does not result in lowered production in other products. Of the faults pinpointed, kempiness is one which from previous experience with Romneys, offers hope of being eliminated without undue difficulty. Observations of the Cheviot flock run at Massey Agricultural College indicated that there was great variability in kempiness at different times of the year and between sheep. Such variability in itself, suggests that kempiness may be eliminated or reduced to negligible amounts by selection of kemp-free sheep.

An attempt was made, in this present study, to determine the variability of kempiness in relation to age, sheep, time of year and body regions and to indicate a suitable criterion and position for the estimation of kempiness in the fleece. In other words, a preliminary investigation of the kemp problem in Cheviots was made.

The importance of this study does not necessarily rest with practical concerns. The kemp fibre is one of a number of different fibre types found in the fleece and as such is of interest to the wool biologist. Nevertheless, it is one of the least studied fibre types probably because before 1933, at least, it was primarily regarded as a fault in the fleece rather than a type of fibre. However, since then Dry's (1933, 1934, 1935) pioneering work on the birthcoat of the Romney lamb has stimulated much work on the biology of the fleece. Such research has generally been approached from a consideration of all fibre types and kemps, being one fibre type of the fleece, have received some attention. This attention is being intensified with the development of knowledge in wool biology. However, there is still a great lack of knowlege of fundamental aspects of the development, growth and shedding of kemp fibres especially in the adult fleece. Furthermore, most work which has been done has been of doubtful value because of the limitations of the techniques used to measure kempiness and the small numbers of sheep used (Burns, 1949; Ryder, 1956).

Thus, in this study, it is hoped to obtain some information on the development, growth and shedding of kemp fibres in the Cheviot to compare with conclusions made by other workers on the development, growth and shedding of kemp fibres in other breeds and to discuss any conclusions drawn with regard to their work.

II REVIEW OF LITERATURE

A. General

1. Definition of kemp.

The problem of dyeing fabrics containing kemps to an even, unblemished colour, first attracted the attention of textile research workers in the early part of the century. Coinciding with research on this problem was the classification of the fibre types of the fleece.

Bowman (1908) referred to a malformation of normal wool which he divided into "flat" kemps (heterotypes) and fully developed kemps (hair or kemp). These abnormal fibres were distinguishable from normal wool by the silvery appearance of part or all of the fibre.

Toldt (1910, 1912) classified the individual fibres of the fleece into Leithaare (outer, thick hairs), Grannenhaare (over-hair) and Wollhaare (fine hairs or wool). No mention was specifically made of kemp although they probably were included in the Leithaare group.

Priestman (1911) made a detailed study of the morphology of kemp fibres and found that the silveriness of kemp was due to the reflection of light by air spaces included in the fibre. He also regarded kemp as a faulty wool fibre. This view was not held by Crew and Blyth (1922) who classified the fibre types of the Blackface lambs coat into three groups corresponding to kemp, hair and wool

Cockayne (1924) further subdivided the fibres found in the Lincoln and Romney breeds into face and leg hair, kemp, medullated wool fibres and wool. He defined kemps as medullated fibres and noted that they only had a limited life. This definition does not appear to have received much recognition until the end of the decade.

At this period, the state of confusion existing as to the correct definition of the various fibre types led workers, such as Duerden and Ritchie (1924) and Cockayne (1924), to use the term kemp to denote the true kemp fibre while workers such as Barker and King (1926) used the term kemp to denote any medullated fibre.

Bliss (1926) considered that the theory developed by Duerden and Ritchie (1924) attempting to show that kemps were a remnant of the outer coat of the ancestral sheep, was evidence that kemps were not abnormal wool fibres.

A series of papers on kemps, published by the British Research Association for the Woollen and Worsted Industries, did much to improve the definition of kemp and knowledge of the morphology of kemps. In this publication Duerden (1926) described the microscopic appearance, the medulla and the dyeing of South African Merino kemps. His definition of a kemp as a hairy fibre lost most of its value as it did not distinguish between kemp and hair. Fraser Roberts (1926) made a detailed study of the macroscopic and microscopic components of kemp in the Welsh Mountain Sheep. His studies also included investigations into the growth and origin of kemp. The main contribution of his work, however, was his definition of a kemp as a hairy fibre which is shed annually. This definition was reconfirmed by Blyth (1926). Hirst and King (1926) studied kemps in the Mohair and found evidence suggesting that the definition of kemp might be incorrect. They found fibres with cut-ends which suggested that kemps were not shed. However, they did not place much reliance on their evidence as "the casual manner of shearing may account for this." (cut ends).

Fraser Roberts' (1926) definition has been shown to be inadequate by Northcroft (1928) and Lang (1942). With the growth of knowledge of the birthcoat and the realisation that kemps may be shed at intervals less than a year, the restriction of the growth of kemps to one year became unreal. A kemp was redefined as a medullated fibre which grew for a limited time and was then shed.

Lang's (1942) definition may also be criticised. Work by Burns (1949, 1953, 1954a, b, 1955) and Ryder (1956, 1957) has indicated that shedding from primary and secondary follicles can be quite extensive at certain periods each year. This suggests that non-kemp fibres may also be shed after a limited period. It is necessary, therefore, to improve Lang's definition. The following definition was used in this experiment; it defines a kemp as a medullated fibre of characteristic appearance which is shed after a limited period of growth.

2. The morphology of kemps.

Coinciding with the development of the definition of a kemp fibre was the development of knowledge regarding the morphology of kemps. Research by Priestman (1911), Duerden and Ritchie (1924), Fraser Roberts (1926), Blyth (1926), Duerden (1942) and Wildman (1955) may be summarised in this generally accepted description of the morphology of kemps; the fibre varies in length according to breed; it is medullated (often grossly so) with a characteristic waviness; it is opaque because of its air-filled medulla and is often deformed or bent; it is elliptical in cross section; it is tapered at the tip end and the root where in shed fibres it usually ends in a small bulb giving the appearance of a brush-end; the cuticle shows a typical scale pattern which in the basal half of the fibre is described as a regular mosaic form and in the tip half as an irregular mosaic form; the cortex is similar to that of wool while the medulla is reticulate with cell walls thickened by spinous processes and partly keratinised. (See fig. 1)

3. The importance of kemp.

The major problem caused by kemps in kempy wool is that of dyeing a kempy worsted cloth to an even unblemished colour. Duerden (1926), Blyth (1926) Lang (1942) considered that the cortex of kemps absorbed dyes as readily as the cortex of wool fibres but that light reflected from the medulla caused the fibres to become off-shade. As the removal of these blemishes takes time and money, a price discrimination against kempy wools exists, except in cases where such wools are required for special cloths. This latter fact was pointed out by King (1926). He regarded the fact that the medulla was of different chemical composition from the cortex as partly the cause of off-shade colours.

Kemps also affect the performance of wool during the manufacturing processes. This has been attributed by Bryant (1933) and Lang (1942) to their being:

a. Less elastic with a stiff smooth character.

b. More brittle and weaker per unit cross-section than wool.

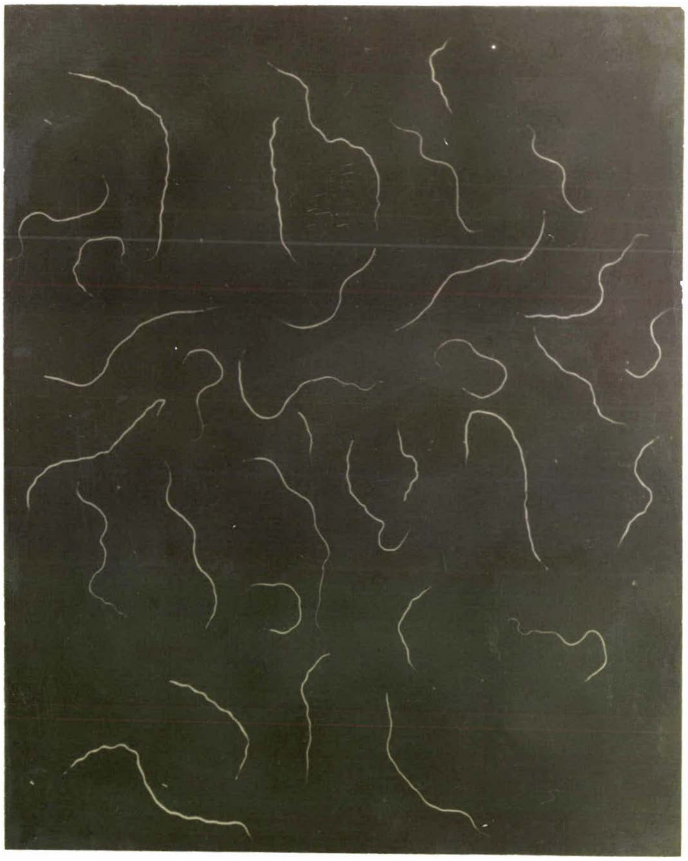
c. Elliptical in cross-section.

Fig 1

Kemps from the fleeces of

Cheviot ewes.

(note brush-ends)



Maré (1936) summed up the disadvantages of kemp in Merino wool. He stated that the two types (kemp and wool) could not be blended and manufactured into a satisfactory worsted as the kemp caused many thread breakages in the spinning process. In Mohair, Hardy (1937) found that there may be a loss of up to 18 per cent on combing Mohair containing many kemps. Kempy wools were not associated with good spinning qualities as "twitty" places and many breakages usually resulted from their presence in wool.

Lang (1942) stated that, generally speaking, the occurrence of kemp in wool is not of great importance to the woollen trade but that the worsted trade strongly discriminated against kempy wool.

The literature shows that much kempiness in the wool of any breed leads to the worsted trade discriminating against it, except in special circumstances. Thus to the farmer and the manufacturer, the importance of kemp lies in its undesirability as a fibre for manufacture.

To the wool biologist, kemp is important not only because it is one fibre type of the fleece but because it may represent the remnants of one coat of the ancestral sheep. Several workers (Duerden and Ritchie, 1924; Duerden, 1926; Fraser Roberts, 1926; Lockner, 1931; and Lang, 1942) believed that kemps evolved from the hairy outer coat of the ancestral sheep during the evolution of the woolled sheep. Lang (1942) has grouped the British breeds according to the type of fleece they produce, in an attempt to show how the type of fleece fitted in with the supposed evolution of the fleece. Not all evidence supports this theory, however, as Ross (1950) has recorded that some fibres of the fine undercoat are medullated. These fibres could have evolved as kemps.

It has also been suggested by Crew and Blyth (1922) and Duerden and Seale (1927) that heterotypism is associated with the disappearance of kemp in the evolution of the woolled sheep. In one sense, their statement is supported by their finding that the degree of development of heterotypic fibres is closely correlated with kemp. Lang (1942) brought forward the theory that heterotypes may be an adaptation of the wool to substitute, in hard conditions, for the loss of the protective hairy coat.

To date, however, there has been no published evidence to prove these theories so that they must await confirmation before being accepted.

Finally, the wool biologist is interested in kemps because, as the fundamental unit of study is the follicle, he may be able to learn about the follicle from the study of this fibre type.

B. The Methods of Measurement of Kempiness

A major problem in research of this type has been to find a suitable method of measuring kempiness accurately.

Quantitative estimation of kemp has been described by Fraser Roberts (1926) and Darling (1932). The method used by them was to separate, by hand, from a scoured, weighed sample of wool, the kemp fraction and the non-kemp fraction. Percentage weight and percentage number could then be calculated.

These measurements are not entirely satisfactory as a change in percentage number or weight of kemps does not necessarily mean that the number or weight of kemps has changed. Factors such as different body weights, follicle densities and wool growth rates between sheep mean that a comparison of wool samples of the same weight does not necessarily fulfil the ideal of comparing wool fibres from the same number of follicles. Another problem which can affect the results is the loss of shed fibres from the fleece or conversely their retention in the fleece.

Which of these measurements is the best to use has not been determined. However, Darling (1932) stated that there appeared to be a correlation between percentage number and percentage weight of kemps. He did not calculate the relationship as he thought that it was non-significant.

Elphick (1932) and later Bosman (1933) first used benzol to distinguish medullated fibres. This method of distinguishing accurately between medullated and non-medullated fibres was developed into the Benzol Test by Elphick (1932). However, while this test is useful to make kemps more distinctive in the separation of kemps from the other types of fibres, other methods of measurement are likely to be confused by the presence of non-kemp medullated fibres.

A further development of the Benzol Test was the medullameter (McMahon, 1937). By using a photo-electric cell to measure the light reflected from the medulla of fibres immersed in benzene, it was possible to construct an arbitrary percentage medullation index. By taking the difference of two readings of a wool sample before and after the removal of kemp fibres, it is possible to find the percentage medullation of the kemps. However, this method is time consuming and the interpretation of the index from a practical point of view is limited.

The more direct method of measuring kempiness from skin sections (both vertical and horizontal) as described by various workers (Carter, 1943; Burns, 1949, 1953, 1954a, b, 1955; Ryder, 1956, 1957 and Rougeot 1957), has its value in determining shedding follicles and the numbers of medullated fibres. However, it is very difficult to identify fibre types from cross sections of follicles. Consequently, the method loses much of its value if one is interested in one particular fibre type. Another drawback to this method is that if a thorough investigation of follicle activity is to be carried out, sections have to be cut at all levels of the follicle (Ryder 1956). This makes the method laborious. Finally, the loss of the fibre from the follicles during the cutting of a section may, if it is extensive, lead to false conclusions about shedding.

Methods of taking fibre cross sections have been described by Hardy (1937), Burns (1949), Wilson (1951) and Pilkington and Purser (1957). From these cross sections, fibre diameter and numbers of medullated and non-medullated fibres can be calculated. However, it is very difficult to identify fibre types from fibre cross-sections. The classification of the various types of medulla developed and used by Burns (1953), Cockrem (1956) and Pilkington and Purser (1957) showed that kemps and coarsely medullated fibres usually had latticed medulla. However, the type of medullation depended on the position along the fibre at which the cross-section was taken. Thus this method is of limited value in estimating the numbers of kemps.

It appears as if no satisfactory method of estimating kempiness has been devised yet. Of the methods described, quantitative methods appear to be the best for measuring general changes in kemp populations.

C. Physiological Aspects of Kemp Development, Growth and Shedding

1. The development of kempiness in the fleece.

A study of the birthcoat of lambs has led to much information on the development of kempiness in the adult fleece. It has been found that the nature and degree of kempiness in the adult fleece is related to and can be predicted from certain characteristics of the birthcoat.

The classification of the various fibre types in the birthcoat was initiated by Toldt (1910, 1912), Crew and Blyth (1922) Duerden (1927, 1929), Duerden and Seale (1927), Boyd (1927), and Duerden (1932). Dry (1935) enlarged on the previous investigators work and developed a system for classifying the birthcoat fibres of the New Zealand Romney lamb. This classification was based on the shape of the tip of the fibre but also included other characteristics such as length, fineness and degree of medullation.

The birthcoat kemps fall into the first two of the three major categories which are:

a. Pre-curly-tips which are characterized by three regions; a post-natal region; a pre-natal curly-tip region; a pre-natal pre-curly-tip region usually sickle shaped but sometimes long and coarsely medullated. The birthcoat kemps in this group are halo-hairs, super-sickle A's, super-sickle B's and sickle fibres.

b. Curly-tips which consist of a pre-natal curly-tip region and a post-natal region. The birthcoat kemps in this group which are most commonly shed are hairy-tip-curly-tip fibres while some shed curly-tips have been found (Wickham, personal communication).

c. Histerotrichs. These fibres are not classified as birthcoat kemps. Descriptions of these fibre types are given by Dry (1935) and Stephenson (1956).

The relationship between fibre type and follicle type has been studied by several workers. The pre-natal development of follicle bundles has been described by Hardy and Lyne (1956) in the Merino and Stephenson (1957), in the Romney and N-type. They, in common with other workers, determined that the first follicles to develop were the primary central follicles. These were followed by primary lateral follicles and then by secondary follicles.

The order of appearance of fibre types after the development of the follicles in the Romney lamb was thought by Dry (1935) to be pre-curly-tips, curly-tips and histerotrichs.

Dry (1935) considered that pre-curly-tip fibres were formed in primary central follicles in non-N Romneys. However, Galpin's (1934) work on fibre frequency showed that pre-curly-tips formed up to 33 per cent of all birthcoat fibres. This strongly suggests that some pre-curly-tips are grown in primary lateral follicles. Carter (1940) believed that the larger diameter of primary follicles was evidence that they grew birthcoat kemps.

Fraser and Hamada (1952) calculated the S/P ratio of several British breeds of sheep and compared this with the ratio of birthcoat fibre types assumed to have grown either in primary or secondary follicles. They concluded that in coarse birthcoats halo-hairs grow in primary central follicles, hairy-tip-curly-tips in primary lateral follicles and curly-tips and histerotrichs in secondary follicles. In fine birthcoats primary central follicles grew sickle tips, primary lateral follicles grew checked curly tips and secondary follicles grew plain curly tips and histerotrichs. However, their conclusions were not always closely supported by their evidence.

Fraser, Ross and Wright (1954) in a study of 33 N/N, 65 N/+ and 17 nr/nr Romney lambs calculated the mean percentage of primary central, primary lateral and secondary follicles for all genotypes at birth. These percentages were compared with the percentage frequency distribution of the fibre types, corrected to that which would have occurred at birth. They produced data on fibre length to support their conclusions. Wickham (1958) using a combination of frequency and fibre diameter comparisons, was able to confirm the results of Fraser et al on the whole, but found some exceptions. The evidence to support the assumption that all or most fibre types are grown in certain follicle types is at present inconclusive so that these results can only be regarded as tentative. Nevertheless, the evidence produced by Fraser et al and Wickham supports the contention that in N/N lambs primary central follicles grow the birthcoat kemps, pre-curly-tips and hairy-tip-curly-tips, primary lateral follicles grow pre-curly-tips and hairy-tip-curly-tips while secondary follicles grow hairy-tip-curly-tips. In N/+ sheep primary central follicles grow pre-curly-tips and primary laterals grow hairy-tip-curly-tips. In nr/nr lambs, primary central follicles grow pre-curly-tips and possibly some hairy-tip-curly-tips and primarly laterals grow hairy-tip-curly-tips.

Curly-tip fibres were believed to develop after pre-curly-tips in the foetus by Dry (1935). However, Ross (1945) found evidence that some curly-tips often appeared as early as super-sickles. She therefore suggested that these fibres (mainly hairy-tip-curly-tips) should be considered as part of the pre-curly-tip series.

All the evidence available suggests that birthcoat kemps may grow in any follicle type according to genotype but that they are most likely to occur in primary central follicles.

The arrangement of the fibre types from a tuft of the birth-coat into the assumed order of appearance in the foetus, led to the development of fibre type arrays (Dry 1935). Pre-curly-tips were assumed to appear first and histerotrichs last. Within groups the first formed fibres were those with the greatest number of curls in the tip. The arrays were named according to the absence or presence of the different fibre types. The arrays in decreasing order of hairiness are Plateau (subdivided into four); Saddle; Ravine; Valley; Plain; Ecarpment (found by Galpin 1934). All in and Incline (Burns 1955). A description of the fibre type arrays is given by Stephenson (1956).

Duerden (quoted Dry 1931) suggested to Dry that the thinning in the necks of sickle fibres was due to a "birth" check. Dry (1935) developed this idea into the pre-natal check concept. By assuming variations in the onset, duration and decline of the check and in the base or inherent coarseness of the birthcoat, Dry produced explanations of the mode of formation of the fibre type arrays.

One important aspect of the check was that if a vigorous follicle, i.e. a follicle producing much fibre substance per unit time, suffered a sufficiently strong check, then, that follicle would produce a persistent fibre. On the other hand, a weakly checked vigorous follicle "being one which works extremely hard, is compelled to take a rest" and shed its fibre. In terms of fibre type array, the Plateau array suffers the least intense pre-natal check and the Plain array the most intense. Thus, the coarser arrays, because they show the least check, may be expected to be made up of more birthcoat kemps.

There is no evidence published by Dry to support his theory of the pre-natal check. In fact, it appears that the pre-natal check theory merely attempts to explain why certain phenonoma occur rather than how they occur. Other hypotheses of the mode of action of the check have been given by Galpin (1934-35). Sutherland (1937), Goot (1940), Ross (1945), Fraser (1952, 1953) and Fraser and Short (1952). None of these theories have proved satisfactory and other work and observations have led to criticism of them (Dry, 1952; Dry and Stephenson, 1954; Wickham, 1958).

Galpin (1934, 1936) followed up observations on fibre type arrays on the back and the rump of the Romney, and carried out investigations into fibre type array gradients in the Romney, Southdown and Ryeland breeds. The Romneys were more intensively sampled (15 positions) than the other breeds (9 positions on four sheep of each breed plus fewer samples on more sheep). Nevertheless the results demonstrated that the checking force increased in intensity from the britch to the poll, giving a posterior-anterior gradient in fibre type arrays and hairiness over the body. A subsidiary inferior-superior gradient for the dorso-lateral portions of the coat was also noted.

Goot (1945) in his study of Romney ewe hoggets, confirmed the gradients found by Galpin for fibre type arrays and medullation. He also reported a highly significant correlation between fibre type arrays and percentage medullation ($r = 0.75$) although he did not think it was very reliable.

Further information on fibre type arrays in Romneys was provided by Stephenson (1952, 1956) in his work on fibre type array gradients, fibre types and medullation in relation to increasing N-gene dosage. He found that Galpin's posterior-anterior fibre array gradient was subject to some anomalies in Romney sheep. For instance, the shoulder patch was found to be the most heavily checked region in all genotypes in the Romney. This evidence refutes Galpin's statement that anterior and inferior arrays are less heavily checked. Furthermore, an anterior-posterior gradient was found in one N/N lamb. In view of this evidence, Galpin's findings can only be regarded as a general rule. Stephenson also showed that increasing N-dosage caused increased medullation, first in the least checked regions and lastly in the most checked regions. A maximum for medullation was achieved in the N/N sheep.

The britch-poll gradient was also demonstrated in the Merino x Herdwick cross by Burns (1935).

The shedding of birthcoat kemps has been found to be mainly from primary follicles (Carter, 1943; Burns, 1949, 1953, 1954a, b, 1955; Dry, 1952; Fraser, 1952 and Fraser, Ross and Wright, 1954) and in some cases, only from primary central follicles (Ross and Wright 1954 in the N-type, Carter 1943 in the Merino). The breeds in which such shedding has been found have been Romney, English Leicester, Blackface, Suffolk, Herdwick, Herdwick x Merino (Burns), non-N and N-type Romneys (Dry, Fraser, Fraser *et al*) and Merino (Carter). It is probable that insufficient sheep have been used in some of these experiments (Burns 1949, 1953, 1954a, b) so that further work is needed to verify these findings. This is indicated by Burns' (1949) observation of shedding from secondary follicles from young Romney lambs. She assumed that these shedding follicles had grown birthcoat kemps although she had no evidence to prove this.

Dry (1935), Sutherland (1939), Goot (1940), Dry and Ross (1944) have all stated that of the birthcoat kemps that are shed, all or nearly all halo-hairs are shed. In cases where halo-hairs do persist, shedding of other birthcoat kemps is poor. Goot (1940) stated that, in general, the more closely a fibre was allied to halo-hairs in Dry's classification, the more likely it was to be shed. That this was not always so was pointed out by Dry and Ross (1944). They found that super-sickles whether they are in Plateau or non-Plateau arrays, sickle fibres in non-Plateau arrays and hairy-tip-curly-tips varied in their shedding from all to none.

Dry (1952), in a study of *N/N*, *nr/nr* and *N/+* lambs, alleged that there was a decrease in vigour in primary follicles, and hence shedding "freedom" as the *N*-gene dosage passed from *N/N* to *nr/nr* to *N/+*. He concluded that the coarser the fibre the more freely it shed, and that fibres produced from primary central follicles shed more freely than those produced from primary lateral follicles. Support for Dry's observation was derived from the work of Ross and Wright (1954). By determining the frequencies of shed and non-shed pre-curly-tips and assuming that pre-curly-tips are produced in primary follicles only, they showed that shedding was restricted to primary follicles. Furthermore, primary central follicles were shown to shed most of their fibres while primary lateral follicles shed few of their fibres (less than 20%). However, it must be borne in mind that evidence supporting their assumptions is indirect and may be proved unsound by further work.

The relationship between shedding and fibre type array has been studied by Sutherland (1939). He found that the least checked of the Plateau arrays shed a higher percentage of birthcoat kemps than the more checked Plateau arrays. He also noted that there was considerable variation in the freedom of shedding of the more checked Plateau arrays. Goot (1940) extended these investigations to non-Plateau arrays and was able to conclude that Plateau arrays had the highest percentage of shedding fibres while of the non-Plateau arrays Valley had the lowest (Plain arrays were not studied). He also found that for the same body region, the more checked the array the fewer fibres of a given type were shed. Conversely, for different body regions, the same array would vary in degree of shedding. In the same array more fibres were shed from the back > rump > half britch > britch > side > withers. (> signifies greater than).

The study of the birthcoat in relation to kempiness in the adult fleece is important. Several workers have observed characteristics in the birthcoat of the lamb from which kempiness in the adult fleece can be predicted. Unfortunately, only general changes in kemp population have been observed as the methods of observing changes in the number of follicles producing kemps are subjective rather than objective. Moreover, little fundamental work has been carried out to determine why follicles should produce different fibre types at different periods of the sheep's life.

In 1926, Fraser Roberts working with Welsh Mountain sheep, stated that there was an association between a thick hairy birthcoat and the adult fleece although he did not publish any evidence to support his statement. However, he noted that in some cases, when the thick, hairy birthcoat was shed, kempiness was negligible in the adult fleece. Duerden (1926) also noted in the Merino, that the kempy birthcoat of the lamb was usually replaced by a fine non-kempy fleece in the adult. In a later paper, (Duerden 1932), he stated that, in general, in the birthcoat of lambs of most breeds, sickle fibres were followed by kemps and curly-tips were followed by heterotypes and wool.

A study of the fleeces of adult Scottish Blackface rams was carried out by Darling (1932). He showed that kempiness as judged by samples from the shoulder and haunch, decreased from ram lambs six months old to rams aged two years six months old; it reached a peak again at approximately the same level as the ram lambs in three year six months old rams and gradually decreased with age thereafter. However, the measurements of kempiness used by Darling, i.e. percentage weight and percentage number of kemps, may have resulted in false conclusions as percentage wool and hair has been found to decrease with age, especially after the age of five years (Bryant 1933). Thus, Bryant (1933), taking into account the decrease of hair and wool and assuming reasonably equable environmental conditions, concluded that from 18 months to five years old there was no appreciable variation in percentage weight of kemps. However, no experimental evidence was published to support this conclusion.

Dry (1935, 1940) studied succession in the New Zealand Romney. Most data were collected from a position on the back at the point of attachment of the last rib, while more scanty data was collected from other body positions. Dry demonstrated that the number of halo-hairs could be used, with caution, as an index of kempiness in the adult fleece, i.e. a high number of halo-hairs usually indicates that much kemp will grow in the adult fleece. Dry termed birthcoat kemps as G_1 kemps, second generation kemps as G_2 kemps and so on.

The major conclusions from Dry's work on non-Plateau arrays were that:

a. The successors of halo-hairs were all or nearly all shed only when three quarters or more of the large sickle fibres were shed.

b. The successors of shed birthcoat fibres other than halo-hairs were rarely followed by secondary kemp.

c. Kemp was plentiful amongst third generation fibres only when the array had been subject to a weak check. Heavily checked arrays did not show much secondary kemp late in the first year even though G_2 kemp was plentiful.

d. There was much later kemp when there was freedom of shedding of pre-curly-tip kemps.

Sutherland (1939) confirmed Dry's finding that if some halo-hairs were persistent then shedding of birthcoat kemps would be poor. Consequently, there would be few kemps growing in the adult fleece. Goot (1940) also investigated succession in the Romney lamb and confirmed Sutherland's finding. He substantiated Dry's conclusion that the less checked the array, the greater the proportion of birthcoat kemps succeeded by second generation kemp.

An investigation of succession in 81 <u>N</u>-type lambs showing Plateau arrays by Ross (1945) led to the following conclusions:

a. If there was little G_2 kemp (less than 75 kemps / 100 halo-hairs) kempiness becomes negligible in the next two generations.

b. It was possible, regardless of the number of halo-hairs on the birthcoat of <u>N</u>-type sheep to have little or no kemp in later generations.

c. The best guides to later kempiness were hairy-tip-curly-tip fibres. If more than 45% of the total numbers of hairy-tip-curly-tip fibres were shed then later kemp was abundant. If a smaller percentage of hairy-tip-curly-tip fibres were shed then the degree of later kemp was variable.

d. Where there was much freedom of shedding of pre-curly-tips then much secondary kemp occurred. This finding is supported by similar conclusions by Lockner (1931) and Dry (1935, 1940). Grandstaff and Wolf (1947) studied the percentage of kemp in Navajo and cross-bred lambs from 28 to 364 days old. Many heavily checked non-Plateau arrays were found in these breeds. They established that over the period studied there was a reduction in percentage kemps from 6.8 per cent to 5.9 per cent in the Navajo lambs and slightly more in cross-bred lambs. They concluded that as the major change occurred between 28 and 84 days, a number of follicles which had shed fibres did not grow kemps again. However, this period coincides with the completion of the follicle population so that the reduced percentage of kemps may have been due to an increase in wool fibres rather than a decrease in kemp fibres.

A study of the effects of increasing <u>N</u> dosage in kemp succession was carried out by Ross and Wright (1954). Their results showed that <u>N/N</u> and <u>nr/nr</u> genotypes had a higher percentage of birthcoat kemps than <u>N/+</u>. However, in succeeding generations the difference between <u>N/N</u> and <u>N/+</u> was maintained while the degree of kempiness in <u>nr/nr</u> genotypes was reduced to a level which equalled that of the <u>N/+</u> genotype. They concluded that the <u>N</u> gene had a more powerful effect on shedding (and hence kempiness in the adult fleece) than the <u>nr</u> gene.

An examination of succession in Merino x Herdwick sheep by Burns (1955) confirmed work on succession in the Romney. Thus, all coarse Plateau arrays were followed by much later kemp, while kemps were not found in the adult fleeces of lambs which had Plain or Ravine arrays. Ragab, Asker and Ghoneim (1956) working with Ossimi, Rahmani sheep and their crosses found some variation in percentage weight of kemps up to 23 months after birth, but this may have been due to cycles of kemp growth.

2. The shedding of kemps.

a. Types of shedding.

In a study of kemps in the South African Merino, Duerden and Ritchie (1924) recorded shed fibres with folded root-ends. The three stages of shedding described by Dry (1926) for the mouse were adopted by him for the sheep. Unfortunately, it was not made clear as to whether this type of shedding was typical of both secondary and primary follicles or either one. The stages are:

a. The anagen phase, which is the growing phase.
b. The catagen phase, which is the period during which the root decreases in size until it becomes medulla free.
c. The telogen phase, in which growth ceases and the "brush-end" is formed.

The formation of a brush-end before shedding is considered to be characteristic of "normal" shedding. This type of shedding was confirmed by Northcroft (1928) in New Zealand breeds and by Frölich, Spöttel and Tänzer (1929) in Karakul sheep.

Hunger shedding in which the proximal portion of the fibre became very thin and the brush small, was described by Rudall (1934).

However, later workers have confirmed that this type of shedding mainly occurred in secondary follicles (Burns, 1954b; Ryder, 1956).

Rudall (1934) described smoky shedding of damaged fibres in Romneys. This type of shedding was also found in Southdown and Ryeland sheep by Galpin (1936). The basal end of these fibres was described as ending in a hollow cavity and not a brush-end. However, Sutherland (1939) pointed out that, as this type of shedding always occurred in fine fibres and smokiness can be caused by tugging, this type of shedding is atypical. Both Sutherland (1939) and Goot (1940) found intermediates between normal and smoky shedding in Romneys. In contrast to Sutherland's view that such shedding is atypical, Goot tended to regard these fibres as normally shed. Goot also showed that some basal ends of normally shed fibres may be enclosed in a sheath which could be readily detected with Orange G stain.

Auber and Burns (1947) examined skin sections from Romney, Leicester and Blackface sheep but found few brush-ended shed fibres. They described shedding in an undefined follicle type in which the old fibre was lost while the replacement fibre was in its early stages of development. This precluded the possibility that the new fibres pushed the old fibres out of the follicles or grew alongside them as occurs in mammals (Segall, cited Auber and Burns 1947). Burns (1953, 1954b) confirmed this method of fibre replacement in Scottish Blackface and Herdwick sheep. Kemps which were shed in autumn were held in the follicle until they were lost in the spring. Replacement fibres were not found to start growing until this occurred.

However, in the Romney and Leicester breeds, Burns (1949) has found replacement fibres in primary follicles growing alongside the ectal margin of old fibres but separated from them by the layers of the root sheath. In secondary follicles, the replacement fibres grew into the lumen previously occupied by the old fibres. Replacement fibres in primary follicles, have also been noted growing alongside the old fibres by Rougeot (1957) and Wickham (personal communication) in the Limousin and Romney breeds respectively.

Burns (1949) could not find fibres with brush-ends in samples taken from Romney and Leicester lambs. Shed fibres, from both primary and secondary follicles, were observed to have bluntly pointed ends. However, as only two sheep of each breed were used, it is difficult to determine whether this type of shedding is common or abnormal.

Different types of follicle abnormality have been described by Burns and Auber (1951) and Auber and Ryder (1955). Of the three abnormalities reported by Burns and Auber (1951) they thought that the "plugged" type and possibly the "lymphatic" type might be related to brush shedding.

Burns (1954a) recorded a type of shedding in Suffolk sheep which she termed attenuation shedding. It appeared that the shedding of the fibre took place through a gradual reduction of cell division in the follicle bulb and of the keratinisation process without the formation of a brush-end. Due to its prevalence, Burns thought that this type of shedding was normal. However, Auber and Ryder (1955) re-examined Burns' material and came to the conclusion that attenuation shedding was due to lymphatic follicles.

An investigation into the effect of nutrition on wool follicle development in Cheviot lambs by Ryder (1955b), showed that lambs from ewes on a high place of nutrition had a higher percentage of lymphatic follicles than lambs from ewes on a low plane of nutrition. It was intimated from these findings that poor nutritional conditions did not bring about lymphatic shedding as was previously believed. As brush shedding and lymphatic shedding were observed in the same sample in this experiment and another one on Masham sheep (Ryder 1956), Ryder discredited Burns' (1954a) suggestion that lymphatic shedding represented normal shedding.

Further evidence that lymphatic shedding is an anomaly rather than normal was provided by Peart and Ryder (1954) who found no lymphatic follicles in Blackface sheep. Auber and Ryder (1955) concluded from evidence presented here plus some unpublished data, that large follicles such as found in kempy breeds, e.g. Herdwick and Scottish Blackface, are probably not as susceptible to lymphatic changes as smaller follicles. Ryder's (1955b, 1956) work suggested that good feed conditions might encourage lymphatic changes in the follicles. In these investigations he also recorded brush-shedding in secondary follicles of Cheviot and Masham sheep.

A survey of the Cheviot, Devon, Wiltshire, Ryeland, Hampshire and Shropshire breeds was carried out by Ryder (1957). He presented information on shedding from primary and secondary follicles and abnormal follicles for these breeds but without relating the type of shedding to the follicle type.

The available evidence suggests that brush-shedding is characteristic of primary follicles and probably some, if not all, secondary follicles of most breeds studied. It is possible that only those follicles producing kemps or medullated fibres form brush-ends. Secondary follicles appear to be more susceptible than primary follicles to factors other than the seasonal one, causing shedding. There are conflicting reports as to the method of fibre replacement which may be due to breed or follicle type differences or to faulty techniques in sectioning or sampling. The place of the abnormal follicle is difficult to determine but may possibly be related to a stage in shedding, changes in blood supply, disease or some other factor.

Most workers (Burns, Ryder, Burns and Auber, Auber and Ryder) have not related fibre type to shedding follicles except by use of fibre cross-sections (Burns 1954b). This method is not very accurate as coarsely medullated fibres and kemp fibres can have similar cross-sections. Furthermore, the results can be confused by the presence of heterotypes. Thus from most experiments reviewed here, only a general indication of what happens to kemps can be obtained. Also in many cases conclusions have been based on too few sheep, e.g. four Masham lambs, Ryder (1956b), two Romney lambs, Burns (1949) so that further work is needed to confirm these results.

Shedding in sheep has been associated with a degeneration of the blood supply to the follicle by Ryder (1955a). Similarly, glycogen which has been reported as absent from the outer root sheaths of human hair follicles (Brunner 1907) and mouse hair follicles (Hardy 1952) has been found only in the epithelial strand below the brush in sheep by Auber (1952) and Ryder (1956). This fact supports the hypothesis that glycogen is concerned with fibre growth.

b. Theories advanced as to the cause of kemp shedding.

Dry (1935, 1940) advanced two speculative theories, based on his observations, as to the cause of shedding. He observed that certain birthcoat fibres had ceased growth before birth (baby halo-hairs) and shortly after birth (sub halo-hairs) whereas halo-hairs, hairy super-sickles and sickle fibres started shedding about the age of seven weeks. In the former group, he concluded that shedding was due to the feeble state of the follicle induced by the pre-natal check. In the latter group, because of the size of fibre grown, it was considered that the follicle was producing fibre substance so vigorously that it needed to take a rest. The term vigour used here was applied by Dry to a follicle producing much fibre per unit time. Again, no experimental evidence was published showing that a follicle growing a medullated fibre was producing more fibre per unit time than a less vigorous follicle producing a non-medullated fibre. Therefore, Dry's hypothesis must be accepted with caution. "Vigour" is apparently under genetic control as well as being a function of the pre-natal check, as increasing <u>N</u>-gene dosage increases vigour. (Dry 1952).

In the Scottish Blackface, the shedding of kemps due to poor nutritional conditions was refuted by Bryant (1933). He postulated, without publishing experimental evidence, that the percentage weight of kemp remained fairly constant regardless of nutritional conditions. The only effect of good nutrition on kemp growth was to increase the rate of growth and diameter of kemps. Although no detailed evidence is given, Dry (1935) considered that poor nutrition could slow up shedding but not prevent it.

In contrast to the primary follicle, Galpin (1936) has shown that hunger shedding of finer fibres (from secondary follicles probably) occurs in the Romney. This type of shedding is thought responsible for "winter break" in British breeds. In this case, "winter break" is used to denote the "break" in the fleece in the late autumn-winter-early spring period due to the fibres being shed from a variable proportion of all types of follicles.

Goot (1940) used observations on the birthcoat of the Romney as evidence that shedding was due to genetic factors. Obviously, breeding experiments are required to verify this statement.

A study of the fleece development of a limited number of Suffolk, Blackface, Herdwick and Merino x Herdwick cross-breds was made by Burns (1953, 1954a, 1954b, 1955). The degree of "winter break" shown by these animals was found to depend on breed type, with a higher proportion of fibres being shed in the coarser woolled breeds. Kemps were not found to follow this pattern completely as, kemp fibres, after the formation of brush-ends in the autumn, remained in the follicle until they were shed in the spring. (Ryder (1956) produced evidence that this may not be so in Masham sheep.) Hence, Burns postulated that winter break is probably not entirely due to poor nutrition. She considered that poor nutrition probably accentuates shedding caused by some other seasonal mechanism such as day length. No clear distinction was maintained between primary and secondary follicles but the fact that primary fibres produced brush-ends in the autumn and did not shed them until spring suggests that nutrition has a lesser effect, if any, on primary follicles than on secondary follicles.

Unfortunately, the interpretation of the response of kemps to nutritional stress is complicated by difficulties in determining accurately the relationship between fibre type and follicle type. However, there is some evidence from Burns' (1954a) investigations which indicates that the shedding stimulus acts on follicle type rather than fibre type. This evidence was the shedding of up to 25% of both primary and secondary follicles in a Suffolk sheep which, as judged by the numbers of halo-hairs in its birthcoat (2% on the midside), showed little kemp.

Ryder (1957) produced further evidence of extensive shedding in non-kemp breeds. Thus, kemp shedding is probably controlled by the factors causing shedding in primary follicles, although follicles producing kemps may be more sensitive to these factors than follicles producing non-kemp fibres. Peart and Ryder (1954) confirmed Burns' findings for the Blackface and supported the idea that a seasonal stimulus might be inducing shedding.

Ryder's experiments on the effect of nutrition on the wool follicles of the Cheviot (Ryder 1955b) and the Masham (Ryder 1956) were based on too small a number of sheep to enable generalisations to be made. Furthermore, as follicle types rather than fibre types were dealt with, it is difficult to determine what role kemps play in the findings. However, results in the Cheviots showed that keeping ewes on different planes of nutrition had no effect on the shedding of birthcoat fibres of the lambs they bore. Similarly, in Masham lambs, poor nutrition alone was not considered to cause increased shedding of fibres from primary and secondary follicles. However, in the case of the Masham sheep, interpretation of the results was confused by individual variation in degree of kempiness, extent of shedding and time of shedding in the two sheep of each group. Such individuality might have led to false conclusions. As a higher proportion of fibres were shed in winter he suggested that a seasonal factor must be operating.

Reports have indicated that seasonal variations in daylength can induce growth of the winter coat in cattle (Yeates 1955) and influence the rate of wool growth of Corriedales (Hart 1955). These findings were extended by Rougeot (1957), who investigated the effect of variation in daylength on primary follicle shedding in 4 Limousin ewes. With two groups subjected to opposing cycles of daylength change, he was able to induce the two groups of ewes to grow and shed primary fibres out of phase with each other. Growth of primary follicle fibres was found to occur when daylength was decreasing while shedding of these fibres occurred soon after the completion of short days. As few sheep were used and errors introduced by estimating follicle activity from cross-sections cut at one level were not determined, further work may invalidate or modify these results.

Evidence that seasonal variation in daylength was not the only cause of shedding was given by Burns (1953, 1954b) and Ryder (1956b, 1958). Their investigations showed that some breeds (Blackface, Herdwick, Masham) had two moults per year, although in the case of kemps, Burns (1953) believed that all were shed at the same physiological moult. Ryder (1958) reported work done at Torridon which indicated that twice yearly shedding was probably a function of primary follicles while once yearly shedding was a function of secondary follicles. Observations on the birthcoat of the N-type Romney have also shown that shedding of the first few generations of kemps takes place at intervals much shorter than a year (Ross and Wright 1954). Finally, Wildman (1958) has found that shedding still occurred when the light/dark ratio was held constant and nutrition was removed as a limiting factor.

The literature available suggests that there is individual variation between breeds; between individuals and between follicles in the shedding of kemps. Regardless of this, shedding is markedly influenced by variations in daylength. Some other factor, probably genetic, appears to control shedding to some extent also. Nutrition, if it has any major effect at all, possibly acts more powerfully on secondary follicles than on primary follicles. As skin sections have been used to determine shedding cycles it is difficult to specify the role of kemps. Burns' (1953, 1954b) work suggests that kemps may behave differently from other primary follicle fibres although Ryder (1956) discredits this. Nevertheless, there is sufficient evidence of shedding of primary and secondary follicles in non-kempy breeds (Burns 1954a, Ryder 1957) to indicate that the shedding stimulas may act on the follicle type regardless of fibre type. In the past, the short growth cycle and distinctive appearance of kemp have probably caused kemp and not other fibre types, to be specifically related to shedding.

D. Variation in Kempiness

1. Regional variation.

To date little intensive work has been done on regional variations in kempiness over the body. If there is much variation in kempiness over the body, many experimental results may not be strictly comparable as kempiness has been estimated from different body regions by different workers.

In the adult Welsh Mountain sheep, Fraser Roberts (1926) considered that the point of the rump showed the highest proportion of kemp while the shoulder was regarded as a good indicator of the extent to which kempiness was spread throughout the fleece. In a more objective study, Darling (1932) analysed samples from 13 regions on the Scottish Blackface. The regions in order of kempiness, highest per cent count first, were found to be britch > rump > back > shoulder > neck.

Bryant (1933) also investigated the Scottish Blackface and found that there was great variability in the distribution of kemps over the body. The least variable region was found to be in a region from about the 8th thoracic rib to the root of the tail for 1 inch on either side of the backbone. Kempiness, as expressed by percentage weight, was considered to be a maximum here and an indicator of kempiness throughout the fleece. In areas other than this strip, kempiness was found to be very variable. In a further experiment, (Bryant 1936) he confirmed his results and showed that the thorax was nearly always free of kemps and that kempiness increased on the ventral side again. An investigation of skin sections of the Scottish Blackface by Burns (1953) indicated that the back and britch positions had a higher proportion of kemps than the midside position. This method of estimating kempiness has already been criticised.

Although few breeds have been studied, the pattern in each breed seems to be similar.

2. Variation between sheep.

Not many workers have studied this aspect as such nor have many workers used sufficient sheep to indicate the degree of variability between each sheep. Their results may be biassed accordingly.

Darling (1932) studied 190 Blackface rams of all ages. Shoulder and haunch samples were analysed and percentage number found. The coefficient of variation of kemp was found to be very high over all ages and for each age group. As this indicates that there is probably much variation in kempiness between sheep, a statistical transformation should probably have been applied before the calculation of the coefficient. Consequently these results may not give a true indication of the variability of kempiness.

Bryant (1933) made a study of 263 Blackface ewes and 62 Blackface rams of all ages. From data collected from the mid-back position at a period when kemp growth was considered to be ending (November) frequency distributions were drawn. For each age group, the frequency distributions were markedly skewed to the right indicating that there is great individual variation between sheep. The highest proportion of sheep had less than four per cent by count of kemps while some sheep had up to 40 per cent of kemps. The mid-back region, however, has been described by Bryant (1933) as the region of maximum kempiness so that this region can show a greater degree of variation than other regions. Also, as samples were taken at the end of the period of kemp growth, samples taken at other times of the year may indicate less variation between sheep.

Although Burns (1955) does not name kemps specifically or give any figures, she stated that there was great variability in every important fleece character in the Merino x Herdwick cross.

The results so far obtained are not directly comparable as the sampling positions used and sampling times were different. Nevertheless, the results indicate that there was much variability between sheep in kempiness in the Blackface breed.

3. Breed variation.

Breed variation in kempiness may depend on the stage of evolution of the breed.

Attempts to explain the evolution of the kemp fibre have been made by Duerden and Ritchie (1924), Duerden (1926), Fraser

Roberts (1926), Northcroft (1928), Lockner (1931) and Lang (1942). By assuming that the wild sheep is very similar to the animal from which domestic sheep have evolved, they postulated that, as the outer hairy coat of the wild sheep comprises fibres of kemp-like appearance which were shed annually, kemp had evolved from this coat.

Lang (1942) grouped the British breeds of sheep according to the type of fleece they produce and attempted to show how the type of fleece they grow fits in with the evolution of the fleece. Thus, he classifies the breeds into:

Long Woolled Mountain breeds (the Blackface, Herdwick etc.)
Short Woolled Mountain breeds (Welsh Mountain, Cheviot etc.)
The Down breeds (Southdown, Shropshire and Hampshire Downs)
The Lustre wools (Romney, Lincoln etc.)
The Merino breed.

The Long Woolled Mountain breeds have fleeces most closely related to the wild sheep and, consequently, more kemp. The Short Woolled Mountain breeds show partial suppression of coarse fibres so that kempiness is not so marked and the fleece shows much heterotypism. The Down breeds show almost complete suppression of coarse fibres. The fleece shows poor medullation and few, if any, kemps (Ryder 1957). The Lustre wools show development of the long fibres and suppression of fine fibres. Kempiness is probably a problem to a lesser extent than in short-woolled Mountain breeds (Cockayne 1924).

In the Merino only the wool fibres have been developed.

The breeds today would probably not fit Lang's classification very closely. The discrimination against kempy wool by manufacturers and the easy method of selecting against kemp in the adult fleece determined by Dry (1940, 1955a) has led to strong selection against kemp in most breeds. For instance, Henderson (1955) found an average of .04% kemps in Romney and Crossbred sheep.

Although little evidence has been brought forward to confirm this theory, apart from the association between time of shedding, the appearance of kemp fibres and coloured kemps in the domestic and wild sheep, no other attempt to explain breed differences in kempiness has been published. No worker appears to have studied breed differences in kempiness as such although it is generally recognised that breed differences do occur (Lang, 1942; Burns, 1954b; Ryder 1958).

4. Seasonal variation.

Ryder (1958) has postulated that shedding of kemps depends primarily on the breeds hereditary tendency to moult. Thus, wild sheep are reported to lose their woolly coat in the spring and their hairy outer coat in both spring and autumn. In domestic sheep, shedding varies from the more primitive domestic sheep, in which a high proportion of fibres are replaced each year, to the Merino, in which each individual follicle appears to have a very long growing phase.

A subjective method of measuring kempiness viz. visual examination, was used by Fraser Roberts (1926) in his investigation of the Welsh Mountain sheep. He found that kemps grew into the fleece in the late spring to late autumn and were shed in winter.

Frölich et al (1929) established in the Karakul that the Leithaare or outer coat (kemps were not mentioned specifically) was shed all the year round.

The percentage number of kemps was found to increase in the coat of the Blackface during early spring to early autumn by Darling (1932) and Bryant (1933). Shed ends to the fibres were noticed during late autumn and winter.

The birthcoat of the Romney lamb was shown to have different cycles of kemp growth from the adult (Dry 1935). He noted that halo-hairs started to shed in the early weeks or months of the lambs life and that other kemps shed somewhat later. By using a cover to prevent shed birthcoat kemps from falling out of the fleece, he was able to observe the growth of two to three generations of kemps in the first fourteen months. Carter (1942) noted in the Merino that shedding from primary follicles occurred soon after birth. Ross and Wright (1954) in a study of N-type sheep, confirmed Dry's findings on the time of birthcoat shedding in non-N Romneys. The first generation of kemps were shed two to three months after birth and succeeding generations at three to four monthly intervals until shearing at fourteen months. Investigations were not carried out after this period.

In the adult Blackheaded Persian, Lang (1942) quoting no evidence stated that one cycle of kemp growth occurred per year with the kemps shedding in the spring. Lang also described partial shedding of kemps in autumn and spring in Long Woolled Mountain breeds.

Burns (1949, 1953, 1954a, b, 1955) carried out a series of investigations on the Romney, English Leicester, Scottish Blackface, Suffolk, Herdwick and Merino x Herdwick breeds.

In the Romney and Leicester breeds Burns (1949) confirmed from skin sections, the general periods of shedding, found by Dry (1935) and Ross and Wright (1954) up to 9 months of age. However, her assumption that these fibres were birthcoat kemps was based on follicle type rather than fibre type. Hence, the fibre types which were shedding could not be determined. She also found that some follicle bundles underwent wholesale shedding while others did not. Her explanation of this was that there had been a temporary local restriction of blood supply.

In her study of the more primitive double-coated Scottish Blackface, Burns (1953) took skin samples at intervals over 43 weeks. Shedding of primary follicles appeared to conclude about the 17th week with peak shedding at 8-12 weeks. A new wave of shedding which involved more primary follicles commenced during the autumn. Many larger secondary follicles shed at this time also. Peak shedding was reached about midwinter, several weeks before the experiment concluded. Burns noted that a small proportion of primary follicles and a large proportion of secondary follicles did not shed at all during the winter.

Burns (1953) cited Deshpande's work on the Blackface which confirmed Burns findings as to the time that each generation of kemps grew and was shed. Without producing experimental evidence for her conclusion, she assumed that G_1 kemps were produced by primary follicles plus perhaps a few secondary follicles. Many primary fibres which formed brush-ends in the autumn did not shed until spring. Thus, she concluded that the two peak periods of shedding in the Blackface as shown by fibre type studies, were physiologically the same moult. Burns also established that there was considerable shedding of fibres from secondary follicles over the winter months. Although her assumption that primary follicles produce kemps is reasonable enough in the light of previous literature there is some doubt as to whether all primary follicles do so. The shedding of hairy fibres from primary lateral follicles could cause confusion in interpretation of the results especially as only four lambs were examined.

In the Suffolk, which has a Down type fleece Burns (1954a) examined skin samples from 4 lambs over a period of 63 weeks. She established that the percentage number of halo-hairs was low (less than 2%) so that it may be assumed that the percentage number of kemps was low. Nevertheless, shedding occurred from both primary and secondary follicles during autumn and winter although the proportion of follicles shedding was lower than in the coarser woolled Blackface.

One of the coarsest and most kempy of British breeds, the Herdwick, was sampled 11 times in a period of 115 weeks. It was estimated from skin sections that birthcoat shedding started about 10 weeks after birth. This moult concluded between 10 weeks and 5 months after birth and the second generation of kemps commenced growth. Later generations of kemps followed a pattern of growing in the spring and shedding by early autumn, then, growing over a longer period in the autumn and shedding in the late autumn to spring. As in the Blackface, some fibres formed brush-ends in the autumn but were not shed until the following spring. Possibly two generations of kemps would have been noted in the Blackface if the investigations had included more sampling times. Similarly, the early generations of kemps in the Herdwick, Suffolk and Blackface may not have been fully investigated due to the time elapsing between samplings.

In a much more valuable study of 80 Merino x Herdwick ewes Burns (1955) found that shedding, as evaluated from skin and wool samples, was of lower proportions in autumn than it was in spring. In the other breeds studied, the reverse happened.

In view of the possibility that waves of shedding occur (Burns 1953) it is difficult to evaluate her results as she took varying numbers of samples in different experiments and quite often, from different positions. Ryder (1956) showed that there were two peaks of shedding with primary follicles of 4 Masham sheep. These occurred in autumn and spring. Secondary follicles appeared to shed steadily over the winter. The sheep showed individual variation in the season in which the greater proportion of primary follicles shed. Presumably kemp shedding followed that of the primary follicles as very few secondary follicles had fibres with latticed medulla. It also appears from this that secondary follicle shedding may not be related to primary follicle shedding.

Rougeot (1957) established in the Limousin breed, that shedding of primary follicles took place over the late winter to early summer while kemp growth occurred over the rest of the year.

The literature suggests that there may be considerable differences in time of shedding of different breeds although the results may be confused because of lack of intensive sampling and standard sampling positions. Nevertheless British breeds show considerable variation in time of shedding. Possibly coarse woolled breeds shed twice a year (autumn and spring) while finer woolled breeds shed once, (autumn). As these results have been obtained primarily for primary follicles it has to be assumed that kemps follow a similar pattern. In the non-British breeds studied, it appears that shedding occurs in the spring. There is some evidence to suggest that the time of primary follicle shedding may be independent of secondary follicle shedding.

E. The Inheritance of Kemps

Papers by Fraser Roberts (1926) and Duerden (1926) commenting on the evolution of the fleece suggested that kempiness has been bred out of the fleece purely by selection against much kempiness. It can be inferred from this that kemp is probably inherited multifactorially. In the Blackface, Bryant (1933) produced evidence which indicated that kempiness was probably inherited multifactorially but with a tendency for low kempiness to be partially dominant over much kempiness.

Dry (1935, 1940, 1955a) published evidence indicating that in New Zealand Romney lambs halo-hair abundance was strongly inherited on a multifactorial basis. Dry (1940) also quoted some evidence showing that genetic factors control fibre type array inheritence and the number of generations of kemps a follicle will grow. Goot (1940) found support from his data for this type of inheritance. Schinckel (1951) investigating the genetic background for birthcoat differences in South Australian Merinos, found that coarse birthcoat grades were the result of a single dominant gene.

Dry (1955b, c) discussed the investigations and findings of himself and his co-workers on the N and nr genes. In N-types halo-hair abundance increased with N-dosage but could be varied according to modifiers which themselves might or might not be inherited multifactorially. Literature on the inheritance of later kemp hairiness was reviewed by Rae (1956).

However, selection against kempiness may cause changes in other attributes of the sheep. For instance, Roberts (1946) considered that hardiness in the Welsh Mountain breed was related to kempiness probably because kempiness is related to a thicker skin. No experimental evidence was produced to support this statement.

III MATERIALS AND METHODS

A. Experimental Design

Normally managed Cheviot ewes run at Tuapaka - a Manawatu hill country farm owned by Massey Agricultural College were used in this experiment. The 80 sheep in the experiment were randomly selected from a flock in which selection for or against kempiness had not been practised. The experimental animals comprised 20 sheep in each of the following four age groups:- two-year-olds; three-year-olds; four-year-olds and five-year-olds. As the experiment progressed, however, several sheep died and other sheep were not present at all sampling times. It was decided, therefore, for the purposes of statistical analysis to discard all discontinuous records. As 17 sheep was the smallest number in any group which had continuous records, several sheep in other age groups had to be discarded. This was done at random. Thus, data from a total of 68 sheep were used in this experiment.

B. Collection of Data

The sheep were sampled four times during 1958, viz. 5/3/58, 19/6/58, 9/10/58 and 20/11/58. These times corresponded with the farming operations of sorting ewes into mating groups; crutching; docking lambs and weaning lambs. It should be noted that the two-year-olds had previously been shorn on the 25/9/57 and the remaining age groups on the 18/11/57. Consequently more wool had grown on the two-tooths than on the remaining age groups by the first sampling time.

The sampling positions and their nomenclature are given in figure 2. The positions, A, B, C, D correspond to the body regions mid-back, mid-shoulder, mid-side and mid-thigh respectively. Of these, position A deserves some comment. It was a square of sides 9 cm and was subdivided into four approximately equal areas. These areas were ventral and anterior to area 1, position A (see fig. 2) which itself is located at the point of attachment of the last rib. The serial order in which the areas of position A were sampled was randomised between sheep to ensure that any bias due to differences between areas was removed.

Areas were not measured for positions B, C, D so that sampling of these regions merely consisted of removing a staple of wool from the appropriate body region.

The reasons for choosing position A for area measurements were that:

a. There was less chance of loss of kemps from contact with other objects.

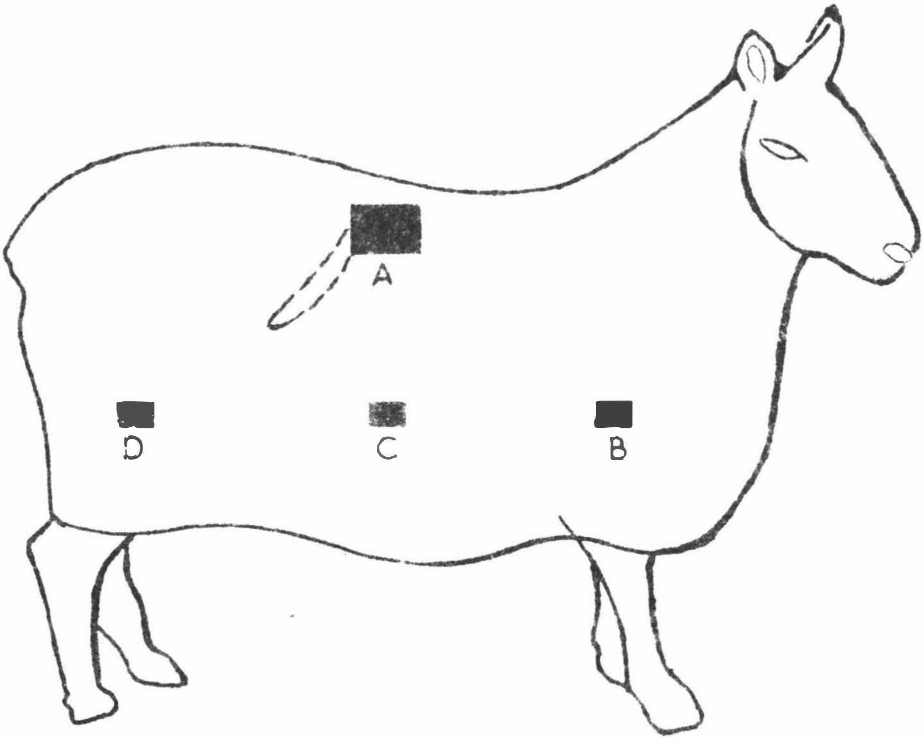
b. It has a definite location point.

c. It is easier to measure than most other regions.

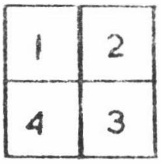
Four areas were sampled in preference to cutting the same area four times in order to avoid any effects that cutting might have on regrowth (as suggested by work by Rudall, 1935; Coop, 1953) and to reduce possible loss of shed kemps from the shorter wool. Nevertheless a recut of the previously sampled area was

Fig. 2

The positions sampled on the Cheviot ewes in this experiment.



Position A



The enumeration of the areas in position A made at sampling times I, II, III and IV for the five-year-olds, the three-year-olds and the four-year-olds respectively.

The sheep were sampled in the standing position, the samples being taken from the right side of the sheep. However, the three-year-old group had position A sampled on both sides at the sampling I.

Sampling was done by means of an Oster electric hair cutting machine having a comb about 4 cm. wide. This machine made it relatively easy to cut a rectangular area when sampling position A.

The four sides of the figure were measured with dividers and rule to the nearest millimeter. In order to assess the accuracy of measurement 9 sheep were caught again at the end of sampling I and the areas remeasured.

C. Treatment and Analysis of Samples

All samples were enclosed in fine nylon mesh bags and were scoured for ten minutes in a liquor consisting of:

15	gallons of water at 115°F
100 mls.	Teepol
3-5 g	Sodium Hydroxide

Agitation of the scouring liquor was ensured by a propeller revolving in the bottom of the scouring tank. The scouring process was completed by rinsing the samples in warm water. After drying, the samples were placed in a humidity room at 65 per cent relative humidity for at least one week before they were analysed.

The analysis of the sample involved weighing the whole sample directly after it was removed from the humidity room. Then .3 g, .5 g, .7 g, .9 g were weighed from the original sample according to whether the sample had been cut at sampling times I, II, III or IV respectively. Subsampling was necessary as it was impracticable in terms of time to analyse whole samples. By increasing the weight of subsample at each sampling time, an attempt was made to maintain the same proportion of fibres in the four grades of subsample weight relative to wool growth. It was not necessary to subsample the wool from the recut areas.

In order to test whether the size of subsample was sufficient to give a good estimate of the whole sample three .3 g subsamples were analysed from each sample from each position from 19 three-year-olds at sampling I. 10 sheep were selected at random from the same age group and three .5 g, .7 g, .9 g subsamples of position A were analysed for sampling times II, III and IV respectively. Time did not allow positions B, C and D to be treated similarly.

The sample was divided by eye into kemp and non-kemp fractions, the separation being done on a board covered with black velvet. A check was made to find whether any kemps had been overlooked in the non-kemp sample, by immersing the sample in benzol. The kemp fibres were then readily distinguishable. Both total and shed kemps (recognized by brush-ends) were counted for each sample and the total kemps in the sample were weighed. The time taken for such an analysis ranged between $\frac{1}{4}$ to $1\frac{1}{2}$ hours per sample.

As time became a limiting factor, it was found impracticable to analyse all samples from all positions. Thus, all samples from position A were analysed while samples from positions B, C and D were analysed from 10 two-year-old and five three-year-old ewes selected at random. The choice of age groups was limited to the groups which had the most practical significance particularly in regard to culling.

Suitable computations were then made to convert the number and weight of kemps per subsample into that estimated for the whole sample. The next step was to calculate data for the following measurements:

a. N/A or number of kemps per sq. cm.

b. W/A or weight of kemps per sq. cm.

c. $\frac{w}{W^1} \times 100$ or percentage weight

d. N^1/W^1 or number of kemps per g of wool.

where N = the total number of kemps (or shed number if specified) in a sample.

A = the area in position A from which the sample containing N was cut.

W = the weight of the total numbers of kemps in a sample.

W^1 = the weight of wool in a subsample.

w = the weight of kemps in a subsample.

N^1 = the number of kemps in a subsample.

The percentage medullation of the non-kemp fraction of all position A samples was estimated by the medullameter developed by

McMahon (1937) and redesigned in the light of Ross' (1950) work.

Routine metrology work on the flock from which the experimental animals were drawn, made available data on mean fibre diameter for position C at sampling IV for 10 two-year-olds and five three-year-olds.

IV RESULTS

A. Methods of Measurement

1. Selection of measures.

In this experiment comparison was made between four methods of measuring variations in the kemp population.

These methods of measurement were:

1. Number of kemps per unit area (square centimetres).
2. Weight of kemps per unit area (square centimetres).
3. Number of kemps per gramme of wool.
4. Percentage weight of kemps.

Observation of the data for the four measures showed that there was much variation between sheep and this was confirmed by drawing frequency distributions of all data for position A for each method of measurement (figure 3). The figure shows that the frequency distributions were all markedly skewed to the right indicating that a transformation was needed to correct the population to normality. As the transformation most likely to do this is a logarithmic one, all observations were converted to logarithms. The resulting frequency distributions are shown in figure 4.

These populations (figure 4) were tested for normality using the test given by Snedecor (1957, p.202). This test is based on skewness and kurtosis which are measured by the statistics g_1 and g_2 respectively. When both g_1 and g_2 are

Fig. 3

The frequency distributions of untransformed data from position A.

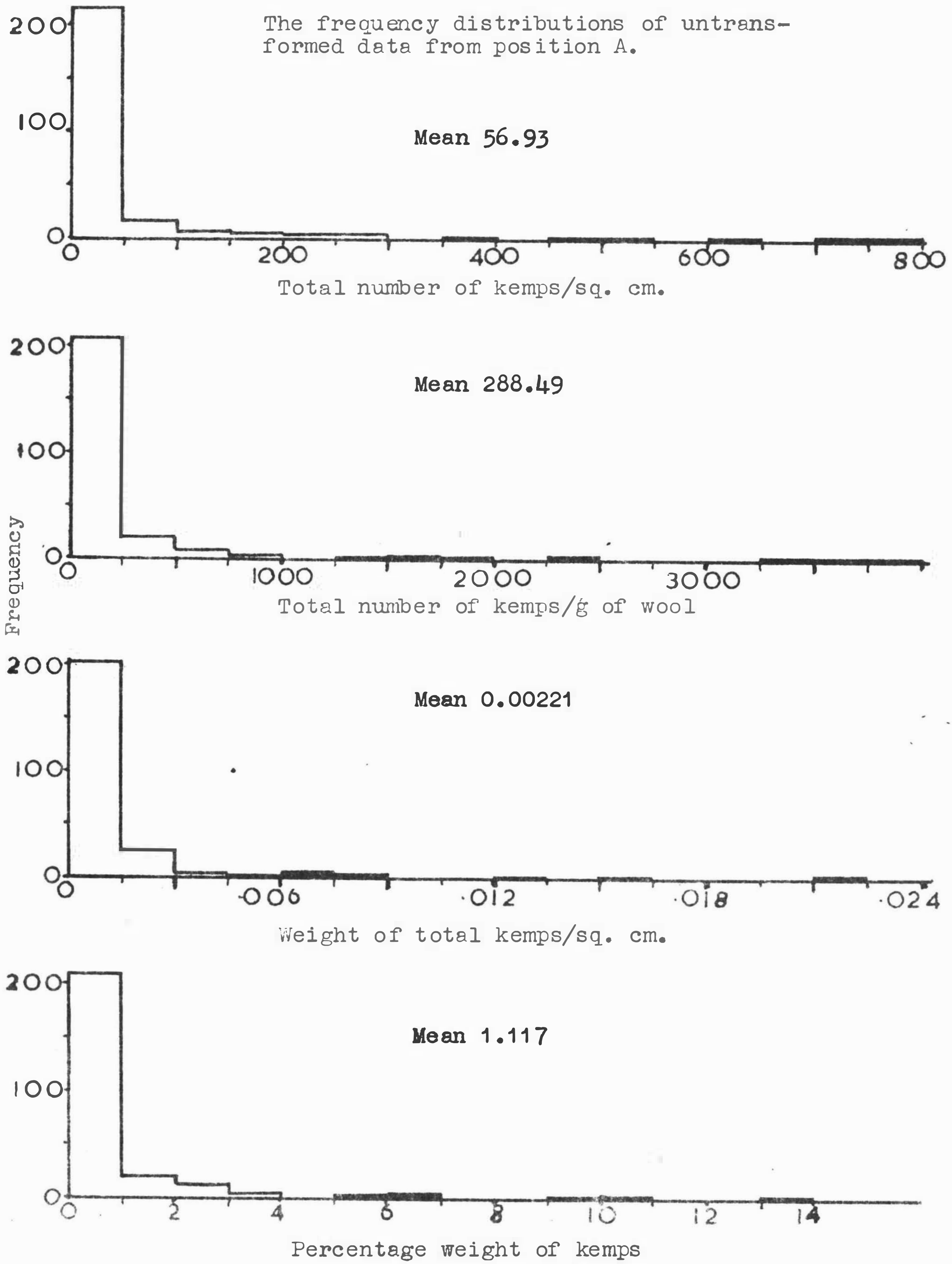
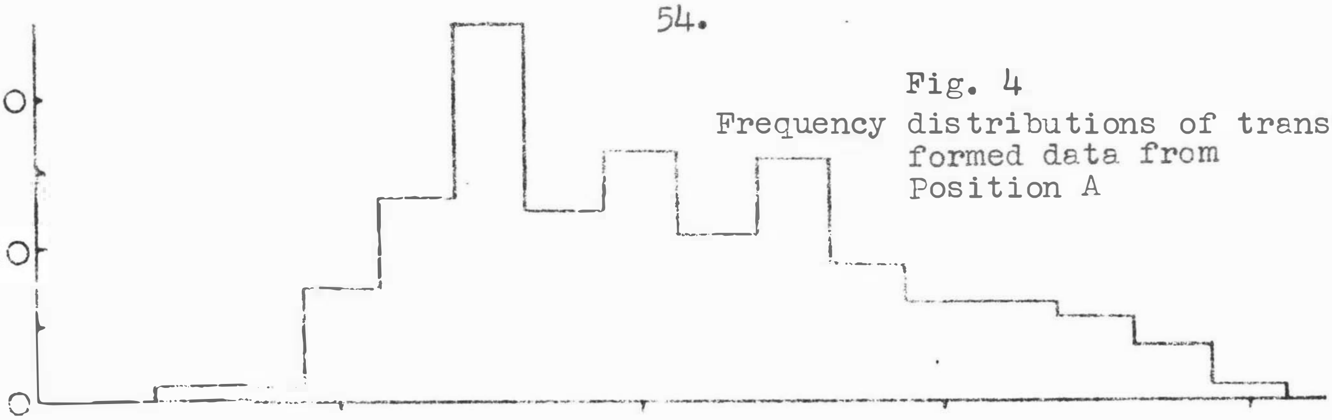
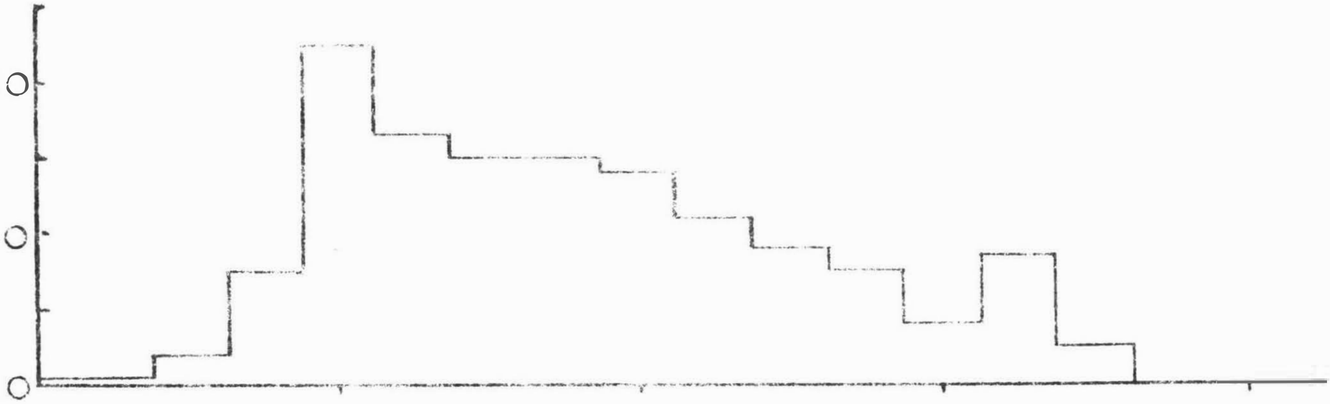


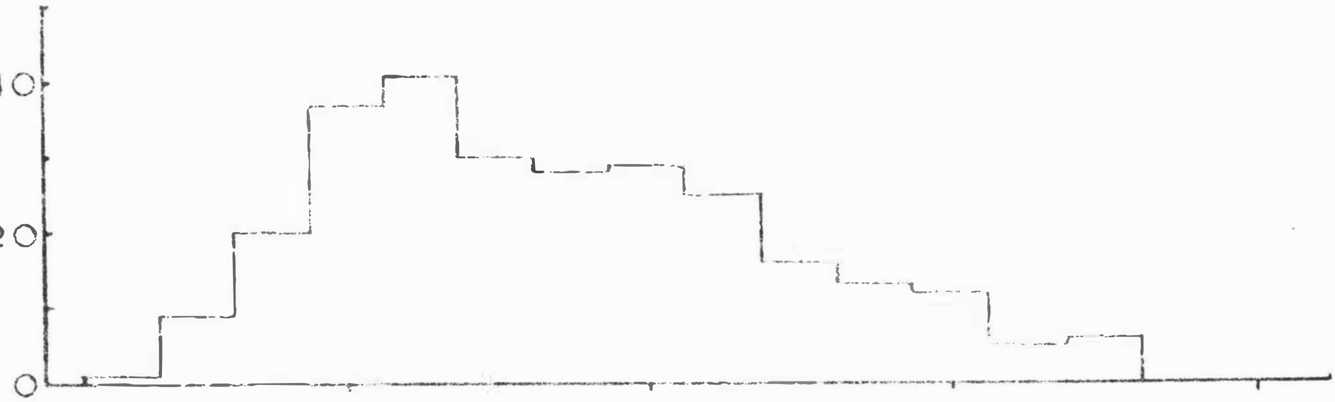
Fig. 4
Frequency distributions of transformed data from Position A



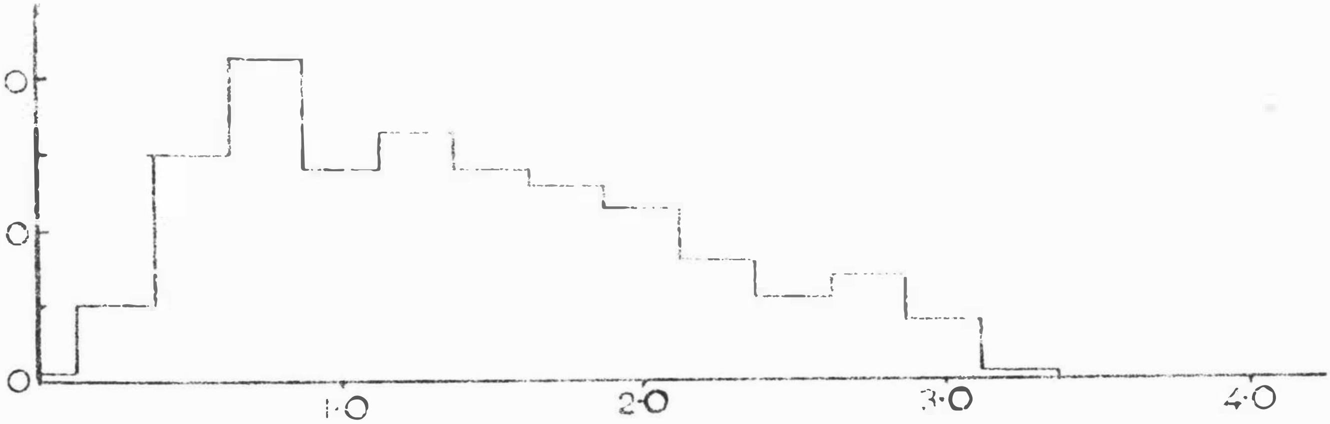
Log Total number of kemps/sq. cm.



Log Total number of kemps/g of wool



Log Weight of total kemps/sq. cm.



Log Percentage weight of kemps

TABLE 1

Normality test of logarithm transformed data.

			Standard deviation		t values	
Method of Measurement	g_1	g_2	g_1^2	g_2^2	g_1	g_2
Percentage weight of kemps	0.33	-2.36	0.148	0.294	2.23^{*}	-8.03^{**}
Number of kemps/g of wool	0.43	-0.65	0.148	0.294	2.91^{**}	-2.21^{*}
Number of kemps/unit area	0.47	-0.61	0.148	0.294	3.8^{**}	-2.08^{*}
Weight of kemps/unit area	0.49	-0.997	0.148	0.294	3.31^{**}	-3.39^{**}

* indicates t significant at 5% level

** indicates t significant at 1% level

zero, the population is deemed normal. Table 1 shows the values of g_1 and g_2, the standard deviations of g_1 and g_2 and the values of t for g_1 and g_2 with d.f ∞. The table indicates that the distributions of all methods of measurement of kempiness used in this investigation depart significantly from normality. In all cases g_1 is positive which indicates that the population has an excess of items smaller than the mean. This draws the peak of the frequency curve toward the left. The statistic g_2 is significantly different from zero at the 5% level for data involving numbers of kemps while data involving the use of weight of kemps are significant at the 1% level. Thus, data involving a measure of the number of kemps appear to show less kurtosis. The negative values of g_2 show that the distributions are plateau-like near the centre with an excess of moderate deviations.

The frequency distributions and the means of the non-transformed data in figure 3 suggest that the mean and the variance are correlated. This being the case, the requirements for tests of significance probably do not hold, i.e. the data are non-additive; there is heterogeneity of variance and the errors are probably not normally distributed. The most important of these requirements is homogeneity of variance. However, before a test for homogeneity of variance was applied, a tentative decision was made as to the best method of measurement of kempiness to use in this experiment.

The relationship between the various criteria was determined with regard to the total number of kemps per unit area.

TABLE 2

Correlation coefficients of total numbers of kemps per unit area with percentage weight, total numbers of kemps per g of wool and weight of kemps per unit area.

	Percentage weight of kemps	Kemps/g of wool	Weight of kemps/ unit area
Kemps/unit area	0.976**	0.978**	0.970**

** indicates p less than .01

d.f for all correlations 270

The correlation coefficients are presented in Table 2. Log transformed data for total numbers or weight of kemps in position A over all age groups and all sampling times were used in the calculations. All correlation coefficients were found to be significant at the 1% level.

In calculating a correlation coefficient and in testing its significance, it is assumed that the observations are drawn from a normally distributed population. As noted earlier, this requirement is not strictly met by the present data. However, skewness and kurtosis are unlikely to distort the results very much for Pearson is quoted by Kendall (1945) as stating that "the normal bivariate surface can be mutilated and distorted to a remarkable degree without affecting the frequency distribution of r." There is adequate justification, therefore, for accepting the results as representing reasonably accurately, the true relationship between the various measures.

As the relationship between the methods of measurement is high and the degree of association is similar for the measures, the selection of the most suitable measure can be based on practical and biological considerations. The methods of measurement of kempiness selected were:

a. The number of kemps per unit area (both total and shed numbers of kemps were used) for measuring changes in the kemp population in position A in all age groups.

b. The number of kemps per gramme of wool for measuring kemp population changes in positions A, B, C and D in 10 two-year-old and five three-year-old ewes.

TABLE 3

Bartletts test for homogeneity of variance of transformed data.

a. Total numbers of kemps per unit area.

Age	Position	χ^2	P	Significance
Two-year-olds	A	0.783	greater than .75	not significant
Three-year-olds	A	0.323	greater than .95	not significant
Four-year-olds	A	1.102	greater than .70	not significant
Five-year-olds	A	3.131	greater than .30	not significant

b. Total numbers of kemps per gramme of wool.

Age	Position	^{2}	P	Significance
Two-year-olds	A	0.370	greater than .9	not significant
	B	3.674	greater than .25	not significant
	C	0.654	greater than .75	not significant
	D	0.709	greater than .75	not significant
Three-year-olds	A	0.326	greater than .95	not significant
	B	0.343	greater than .95	not significant
	C	0.995	greater than .75	not significant
	D	0.269	greater than .95	not significant

The major reason for discarding measures involving weight is that it is easier to estimate the numbers of kemps visually than it is to estimate weight. This is important in appraising wool for culling or buying.

The biologist considers the follicle as the basic unit of the fleece and the fibre or kemp as the unit produced by the follicle. As the weight of kemps in a sample is dependent on the number of kemps rather than the number of kemps being dependent on the weight of kemps, the number of kemps is of more value to him as a measure of follicle activity.

Ryder's (1957) work suggested that shedding of non-kemp fibres can be extensive. This indicates that a change in percentage weight of kemps might result from a change in either kemp fibres or non-kemp fibres. Hence, to use this measure without any objective measure of changes in both kemp and non-kemp fibres may lead to substantial errors in the interpretation of the results.

By considering the above factors and the fact that area measurements were only taken for position A, the choice of the methods of measurement of kempiness becomes relatively simple.

Bartlett's test for homogeneity of variance (Scedecor 1957, p. 285) was applied to log transformed data for the two selected methods of measurement of kempiness. The chi-squared value, the probability and the significance of the test are presented in Table 3. In no case was there a significant departure from homogeneity of variance. Thus although the transformation does not correct the populations to normality, it brings about the most important requirement in tests of significance viz. homogeneity of variance.

The effect that skewness and kurtosis might have on the results has been discussed by Mather (1949). He pointed out that skewness and kurtosis are tested by the third and fourth moments respectively, whereas statistical analysis involves mainly the use of second moment statistics (variances). Thus, he states that "it is nearly always assumed that the data fall on a normal distribution and though the fact that skew curves are not too uncommon shows that this assumption is not generally justified, the errors introduced into second moment calculations by such departures from normality are small and may be neglected."

The evidence produced indicates that the departure from normality shown by log transformed data is unlikely to affect the results to any great extent. Hence, all calculations with the selected measures were carried out with log transformed data.

The selected methods of measurement of kempiness have been shown to fulfil best the requirements of the experiment. However, their limitations deserve some comment.

Ideally, the same number of follicles should be sampled in different regions of the sheep, between different sheep and at different sampling times. Thus a change in the value of the measure represents a change in the number of follicles producing kemps. In practice, however, a method of sampling has not been perfected which permits comparisons of the same number of follicles. Therefore, some estimate of the errors involved in collecting data for the experiment is necessary before changes in the values of the methods of measurement can be taken to represent actual changes in the kemp population.

2. Some errors involved in obtaining data for the number of kemps per unit area and their likely effect on the results.

a. The calculation of the areas in position A from which samples were cut.

Cockrem (1956) measured the diagonals of the sampled areas in order to calculate area. However, Cockrem (personal communication) found that there was little loss in accuracy by calculating area as for a rectangle after averaging the lengths of opposite sides. Any loss of accuracy was considered insignificant in comparison to errors caused by other variables.

As the latter method was used to calculate area in this experiment, an attempt was made to determine the bias resulting from non-rectangularity in 10 areas measured on sheep selected at random.

In the calculation of the area of a rectangle from measurements of the four sides, it was assumed that the angle formed by two sides was a right angle. This is a reasonable assumption in view of the fact that it was endeavoured, when sampling, to cut rectangular areas. Hence, large deviations from rectangularity are unlikely.

If this assumption is accepted, area can be calculated from the area of a rectangle plus a right angled triangle (see diagram).

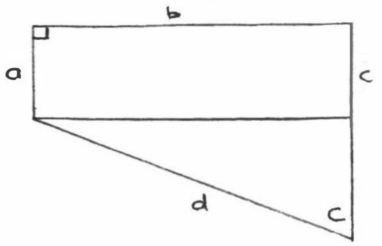
TABLE 4

The differences in sampled areas calculated as for a rectangle and a non-rectangular figure for 10 randomly selected Cheviot ewes.

	Sheep 1	2	3	4	5	6	7	8	9	10
A Area calculated as for a rectangle (sq. cm.)	19.11	18.83	16.80	19.14	16.40	16.19	22.71	10.73	7.55	13.11
B The difference between A and the area as calculated for a non-rectangular fig. (sq. cm.)	1.05	0.61	-1.26	1.54	0.40	-0.30	0.16	-0.32	0.59	1.36
C The difference expressed as a percentage of A	5.49	3.23	-7.50	8.04	2.43	-1.85	0.70	-2.98	7.81	10.3

Mean difference in area 0.47 sq. cm.

Mean difference as a percentage 2.60 per cent



The area of the triangle is derived from the formula:

$$\text{area} + \tfrac{1}{2}(c-a)\, d \sin C \quad \text{where } \sin C = \frac{b}{d}$$

The area of the rectangle is $a\,b$

Hence the calculated area of the figure is:

$$ab + \tfrac{1}{2}(c-a)\,b$$

The estimated area as calculated in the experiment is:

$$\frac{(a+c)\,(b+d)}{4}$$

Therefore the error of calculation is:

$$\frac{(a+c)\,(b+d)}{4} - ab - \tfrac{1}{2}(c-a)\,b$$

$$\text{or } \frac{ad - bc - ab + cd}{4}$$

Table 4 presents the sampled areas of 10 randomly selected ewes as calculated in the experiment, i.e. as for a rectangle and shows the difference in areas when the area is calculated as for a non-rectangular figure (see above). The results show that the method used to calculate sampled areas (as for a rectangle) in this experiment may result in errors of ± 10% of the "true" area. The mean difference between the areas calculated by both methods is low however. The effect of these errors in the computation of the number of kemps per unit area will be to obscure differences in kempiness between sheep unless such differences are large. As previous work on the distributions of the measures has indicated that differences in kempiness between sheep are large, this error may be neglected.

TABLE 5

Analysis of variance of areas calculated from two sets of measurements taken at different periods of time.

Source	s s	d.f	m.s.	F
Areas on different sheep	143.4	8	17.9	4.97*
Between repeat measurements of the same area	0.1	1	0.1	0.03 n.s.
Error	28.8	8	3.6	
Total	172.3	17		

* indicates F significant at 5% level

n.s. indicates F not significant at 5% level

Differences in kempiness between age groups of sheep and between sampling times are not likely to be affected as the means of the differences in areas show that the errors tend to cancel themselves out to negligible values.

b. Errors associated with the measurement of the sampled area.

Changes in body position, degree of "fill", breathing and stretching of the skin when measuring the sides of the sampled area in position A may result in large errors in the measurements obtained. Remeasurement of the sampled areas of nine ewes caught again (1 – 2 hours) after sampling enabled an analysis of variance to be carried out on areas calculated from these measurements. From the analysis it was hoped to determine whether the errors involved in the measurement of the sampled areas were large enough to mask differences in the size of areas cut on different sheep. The analysis of variance, presented in Table 5, shows that the differences in area between sheep are significant at the 5% level while differences in the areas calculated from the two sets of measurements are non-significant. Hence, the errors involved in measuring the sampled areas are insignificant in comparison to the differences in size of areas between sheep and can be neglected.

The correlation coefficient $r = 0.71$ was calculated to determine the relationship between the two areas and was significant at the 5% level (7 d.f). The errors due to calculation of area may have resulted in a poorer relationship being obtained than might have been the case if the repeatability of the measure-

TABLE 6

Area and density changes in recuts of previously sampled areas.

a = original area (sq. cm.) $\triangle$a = change in area (sq. cm.)
N = number of kemps in initial cut $\triangle$N = change in number of kemps.
$\triangle$P = change in density (number/sq. cm.)
C = number of kemps counted in recut sample
G_1 = number of kemps growing at initial sampling
G_2 = number of kemps growing in recut

Five-year-olds. Areas sampled at First Sampling;
Recut at Second Sampling. Position A

a	$\triangle$ a	N	$\triangle$ P	$\triangle$ N	C	G_1	G_2
20.40	-5.01	75	-2.06	-50.12	25	-	13
18.63	+3.96	75	-1.35	-14.82	61	7	26
14.97	+0.24	33	-1.29	-19.09	14	-	5
19.14	-4.15	519	-2.43	-148.96	376	230	332
17.00	+0.85	77	-2.18	-35.06	42	18	24
13.60	+0.14	50	-1.06	-14.05	36	7	7
17.75	-4.25	157	+3.30	+ 6.96	164	129	53
16.97	-2.35	15	-0.54	- 9.97	5	-	1
15.66	-4.26	2,955	-60.02	-1488.08	1467	1442	1392
14.97	-5.52	18	-0.88	-14.95	3	-	1
15.93	-0.72	1185	+75.81	+1099.51	2285	156	1560
17.36	-3.51	70	-3.38	-60.97	9	11	1
17.38	-4.59	657	-25.45	-499.02	158	244	111
19.76	-2.99	160	+4.12	+44.88	205	92	151
18.69	-5.98	364	-11.84	-266.95	97	144	76
16.58	+0.62	26	-0.87	-13.99	12	5	-
17.33	-0.73	9	+0.38	+ 5.93	15	-	6

Three-year-olds. Areas Sampled at Sampling 2: **Recut at Sampling 3**

a	$\triangle$ a	N	$\triangle$ P	$\triangle$ N	C	G_1	G_2
14.81	-	154	-9.93	-147.06	7	32	-
18.63	-6.12	35	-0.76	- 21.01	14	12	2
9.31	-1.37	27	-1.26	- 13.98	13	-	-
16.53	-0.15	62	-3.38	- 55.93	6	-	3
15.80	-8.0	1286	-64.21	-1151.97	134	542	66
11.46	-2.33	11	-0.52	- 6.98	4	-	1
11.16	-2.18	24	+0.64	-10.44	25	8	23
14.94	-2.89	26	-0.99	- 10.27	9	-	3
12.75	-5.49	357	-6.37	-199.97	157	104	133
13.28	-1.47	114	-3.92	- 58.91	55	49	39
12.16	-0.11	140	-7.69	- 93.93	46	51	3
12.66	+1.74	23	-0.42	- 2.89	20	-	16
14.60	-3.22	3983	-238.88	-3596.89	386	961	687
14.63	-2.97	66	-3.57	- 55.02	11	36	4
11.14	-5.38	396	-33.64	-385.01	11	169	6
15.23	-1.88	27	- 1.62	- 24.84	2	-	2
12.60	+0.63	72	-4.58	- 56.99	15	5	4

Four-year-olds. Areas Sampled at Sampling 3: **Recut at Sampling 4**

a	$\triangle$ a	N	$\triangle$ P	$\triangle$ N	C	G_1	G_2
12.78	+4.21	392	+2.36	169.23	561	11	553
14.43	+0.97	157	-8.79	-124.81	32	22	29
16.79	-9.99	528	-20.26	-442.98	85	37	84
15.97	+2.36	198	-11.13	-174.75	23	21	-
14.76	-0.51	25	-1.62	- 23.98	1	-	-
11.21	+1.02	2702	-166.29	-1787.87	914	25	872
15.75	-4.20	1154	-10.76	-432.01	722	109	702
14.81	+0.7	71	-2.08	- 28.9	42	5	11
14.44	+0.97	717	-16.03	-198.9	518	110	442
15.4	+2.45	634	-35.23	-527.99	106	-	45
13.37	+0.83	43	-1.74	- 22.03	21	66	21
5.89	+2.75	19	-3.10	- 17.91	1	-	1
11.01	+0.53	1485	-131.30	-1443.71	42	9	20
12.60	+1.27	551	- 35.08	-431.02	120	18	67
13.39	-0.97	5002	-302.69	-4121.76	881	-	480
11.59	+0.29	29	- 2.25	- 25.92	3	-	-
12.16	+3.25	45	- 3.01	- 36.36	10	-	1

ments had been studied. Nevertheless the relationship indicates that there is good repeatability of areas calculated from measurements of the same area taken a few hours apart.

3. The recut of previously sampled areas.

By recutting a previously sampled area, information can be gained on changes on body weight and kemp population at different sampling times. As areas were recut in different age groups at different sampling times, it is assumed that changes in the recut samples of the age group under consideration at any one sampling time are probably representative of the experimental flock as a whole.

Table 6 shows the values of the following measurements:

a = original area sampled (sq. cm.)

$\triangle a$ = change in the sampled area between sampling times.

N = the total number of kemps in the original sample.

$\triangle N$ = change in the total number of kemps between the original sampling and the recut.

$\triangle P$ = change in density (kemps/sq. cm.) between the original sampling and the recut.

C = the total number of kemps counted in the recut sample.

G_1 = the number of kemps growing at initial sampling.

G_2 = the number of kemps growing in the recut sample.

Between samplings I and II the negative values of $\triangle a$ for the five-year-olds indicate that there was a reduction of skin area probably resulting from a loss of body weight. This loss is probably real. Firstly, it has been shown that measurement errors are not likely to cause such large errors and secondly, it is unlikely that consistently small areas would be recut as care was taken to remove all short wool from the area. The ewes might also be expected to start losing some weight at this time of the year (late autumn) due to shortage of feed. Consideration must also be given to the possibility that the differences in area are due to the stretching of the skin when sampling and errors in calculation of area. The stretching of the skin when sampling cannot explain how areas increase over a period and is unlikely to cause such large errors. The errors of calculation of area are probably responsible for some part of the differences between areas but are not likely to cause such large and consistent differences (see Table 4).

If the indicated body loss is assumed real, then the recutting of the smaller areas with the fixed width of the hair clippers is likely to result in larger areas than the original one being cut. This may account for all or some of the positive changes in area. Under these conditions, density at sampling II could be expected to increase, provided that the kemp population remained the same over the period between sampling times. However, the decrease in density is consistent and indicates that shedding may have taken place. Shedding of such an extensive nature is doubtful in view of possible factors affecting the results.

The decrease in density may have been distorted by the retention of shed kemps in the longer wool at sampling I whereas between samplings I and II shed kemps may have been lost from the regrowing wool very easily because of the shorter wool.

To the wool biologist interested in the time that kemps grow into the fleece, a better indication of changes in kemp population can probably be acquired from the data on growing kemps. The values for G_1 and G_2 show that eleven out of the seventeen sheep are growing more kemps in the recut sample than in the original sample. This indicates that the decrease in density may be largely accounted for by the retention of shed kemps in the staple rather than a decrease in the number of follicles producing kemps. Thus, although the trend is not conclusive, there is some indication that a cycle of kemp growth has occurred or is occurring about the autumn period. As shed kemps were found in many samples, shedding is also taking place during the period between the two sampling times.

In the recut of areas sampled initially at sampling II, the results show that area, and hence body weight, is decreasing. The two positive values for a probably result from errors in cutting.

Shedding is again denoted by the negative values obtained for density. However, the figures for growing kemps indicate that ten sheep out of the seventeen are growing fewer kemps at sampling III than at sampling II. This may signify the conclusion or commencement of a wave of kemp growth. In view of the increase in growing kemps at sampling IV, the latter hypothesis is probably more valid. Unfortunately, the time period between samplings II and III is too long to determine whether there was a cessation of kemp growth during the winter or whether kemp growth was continuous throughout the winter. Presumably, this is a period when many sheep are shedding kemps while some sheep which have undergone a moult by sampling II are starting to grow kemps again by sampling III.

The age group which had their samples recut at sampling IV were the four-year-olds. The data for Δa showed that some sheep were showing increased skin areas probably as a result of body weight gain. This is to be expected in view of the decreased drain on the ewe's body reserves by the lamb at this time (late spring) and the better feed conditions.

The shedding indicated by the negative density values is probably due to retention of shed kemps as the figures for growing kemps indicate that the kemp population is increasing in all but four ewes.

From a practical viewpoint, the indicated changes in body weight will mean that different follicle populations will be sampled at each sampling time assuming that similar areas are cut at each sampling time. Thus, a loss in body weight will mean that more follicles will be sampled at later sampling periods than at the initial sampling. As the extra area will probably include more kemp fibres, the overall effect will be to reduce in magnitude a negative change in the kemp population or increase in size a positive change in the kemp population. Reverse changes in the manner in which the error will affect changes in the kemp population will occur if body weight increases. However, as it has been shown in a previous section (IV A 2 b) that significant differences occur between sheep in areas cut, similar differences are likely to occur on the same sheep at different sampling times. Hence, the errors due to sampling different follicle populations as a result of body weight changes are likely to be obscured by the sampling of different sized areas at each sampling time.

Other variables make the interpretation of the present results difficult. It has been pointed out that all sheep did not follow the same pattern. Also, it is not possible to trace the pattern in one sheep over the four sampling times as different age groups were used at different sampling times. Finally, the effect that age might have on these results is unknown.

However, in view of the large differences in kempiness between sheep, changes in body weight are not likely to be important in obscuring between sheep variability. It is more likely that the differences between sampling times will be affected. As a loss in body weight is indicated in most sheep over the winter, there will be a tendency for decreases in kempiness to be nullified and increases to have a higher than true value. This pattern will be reversed at sampling IV when body weight in most sheep is increasing although it is doubtful whether body weight increases sufficiently to allow direct comparisons of follicle populations cut at samplings I and IV.

Table 6 provides some information on the time of kemp growth in Cheviot ewes.

Although the sheep were sampled at intervals too far apart to allow any trustworthy conclusions to be drawn, certain

TABLE 7

Analysis of variance of data from position A
samples taken from both sides of the body of
17 three-year-old Cheviot ewes.

Method of measurement of kempiness: Total numbers of kemps per square centimetre

Source	ss	d.f	m.s.	F
Between sheep	9.670,860	16	0.604,429	8.1**
Between sides	.000,024	1	.000,024	.00003 n.s.
Error	1.195,181	16	.074,699	
Total	10.866,065	33		

** indicates F significant at 1% level.

n.s. indicates F non-significant at 5% level.

TABLE 8

Logarithm means of total numbers of kemps per
square centimetre of samples from position A
on both sides of body.

Means	1.580	1.578
Standard error	0.14	0.14
Antilog of means	3.80	3.78

Note: log 2.0 = antilog 10.0

tendencies can be noted.

A wave of kemp growth appeared to occur during the autumn. Shedding which was occurring to some extent in most samples apparently became quite extensive in most sheep by late autumn-early spring. However, by early spring there is some suggestion of another wave of kemp growth starting although many sheep are still shedding fibres which have probably grown in the autumn or have not started another cycle. This wave of kemp growth is common to all but four sheep examined, by late spring. It could not be determined whether there was a complete cessation of kemp growth over the winter or not. The results suggest that there is individual variation in the time of shedding.

Further evidence points to the fact that shed kemps may be retained in longer wool for some time. This makes the interpretation of changes in kemp population difficult.

4. The bilateral symmetry of kemp density in position A.

The sampling of position A on both sides of the body enabled information to be gained on the bilateral symmetry of kemp density.

The analysis of variance is presented in Table 7. The results show that the difference between sheep in the total kemps per sq. cm. is highly significant indicating that the between sides variation is insufficient to mask between sheep variation. The log means of the samples taken from both sides are presented in Table 8. As indicated by Table 7 there is no significant difference between sides in kemp density. The close association of kemp density on both sides of the body is further indicated by the highly significant correlation ($r = 0.78$ d.f 15) between the total kemps per sq. cm. of samples taken from position A on both sides of the body.

Thus, one may conclude that for the purposes of this experiment, information obtained from position A on one side of the body will be closely related to information obtained from position A on the other side of the body.

B. The Variation of Kempiness over the Body of the Cheviot Ewe.

1. The variation of kempiness within sampled areas.

By subsampling, one is assuming that there is no variation in the density of kemps over the sampled area. The test to show whether the size of the subsample is large enough to estimate the number of kemps in the whole sample may also give some information on kemp variability over small regions of the body.

It was assumed that the results from the 19 sheep included in the analysis at sampling I and the 10 sheep included in the analyses at samplings II, III and IV would give a good indication of the variability in kempiness over small regions of the body for the experimental flock. Similarly, as time did not allow analyses of samples for positions B, C and D over the last three sampling times, it was assumed that the same general pattern at sampling I would be followed at the three remaining samplings.

TABLE 9

Analyses of variance of numbers of kemps in repeat subsamples from three-year-old Cheviot ewes (position A)

Position A Sampling I 19 sheep

Source	s s	d.f.	m.s.	F
Between Sheep	22.5364	18	1.2520	90.7 **
Between subsamples	0.1260	2	0.0630	4.57 *
Error	0.4971	36	0.0138	
Total	23.1595	56		

Coefficient of variation 10.68%

** indicates p less than .01

* indicates p less than .05

Position A Sampling II 10 sheep

Source	s s	d.f.	m.s.	F
Between sheep	18.469	9	2.052	684 **
Between subsamples	0.001	2	0.0006	0.02 n.s.
Error	0.066	18	0.003	
Total	18.536	29		

Coefficient of variation 3.43%

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

Position A Sampling III 10 sheep

Source	s s	d.f.	m.s.	F
Between sheep	12.249	9	1.361	90.7 **
Between subsamples	0.081	2	0.041	2.73 n.s.
Error	0.261	18	0.015	
Total	12.591	29		

Coefficient of Variation 8.40%

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

Position A Sampling IV 10 sheep

Source	s s	d.f.	m.s.	F
Between sheep	11.208	9	1.245	88.9 **
Between subsamples	0.186	2	0.093	6.64 **
Error	0.244	18	0.014	
Total	11.638	29		

Coefficient of Variation 7.85%

** indicates F significant at 1% level

Table 9 presents the analyses of variance and the coefficients of variation of the data from position A for repeat subsamples. As the between sheep variation was significant at the 1% level, it may be concluded that the variation in kempiness in repeat subsamples is insufficient to mask differences in kempiness between sheep. The analyses also show that significant differences occurred between repeat subsamples at samplings I and IV. This implies that the size of the subsample was not large enough to give an accurate estimate of the number of kemps in the whole sample. However, in view of the highly significant differences between sheep, such errors can probably be neglected in comparisons of kempiness between sheep and between age groups although they may nullify or accentuate differences in kempiness between sampling times. Another point to consider is that these results may not be valid for the other age groups although it was assumed that the sheep in these analyses would be representative of the experimental flock. No endeavour was made to determine whether the differences between subsamples were due to shed or growing kemps.

These results may also be interpreted as indicating that differences in kemp density over small areas can be significant.

The coefficients of variation indicate that the variability between the subsamples of position A was much lower at sampling II than the other sampling times. This is probably accounted for by the size of subsample at sampling II being sufficiently large to considerably reduce the variation in kempiness between subsamples.

TABLE 10

Analyses of variance of numbers of kemps in repeat subsamples from three-year-old Cheviot ewes (positions A, B, C, D).

Position A	Sampling I		19 sheep	
Source	s s	d.f.	m.s.	F
Between Sheep	22.5364	18	1.2520	90.7 **
Between subsamples	0.1260	2	0.0630	4.57 *
Error	0.4971	36	0.0138	
Total	23.1595	56		

Coefficient of Variation 10.68%

** indicates p less than .01

* indicates p less than .05

Position B	Sampling I		19 sheep	
Source	s s	d.f.	m.s.	F
Between sheep	3.341	18	0.186	11.14 **
Between subsamples	0.001	1	0.001	0.06 n.s.
Error	0.301	18	0.0167	
Total	3.643	37		

Coefficient of variation 20.46%

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level.

Position C	Sampling I		19 sheep	
Source	s s	d.f.	m.s.	F
Between sheep	12.603	18	0.700	35.0 **
Between subsamples	0.007	1	0.007	0.3 n.s.
Error	0.358	18	0.020	
Total	12.968	37		

Coefficient of variation 15.78%

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

Position D	Sampling I		19 sheep	
Source	s s	d.f.	m.s.	F
Between sheep	17.158	18	0.935	133.57 **
Between subsamples	0.001	1	0.001	0.14 n.s.
Error	0.134	18	0.007	
Total	17.293	37		

Coefficient of variation 5.4%

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

TABLE 11

Analysis of variance testing in 12 sheep of each age group the variation in total kemps per square centimetre in the four areas of position A.

Source	s s	d.f.	m.s.	F
Between ages	9.707,900	3	3.235,967	8.47 **
Between areas within ages	11.843,000	12	0.986,917	2.58 **
Between treatments	20.149,870	12	1.679,156	4.39 **
Between sampling times	1.291,030	12	0.107,586	0.28 n.s.
Error	58.089,640	152	0.382,169	
Total	101.081,440	191		

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

The analyses of variance for positions B, C and D (Table 10) show that in all positions there are no significant differences between repeat subsamples. On face value, these results signify that, at sampling I, position A shows greater variability over small regions than the other positions. However, as only two subsamples were taken from each sample from positions B, C and D, the results may not give a very accurate picture of the variability in the number of kemps in these samples. Another factor which could affect the results is the larger area cut in position A samples. The greater the area sampled the more likely are significant differences to occur. This may partly or wholly account for the significant differences between the subsamples of position A and not the other positions.

The coefficients of variation for positions B, C, A and D show a reduction in magnitude in that order. This possibly results from a gradient in kempiness. With decreasing kempiness, there is probably greater variability in kempiness between subsamples.

2. The variation in kempiness in the areas comprising position A.

Because the sampling sequences within the four areas of position A were chosen at random, it is possible to analyse the data for differences in kemp density between the areas.

Table 11 presents the analyses of variance of data from areas in position A from 12 sheep in each age group. The method of measurement of kempiness used was total kemps per sq. cm.

TABLE 12

The log means and standard errors of total kemps per square centimetre for each area in position A over all sampling times and for each age group.

Log means

Age Area	1	s.e.	2	s.e.	3	s.e.	4	s.e.
Two-year-olds	1.928	0.52	2.663	0.72	2.673	0.70	2.059	0.64
Three-year-olds	1.721	0.61	1.961	0.63	2.008	0.70	1.635	0.45
Four-year-olds	2.216	0.53	2.684	0.60	2.502	0.64	2.003	0.35
Five-year-olds	1.749	0.62	2.204	0.68	2.126	0.71	1.819	0.59
All age groups	1.904	0.29	2.378	0.35	2.327	0.36	1.879	0.26

Note: log 2.00 = antilog 10.0

Antilog of means

Age Area	1	2	3	4
Two-year-olds	8.49	46.03	47.10	11.46
Three-year-olds	5.26	9.14	10.19	4.32
Four-year-olds	16.44	48.31	31.77	10.07
Five-year-olds	5.61	16.00	13.37	6.59
All age groups	8.02	23.88	21.23	7.57

TABLE 13

Multiple range test for differences in areas in position A.

a. All ages

Area	4	1	2	3

log mean $\underline{1.879 \quad 1.904}$ $\underline{2.327 \quad 2.378}$

Note: log 2.00 = antilog 10.0

Results: Any two means not underscored by the same line are significantly different at the 5% level.

Any two means underscored by the same line are not significantly different.

TABLE 14

Analysis of variance of data from positions A, B, C and D sampled in 10 two-year-old and 5 three-year-old Cheviot ewes.

Method of measurement of kempiness: Total number of kemps per gramme of wool.

Source	s s	d.f.	m.s.	F
Between ages	1.070,591	1	1.070,591	2.09 n.s.
Between sampling times	2.740,409	3	0.913,469	1.79 n.s.
Between positions	53.650,658	3	17.883,553	34.90 **
Age x sampling times	0.246,002	3	0.082,001	0.16 n.s.
Age x positions	3.533,006	3	1.177,669	2.30 n.s. ($F_{5\%}$ 2.65)
Positions x sampling times	1.269,701	9	0.141,078	0.28 n.s.
Error	111.204,210	217	0.512,462	
Total	168.665,868	239		

** indicates F significant at 1% level

n.s. indicates F not significant at 5% level

TABLE 15

Log means and standard errors of positions A, B, C and D over all age groups and all sampling times.

Position	A	B	C	D
Log mean	1.912	1.018	1.457	2.274
s.e.	0.34	0.22	0.28	0.29
Antilog of means	8.17	1.04	2.86	18.79

The log means and standard errors of each area in position A for each age group and over all age groups are presented in Table 12.

The significant difference between areas shown by the analysis of variance in Table 11 indicates that kemp density varies considerably between adjacent areas in position A.

Duncan's (1955) multiple range test (Table 13) shows that over all age groups areas two and three (see figure 2) are significantly different from areas one and four. The anterior areas of position A are, therefore, more kempy than the posterior regions.

3. The variation in kempiness between positions A, B, C and D.

The variation of kempiness between positions was determined for 10 two-year-old and five three-year-old. In these calculations data for total kemps per g of wool was used. The positions were also tested for gradients.

The analysis of variance is presented in Table 14. The major point of interest is the significant difference in kempiness between positions. The means in Table 15 and the graph presented in figure 5 demonstrate that the order of kempiness of the positions is $D > A > C > B$ ($>$ signifies greater than). By applying Duncan's (1955) multiple range test, it was found that the means were significantly different from each other.

It should be pointed out here that the absolute values of the means are likely to be reduced. The reason for this

Fig. 5

The log means of kempiness in positions A, B, C and D with time for two and three-year-old ewes.

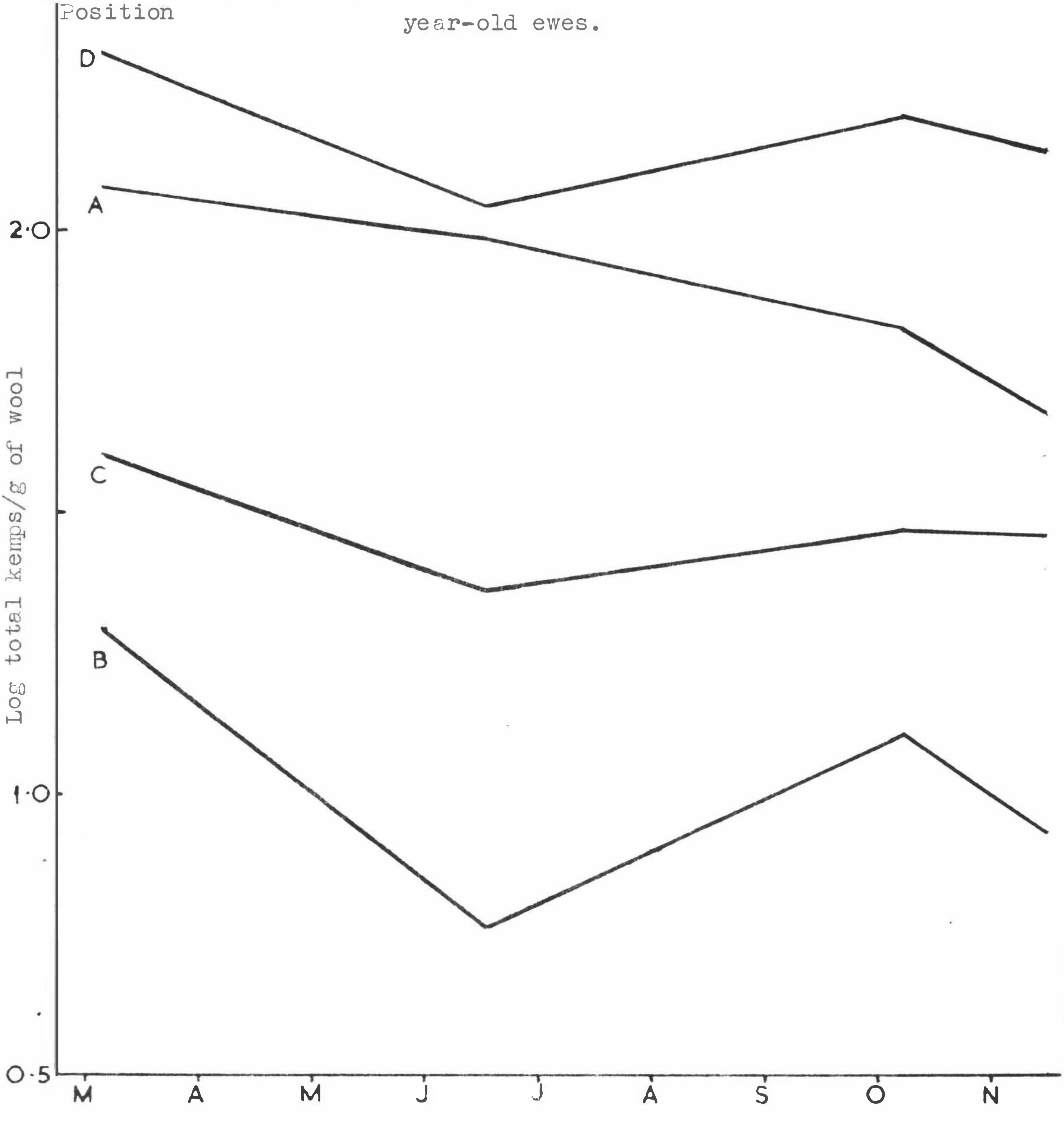


TABLE 16

Orthogonal comparisons of between positions variation (Table 15).

Source	s s	d.f.	m.s.	F
Between positions	53.650,658	3	17.883,553	34.90 **
Antero-posterior gradient	47.329,848	1	47.329,848	92,36 **
Dorso-ventral gradient	6.228,963	1	6.228,963	12.16 **

** indicates F significant at 1% level

is that as the number of kemps in a sample are related to one weight of wool (1 g) over all sampling times, the number of fibres at each sampling time becomes less as the wool grows longer. Hence, a smaller follicle population (and consequently fewer follicles producing kemps) is being sampled at each sampling time. While this does not affect differences between sheep or positions, it will affect differences occurring at different sampling times and reduce the absolute value of the means.

A test for gradients was made using orthogonal comparisons (Table 16). The following comparisons were made.

$$\begin{tikzcd}
 & a \arrow[d] & \\
d & c \arrow[l] & b \arrow[l]
\end{tikzcd}$$

Antero-posterior gradient - d + b

Dorso-ventral gradient - a + c

where a = the sum of all data from the selected sheep for position A

b = " " " " " " " " " " B

c = " " " " " " " " " " C

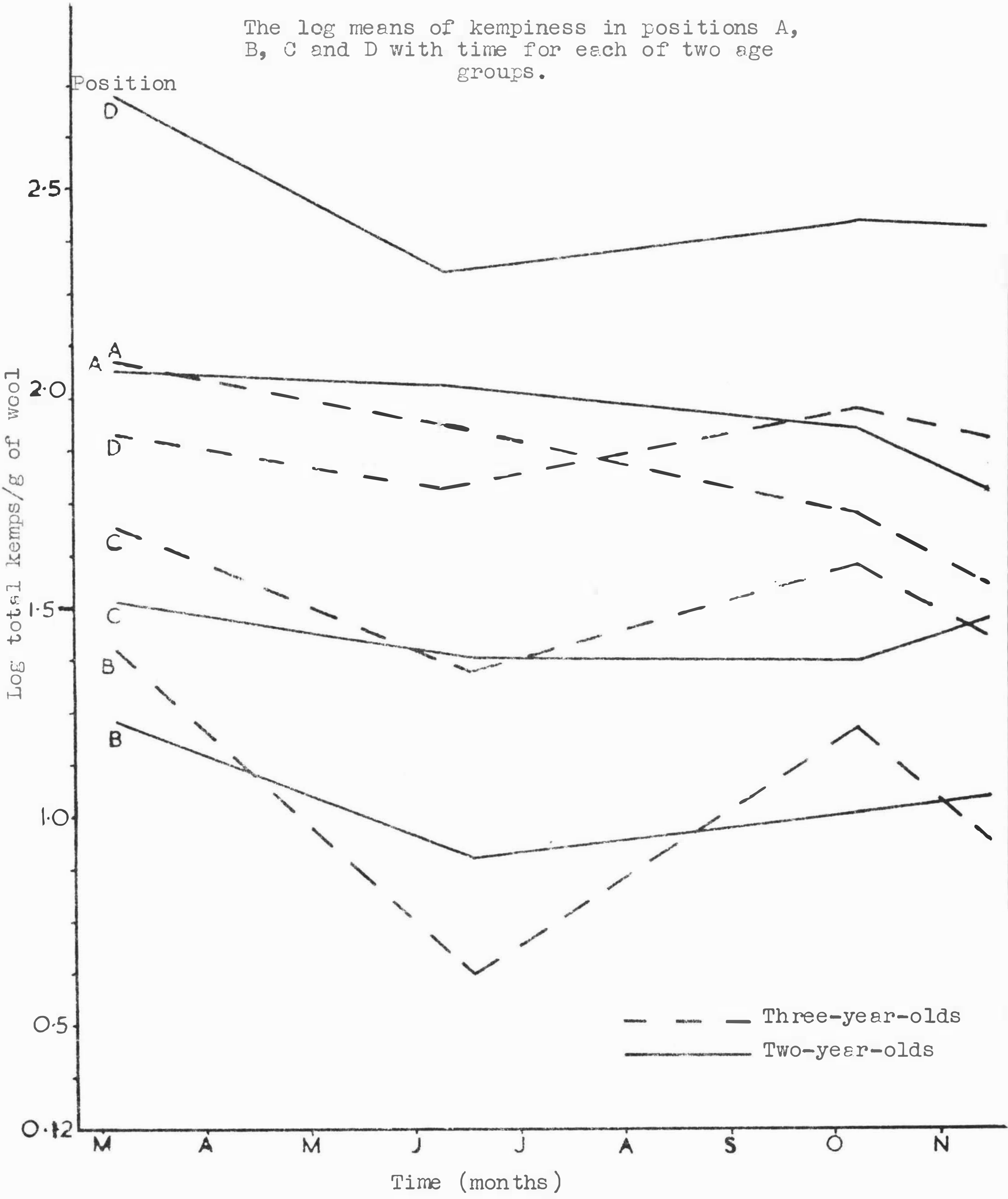
d = " " " " " " " " " " D

The results from Table 16 indicate that there is a highly significant antero-posterior gradient. The means (Table 15) show that the order of kempiness is D > C > B. The dorso-ventral gradient is also highly significant and the order of kempiness is A > C.

The age x position interaction approaches significance at the 5% level although it does not reach it. The results may

Fig. 6

The log means of kempiness in positions A, B, C and D with time for each of two age groups.



be interpreted as meaning that the positions rank the same in each age group, i.e. the gradients are the same in both age groups. However, the fact that the interaction approaches significance might indicate that some positions are tending to rank differently for different age groups. Figure 6 shows that this tendency is not very marked.

The positions x sampling times interaction is also non-significant. Thus, each position ranks the same at each sampling time. Figures 5 and 6 demonstrate this point. It may be concluded that, for the period studied, no waves of kemp population change are passing down the body.

The results presented in this section demonstrate that there are marked gradients in kempiness over the body in the two age groups studied. The occurrence of waves of kemp population change was not apparent in the period studied.

C. The Relationship between Positions A, B, C and D.

One important aspect in selection is the estimation of the degree of kempiness in the fleece. To save the time consuming practice of examining the whole fleece to estimate kempiness, an attempt was made to determine the relationships between the positions in an effort to indicate the degree of predictability of kempiness in the various positions and the whole fleece.

1. The relationship between total kempiness in the fleece and kempiness in positions A and D.

Positions A and D were selected as being the most suitable

TABLE 17

The correlation and regression coefficients of total kempiness on kempiness in positions A and D at each sampling time for 10 two-year-old and 5 three-year-old Cheviot ewes.

Method of measurement of kempiness: Total kemps per g of wool

Correlations and regressions of total kempiness on kempiness in position A for

a. Two-year-olds	r	b	$\bar{y} - b\bar{x}$	Standard error (s.e.) of estimate
Sampling 1	0.88^{**}	2.17^{**}	+3.017	0.42
2	0.88^{**}	2.75^{**}	+1.030	0.45
3	0.93^{**}	2.48^{**}	+1.937	0.29
4	0.98^{**}	2.06^{**}	+3.718	0.46

b. Three-year-olds	r	b	$\bar{y} - b\bar{x}$	Standard error (s.e.) of estimate
Sampling 1	0.88^{*}	2.78^{*}	+1.308	0.72
2	0.96^{**}	2.72^{**}	+0.306	0.58
3	0.97^{**}	3.22^{**}	+0.626	0.48
4	0.90^{*}	2.73^{*}	+1.255	0.56

* p less than .05
** p less than .01

Correlations and regressions of total kempiness on kempiness in position D for

a. Two-year-olds	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.90^{*}	3.18^{**}	−1.146	0.41
2	0.96^{**}	3.44^{**}	−1.327	0.55
3	0.97^{**}	3.28^{**}	−1.241	0.45
4	0.96^{**}	3.65^{**}	−2.172	0.33

b. Three-year-olds	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.98^{**}	2.90^{**}	+0.357	0.36
2	0.90^{*}	3.52^{*}	−1.493	0.88
3	0.97^{**}	2.91^{**}	+0.10	0.45
4	0.94^{*}	3.17^{*}	−0.968	0.64

* p less than .05
** p less than .01

positions to use in determining the degree of kempiness in the whole fleece. The selection was based mainly on the view that, as these are the most kempy positions sampled in this experiment, kempiness in the whole fleece is likely to be a minimum when kempiness is at a minimum in these positions.

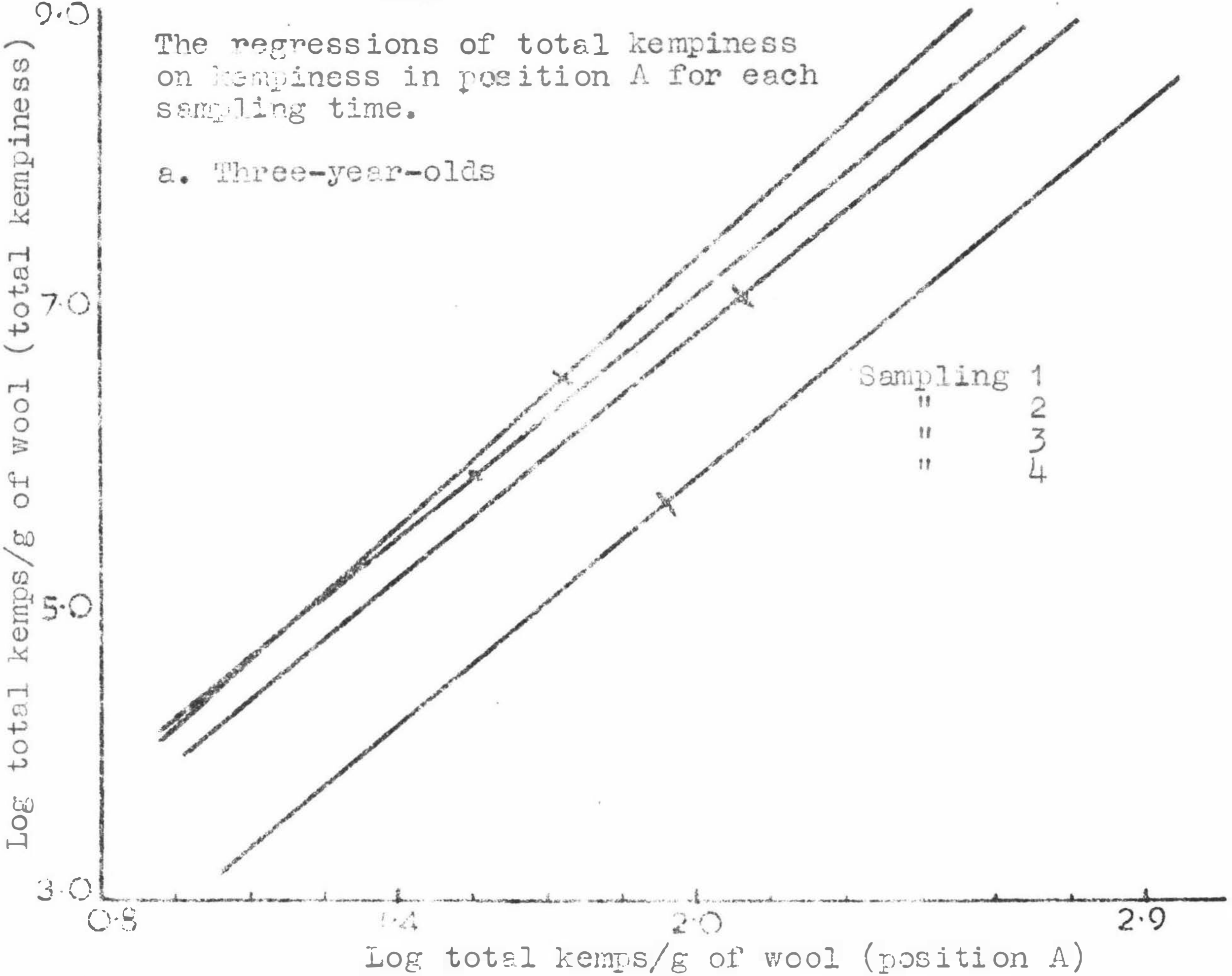
As total kempiness was composed of the total of all positions, a relationship between total kempiness and any other position is likely on that count alone.

The correlations and regressions and the standard errors of estimate of the regressions of total kempiness on kempiness in positions A and D are presented in Table 17 and the regression lines are graphically represented in figures 7 and 8. Inspection of the table demonstrates that there are no cases of non-significance in the correlation coefficients of total kempiness with position A. On the whole, it appears as if there is a better relationship between total kempiness and position D than there is between total kempiness and position A. This may be largely due to the fact that position D, being the most kempy position, comprises a larger part of total kempiness and may be expected to show a better relationship. There appears to be no regular pattern to changes in the magnitude of the correlation coefficient so that they are probably due to random variations in kempiness and errors involved in obtaining the data.

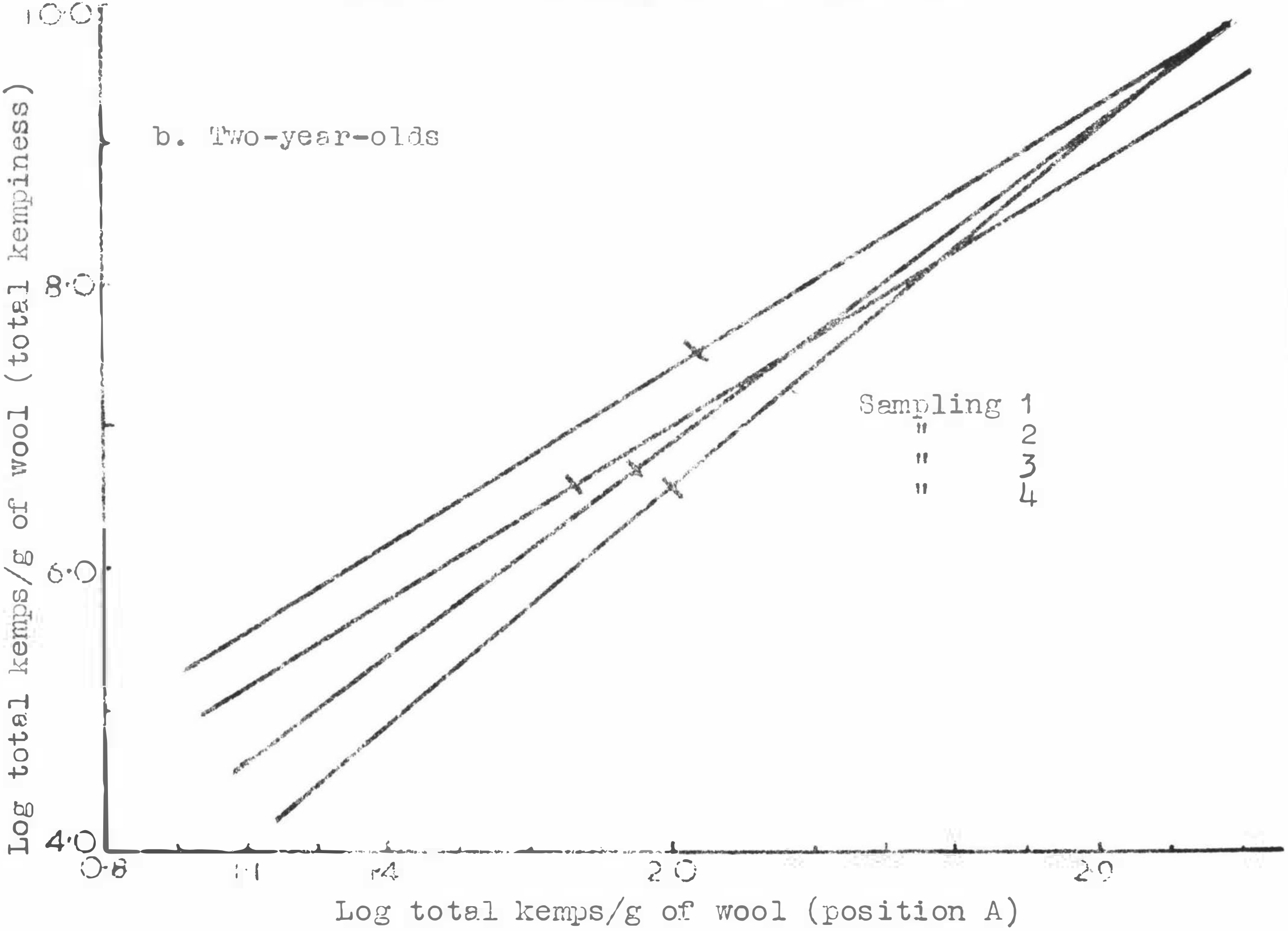
The regression coefficients presented in Table 17 show that a given change in position D results in a greater change in total kempiness than a given change in position A with one exception, viz. sampling III in the three-year-olds. However, a greater

Fig. 7

The regressions of total kempiness on kempiness in position A for each sampling time.



a. Three-year-olds

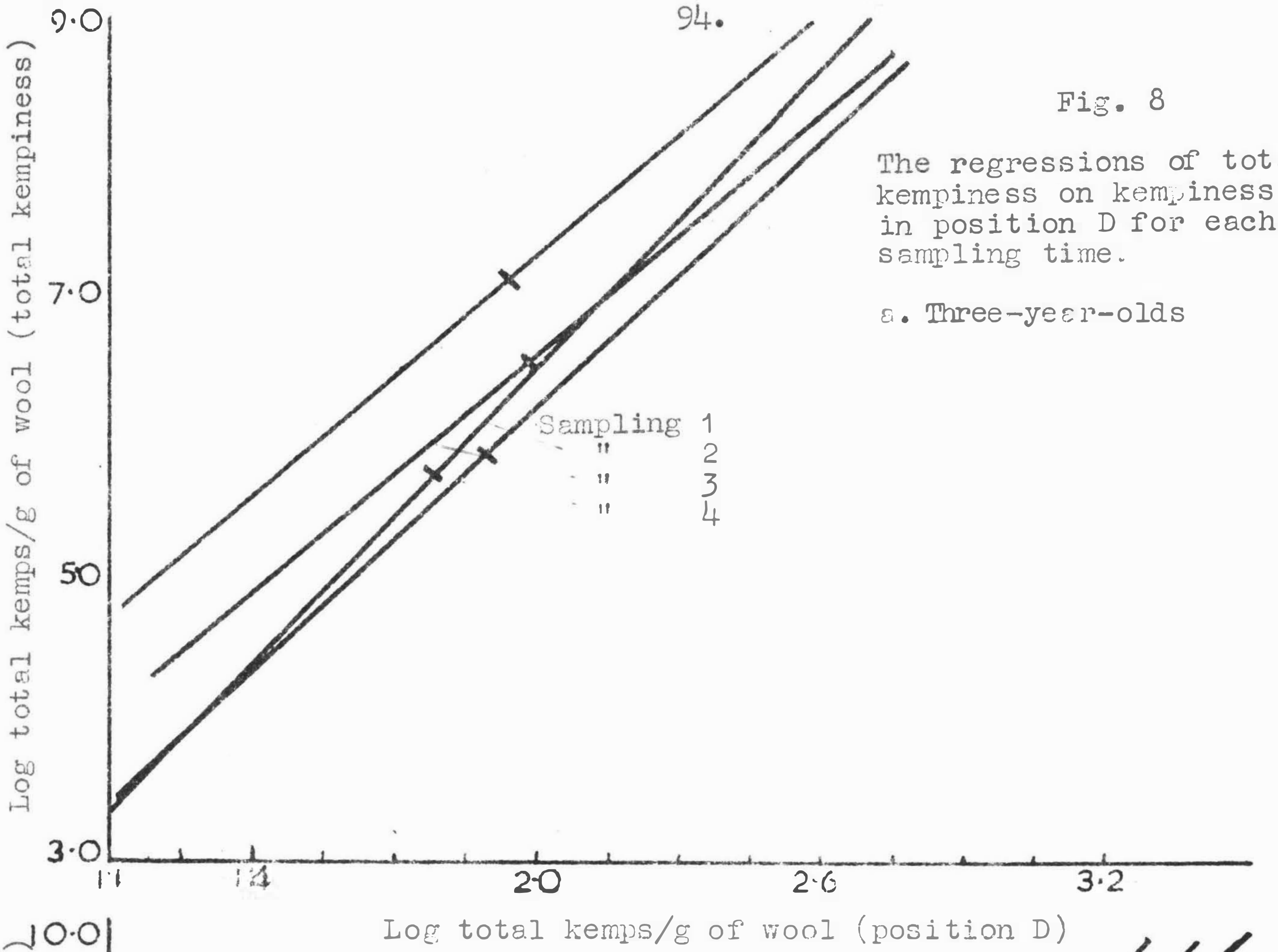


b. Two-year-olds

Fig. 8

The regressions of total kempiness on kempiness in position D for each sampling time.

a. Three-year-olds



b. Two-year-olds

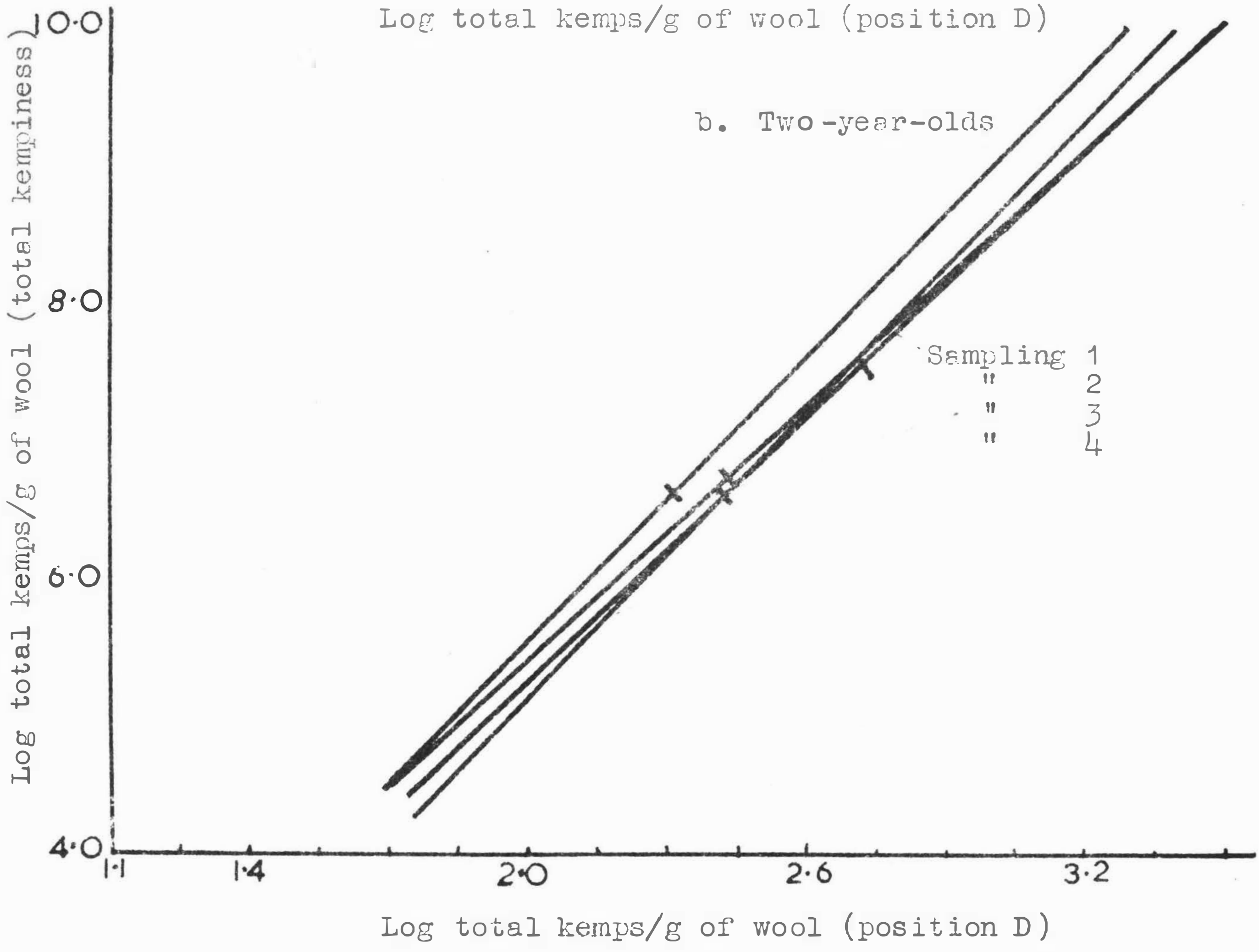


TABLE 18

The test for differences between sampling times in the regression coefficients of total kempiness on kempiness in positions A or D at different sampling times for different age groups.

Three-year-old ewes — Regression of Total Kempiness on A

Source	dyx^2	d.f.	m.s.	F
Within Samples	12.153	12	1.013	F_1=0.21 n.s.
Difference Between Regression Coefficients	0.624	3	0.208	
Common Regression	12.777	15	0.852	F_2=2.32 n.s.
Adjusted Means	5.919	3	1.973	
Total	18.696	18		

Two-year-old Ewes — Regression of Total Kempiness on A

Source	dyx^2	d.f.	m.s.	F
Within Samples	42.472	32	1.327	F_1=0.43 n.s.
Between Regression Coefficients	1.704	3	0.568	
Common Regression	44.176	35	1.262	F_2=0.89 n.s.
Adjusted Means	3.370	3	1.123	
Total	47.546	38		

Three-year-old Ewes — Regression of Total Kempiness on D

Source	dyx^2	d.f.	m. s.	F
Within Samples	13.709	12	1.142	F_1=0.21 n.s.
Between Regression Coefficients	0.707	3	0.236	
Common Regression	14.416	15	0.961	F_2=1.33 n.s.
Adjusted Means	3.851	3	1.284	
Total	18.267	18		

Two-year-old Ewes — Regression of Total Kempiness on D

Source	dyx^2	d.f.	m.s.	F
Within Samples	49.936	32	1.561	F_1=0.69 n.s.
Between Regression Coefficients	0.324	3	0.108	
Common Regression	50.26	35	1.436	F_2=0.28 n.s.
Adjusted Means	1.195	3	0.398	
Total	51.455	38		

n.s. indicates p greater than .05

change in total kempiness for a given change in position D is expected as kempiness in position D makes up a larger part of total kempiness than kempiness in position A. The standard errors of estimate of the regression coefficients are, in general, of similar magnitude regardless of whether total kempiness is related to kempiness in position A or position D. The conclusion which the results indicate is that more accurate prediction of total kempiness can be obtained from kempiness in position D than from kempiness in position A. However, if the other factors are taken into account, there is probably not much difference in accuracy if either position is used. Moreover, the relatively high standard errors of estimate indicate that the accuracy of prediction of kempiness in the fleece at any one sampling time will not be very good anyway. In this regard, prediction of total kempiness in the three-year-olds from either position at any one sampling time will be less accurate than that in the two-year-olds as the three-year-olds have higher standard errors of estimate of the regression coefficients. This is probably the result of too few sheep being included in the analysis.

The regression lines of both total kempiness on kempiness in position A and total kempiness on kempiness in position D were tested to determine whether in each age group, the regression lines differed significantly between sampling times. The test used is given in Snedecor (1957 p.400). The results of the test are presented in Table 18.

The F_1 value indicates whether the regression lines differ significantly in slope. If the mean square for the regression coefficients is smaller than the mean square of the within samples variation, the lines can be assumed to be parallel. Significance of this value indicates a significant difference in slope. The F_2 value determines whether the means of the regression lines differ significantly from each other.

The information in Table 18 and figures 7 and 8 shows that there is no significant departure in slope or means of the regression lines between sampling times for each age group.

Theoretically, the four regression lines for the same variables in any one age group could be replaced by one regression line representing the whole experimental period. However, in view of the time elapsing between sampling times, such a line might not be truly representative of the whole period as changes in the kemp population might have occurred undetected.

The main point arising from these results is that the accuracy of prediction of kempiness in the four positions (total kempiness) is probably very similar whether the prediction is made from kempiness in position A or position D. There are no significant differences in predictability of the same variables at different sampling times for the same age group. However, the accuracy of prediction of total kempiness at any one sampling time is not very good. In this regard, the three-year-olds show poorer accuracy than the two-year-olds. As these results are based on only a few sheep they need to be confirmed.

TABLE 19

The correlation and regression coefficients of kempiness in positions B, C and D on kempiness in position A at each sampling time for 10 two-year-old Cheviot ewes.

Method of measurement of kempiness: Total kemps per g of wool

a. The correlations and regressions of position B kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.25 n.s.	0.10 n.s.	+0.999	0.21
2	0.67 *	0.57 *	+0.259	0.19
3	0.58 n.s.	0.36 n.s.	+0.319	0.15
4	0.25 n.s.	0.18 n.s.	+0.594	0.20

d.f. 8

b. The correlations and regressions of position C kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.75 *	0.64 *	+0.019	0.20
2	0.76 *	0.71 *	−0.062	0.18
3	0.68 *	0.61 *	+0.175	0.19
4	0.51 n.s.	0.40 n.s.	+0.746	0.20

d.f. 8

c. The correlations and regressions of position D kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.64 *	0.43 *	+1.831	0.18
2	0.64 *	0.47 *	+1.352	0.18
3	0.77 **	0.51 **	+1.442	0.12
4	0.75 *	0.49 *	+1.516	0.12

d.f. 8

n.s. indicates p greater than .05

* indicates p less than .05

** indicates p less than .01

TABLE 20

The test for differences between sampling times in the regression coefficients of kempiness in positions B, C and D on kempiness in position A for 10 two-year-old Cheviot ewes.

Two-year-olds

a. B on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	32	5.197	0.162	$F_1 = 6.6^{**}$
Between Regression Coefficients	3	3.209	1.069	
Common Regression	35	8.406	0.240	$F_2 = 0.65$ n.s.
Adjusted Means	3	0.463	0.154	
Total	38	8.869		

b. C on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	32	9.346	0.292	$F_1 = 0.35$ n.s.
Regression Coefficient	3	0.304	0.101	
Common Regression	35	9.650	0.276	$F_2 = 0.36$ n.s.
Adjusted Means	3	0.297	0.099	
Total	38	9.947		

c. D on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	32	5.937	0.186	$F_1 = 0.032$ n.s.
Regression Coefficient	3	0.019	0.006	
Common Regression	35	5.956	0.170	$F_2 = 1.55$ n.s.
Adjusted Means	3	0.790	0.263	
Total	38	6.746		

n.s. indicates p greater than .05

** indicates p less than .01

2. The relationship between kempiness in position A and positions B, C and D.

Table 19 presents the correlation coefficients and regression coefficients and their standard errors of estimate of kempiness in positions B, C and D on kempiness in position A for 10 two-year-olds.

In this age group, the poorest relationship exists between positions A and B and the correlation coefficient reaches significance at sampling II only. There does not appear to be much difference in the relationship between positions A and C and positions A and D and all correlations are significant.

Kempiness in position C can be predicted from kempiness in position A best although the regression coefficient is non-significant at sampling IV. In view of the higher standard errors associated with the regression of position C on position A, there is probably not much difference in the accuracy of predicting kempiness in positions C and D from kempiness in position A. There is very poor prediction of kempiness in position B from kempiness in position A and significance is reached at sampling II only. Table 20 shows that the regression lines differ significantly in slope from each other whereas the regression lines of position C on position A and position D on position A were not found to differ significantly in slope or in means.

The magnitude of the standard errors of estimate for the regressions of positions B, C and D on position A indicates

TABLE 21

The correlation and regression coefficients of kempiness in positions B, C and D on kempiness in position A at each sampling time for five three-year-old Cheviot ewes.

Method of measurement of kempiness. Total kemps per g of wool.

a. The correlations and regressions of position B kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.19 n.s.	0.01 n.s.	+1.368	0.18
2	0.35 n.s.	0.20 n.s.	+0.241	0.38
3	0.91 *	0.52 *	+0.299	0.40
4	0.94 *	0.53 *	+0.121	0.13

d.f. 3

b. The correlations and regressions of position C kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.80 n.s.	0.76 n.s.	+0.144	0.30
2	0.96 **	0.89 **	−0.383	0.19
3	0.85 n.s.	0.66 n.s.	+0.456	0.25
4	0.87 n.s.	0.51 n.s.	+0.653	0.19

d.f. 3

c. The correlations and regressions of position D kempiness on position A kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.90 *	0.93 *	−0.04	0.24
2	0.89 *	0.64 *	+0.541	0.24
3	0.94 *	1.04 *	+0.19	0.24
4	0.82 n.s.	0.69 n.s.	+0.822	0.34

d.f. 3

n.s. indicates p greater than .05

* indicates p less than .05

** indicates p less than .01

TABLE 22

The test for differences between sampling times in the regression coefficients of kempiness in positions B, C and D on kempiness in position A for five three-year-old Cheviot ewes.

a. B on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	2.442	0.204	F_1 = 1.00 n.s.
Regression coefficient	3	0.638	0.213	
Common Regression	15	3.080	0.205	F_2 = 1.3 n.s.
Adjusted Means	3	0.781	0.260	
Total	18	2.299		

b. C on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	1.906	0.159	F_1 = 0.89 n.s.
Regression coefficient	3	0.427	0.142	
Common Regression	15	2.333	0.156	F_2 = 1.03 n.s.
Adjusted Means	3	0.484	0.161	
Total	18	2.817		

c. D on A

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	2.582	0.215	F_1 = 0.62 n.s.
Regression Coefficient	3	0.399	0.133	
Common Regression	15	2.981	0.199	F_2 = 1.19 n.s.
Adjusted Means	3	0.712	0.237	
Total	18	3.693		

n.s. indicates p greater than .05

that the accuracy of prediction of kempiness in the other positions is not very good.

In the three-year-olds (Table 21) the number of sheep on which the results are based is insufficient to allow reliable conclusions to be drawn.

The best relationship is obtained with positions A and D. The relationship of positions A and B is very poor in the first two sampling times but significant in the last two sampling times. Although the relationship of positions A and C is generally consistently higher than that of positions A and B, it only reaches significance at sampling II.

Kempiness in position A predicts best kempiness in position D although non-significance is recorded at sampling IV. A test for differences in regression lines (Table 22) shows that there are no significant differences between the regression lines of these two variables in slope or means.

The prediction of kempiness in positions C and B from kempiness in position A is very variable and only reaches significance at sampling II and samplings III and IV respectively. The test for differences in regression lines (Table 22) shows that the regressions of position C on position A do not differ significantly in slope or means but that the regression lines of position B on position A differ in slope but not significantly so.

The standard errors of estimate of the regression coefficients indicate that the accuracy of prediction of position B on position A at any one sampling time is poor while the accuracy

TABLE 23

The correlation and regression coefficients of kempiness in positions A, B and C on kempiness in position D at each sampling time for 10 two-year-old Cheviot ewes.

Method of measurement of kempiness: Total kemps per g of wool.

a. The correlations and regressions of position A kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.64^{*}	0.93^{*}	−0.462	0.26
2	0.64^{*}	0.86^{*}	+0.044	0.24
3	0.77^{**}	1.16^{**}	−0.888	0.18
4	0.75^{*}	1.16^{*}	−0.980	0.19

d.f. 8

b. The correlations and regressions of position B kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.36 n.s.	0.21 n.s.	+0.633	0.13
2	0.50 n.s.	0.57 n.s.	−0.418	0.23
3	0.25 n.s.	0.23 n.s.	+0.454	0.17
4	0.52 n.s.	0.59 n.s.	−0.498	0.18

d.f. 8

c. The correlations and regressions of position C kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.82^{**}	1.04^{**}	−1.326	0.17
2	0.80^{**}	1.00^{**}	−0.928	0.17
3	0.66^{*}	0.89^{*}	−0.817	0.19
4	0.74^{*}	0.90^{*}	−0.693	0.16

d.f. 8

n.s. indicates p greater than .05

* indicates p less than .05

** indicates p less than .01

of prediction of positions C and D from position A is better but still not very accurate. As in the two-year-olds, the accuracy of prediction varies much between sampling times.

Thus, for the two-year-olds the best relationship is obtained between kempiness in position A and kempiness in positions C and D. Position A predicts best the kempiness in position C although the prediction of kempiness in position D is more accurate. There is much variability in the relationship and predictability of kempiness in position B from kempiness in position A.

In the three-year-old group, positions A and D show the best relationship. Kempiness in position A predicts best kempiness in position D while the prediction of kempiness in the other positions only reaches significance at certain sampling times.

In both age groups, the accuracy of prediction of kempiness is not very good and varies at different sampling times. There were no significant differences between sampling times in the regression coefficients except for the regression of position B on position A in the two-year-olds.

3. The relationship of position D with positions A, B and C.

The correlation coefficients and regression coefficients and standard errors of estimates for ten two-year-olds are presented in Table 23.

The best relationship occurs between kempiness in position D and kempiness in positions A and C. In all cases the relationship is significant. The relationship between kempiness in

TABLE 24

The test for differences between sampling times in the regression coefficients of kempiness in positions A, B and C on kempiness in position D for ten two-year-old Cheviot ewes.

1. Two-year-olds

A on D

Source	d.f	dyx^2	m.s.	F
Within Samples	32	12.523	0.391	F_1= 0.16 n.s.
Between Regression Coefficients	3	0.190	0.063	
Common Regression	35	12.713	0.363	F_2= 0.80 n.s.
Adjusted Means	3	0.774	0.291	
Total	38	13.487		

B on D

Source	d.f.	dyx^2	m.s.	F
Within Samples	32	8.332	0.260	F_1= 0.47 n.s.
Between Regression Coefficients	3	0.366	0.122	
Common Regression	35	8.698	0.249	F_2= 0.20 n.s.
Adjusted Means	3	0.148	0.049	
Total	38	8.846		

C on D

Source	d.f.	dyx^2	m.s.	F
Within Samples	32	7.599	0.238	F_1= 0.06 n.s.
Between Regression Coefficients	3	0.044	0.015	
Common Regression	35	7.643	0.218	F_2= 0.75 n.s.
Adjusted Means	3	0.491	0.164	
Total	38	8.134		

TABLE 25

The correlation and regression coefficients of kempiness in positions A, B and C on kempiness in position D at each sampling time for five three-year-old Cheviot ewes.

Method of measurement of kempiness: Total kemps per g of wool

a. The correlations and regressions of position A kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.90^{*}	0.86^{*}	+0.436	0.24
2	0.89^{*}	1.21^{*}	−0.234	0.33
3	0.94^{*}	0.84^{*}	−0.059	0.21
4	0.81 n.s.	0.96 n.s.	−0.264	0.40

d.f. 3

b. The correlations and regressions of position B kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.36 n.s.	0.19 n.s.	+1.023	0.28
2	0.25 n.s.	0.19 n.s.	+0.291	0.39
3	0.98^{**}	0.50^{**}	+0.205	0.07
4	0.80 n.s.	0.53 n.s.	−0.059	0.27

d.f. 3

c. The correlations and regressions of position C kempiness on position D kempiness.

	r	b	$\bar{y} - b\bar{x}$	s.e. of estimate
Sampling 1	0.94^{*}	0.84^{*}	+0.075	0.15
2	0.86 n.s.	1.10 n.s.	−0.617	0.34
3	0.80 n.s.	0.56 n.s.	+0.483	0.28
4	0.98^{**}	0.68^{**}	+0.157	0.08

n.s.	indicates p greater than .05
*	indicates p less than .05
**	indicates p less than .01

positions D and position B is non-significant at all sampling times.

The prediction of kempiness in positions A and C from kempiness in position D appears to be equally good and the test for differences between regressions (Table 24) shows that the regression coefficients do not differ significantly from each other. The regressions of position B on position D are all non-significant so that prediction of kempiness in position B from kempiness in position D is not accurate. Nevertheless, there are no significant differences between means or slopes of the regression lines for different sampling times (Table 24).

There is much variability in the accuracy of prediction at different sampling times and the standard errors of estimate indicate that the accuracy of prediction at any one sampling time is not good either.

In the three-year-olds any conclusions reached can only be tentative as they are based on too few sheep.

In this age group the pattern is different. Examination of Table 25 reveals that there is a better relationship in kempiness over the four sampling times between position A and position D than there is between kempiness in position C and position D. The correlation coefficients of kempiness in positions A and D are non-significant at sampling IV only whereas the correlation of kempiness in positions C and D is non-significant at sampling II and III.

The relationship between kempiness in positions B and D

TABLE 26

The test for differences between sampling times in the regression coefficients of kempiness in positions A, B and C on kempiness in position D for five three-year-old Cheviot ewes.

a. A on D

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	3.316	0.276	F_1 = 0.30 n.s.
Between Regression Coefficients	3	0.246	0.082	
Common Regression	15	3.562	0.237	F_2 = 1.49 n.s.
Adjusted Means	3	1.061	0.354	
Total	18	4.623		

b. B on D

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	1.809	0.151	F_1 = 2.47 n.s.
Between Regression Coefficients	3	1.120	0.373	
Common Regression	15	2.929	0.195	F_2 = 2.32 n.s.
Adjusted Means	3	1.362	0.450	
Total	18			

c. C on D

Source	d.f.	dyx^2	m.s.	F
Within Samples	12	2.002	0.167	F_1 = 0.09 n.s.
Between Regression Coefficients	3	0.481	0.016	
Common Regression	15	2.483	0.166	F_2 = 0.35 n.s.
Adjusted Means	3	0.177	0.059	
Total	18	2.660		

n.s. indicates p greater than .05

is poor and is significant at sampling III only.

The prediction of kempiness in position A from kempiness in position D is better than the prediction of kempiness in position C from kempiness in position D. Table 26 demonstrates that there are no significant differences between sampling times in the means and the slopes of the regression lines of the variables.

The only time in this study in which significant predictions of kempiness in position B can be made from kempiness in position D is at sampling III. Table 26 shows that the regression lines of these variables are not parallel but do not differ significantly in slope.

The accuracy of prediction again varies between sampling times and is not very accurate at any one sampling time except where significance is recorded.

The standard errors of estimate of this age group are in general higher than the standard errors of estimate of the two-year-olds. It may be concluded that less accurate prediction of kempiness at any one sampling time will be made from the three-year-olds.

These results indicate for the two-year-olds that kempiness in positions C and D have the best relationship with kempiness in position D. Kempiness in position D predicts kempiness in these positions equally well. There is no significant relationship of kempiness in position D with kempiness in position B.

In the three-year-olds, kempiness in position A has a better relationship with kempiness in position D than position C has but in both relationships non-significant coefficients were recorded. Again the relationship between positions B and D is poor. The kempiness in position D predicts kempiness in position A best while the regression of the kempiness of position B on position D was significant only once. Although no significant differences occurred between sampling times for the regressions of the variables, there was much variation in the accuracy of prediction of kempiness between sampling times. Accuracy of prediction was not good at any one sampling time except where significant regression coefficients were recorded. Prediction at any one sampling time was again poorer in the three-year-olds than the two-year-olds.

D. The Variation of Kempiness Between Individual Sheep

The rate of progress in selecting against kempiness depends in part, on the amount of variation in kempiness between sheep. Therefore, an attempt was made in this experiment to determine the variation in kempiness between individual sheep.

The differences between sheep were determined from position A with kempiness measured by total kemps per sq. cm.

The highly significant F values in Table 9 indicated that there was much variability in kempiness between sheep in the three-year-old group. This was further confirmed

TABLE 27

The analysis of variance of data on total kemps per square centimetre from position A of all sheep.

Source	s s	d.f.	m.s.	F
Between Ages	15.440,300	3	5.146,766	3.334*
Between Sampling Times	1.046,500	3	0.348,833	0.226 n.s.
Between Sheep Within Ages	98.797,622	64	1.543,713	8.325**
Error	37.270,760	201	0.185,427	
Total	152.555,182	271		

** p less than .01

* p less than .05

n.s. p greater than .05

TABLE 28

The analysis of variance of data on shed kemps per square centimetre from position A of all sheep.

Source	s s	d.f.	m.s.	F
Between Ages	16.346,100	3	5.448,700	4.06**
Between Sampling Times	2.673,100	3	0.891,033	0.66 n.s.
Between Sheep Within Ages	85.852,249	64	1.341,441	6.94**
Error	38.824,884	201	0.193,157	
Total	143.696,33	271		

n.s. p greater than .05

** p less than .01

TABLE 29

The variances of data for position A for each age group at each sampling time.

Method of measurement of kempiness: Total kemps per sq. cm.

Age (years)		2	3	4	5
Sampling Time	1	0.845	0.353	0.363	0.488
	2	0.857	0.454	0.599	0.617
	3	0.575	0.412	0.531	0.381
	4	0.726	0.365	0.434	0.432

in Table 27 in which highly significant differences between sheep within ages were recorded. Figures 12, 13, 14 and 15 demonstrate the differences in kempiness between sheep at each sampling time for each age group. The log means and the antilog of the means are presented in Appendix I.

By analysing the variation in data for shed kemps per sq. cm. it is possible to gain some idea of whether the differences between sheep are made up of shed or growing kemps. The analysis of variance presented in Table 28 gives similar results to those presented in Table 27 for total kemps per sq. cm. The F values indicate that the variation of shed kemps per sq. cm. is not markedly different from the variation of total kemps per sq. cm. in these ewes. Figure 11 and Tables 30 and 32 demonstrate that shed kemps make up the greater proportion, on average, of total kemps. Hence, on this evidence it may be concluded that shed kemps account for the major part of the differences between sheep.

Table 29 indicates that the variation in kempiness between sheep changes with sampling time. The maximum variation in kempiness between sheep for all age groups is at sampling II when mean growing kemps in all age groups but the two-year-olds is at a maximum (Figure 11). However, it is doubtful whether much importance can be attached to this fact as differences in the mean number of growing kemps at samplings I and II are small except in the case of the two-year-olds. Variation between sheep is least at sampling III for the two and five-year-olds and at sampling I for the three and four-year-olds. These variances also show that some part of the difference between individuals in kempiness in the two-year-olds is due to incomplete stabilisation of the variance by the logarithmic transformation. Inspection of figure 12 bears this out.

The results show that there are significant differences between sheep within age groups in kempiness. These differences are largely due to shed kemps. The variation in kempiness between sheep in each age group varies with time and reaches a maximum at sampling II.

E. The Variation of Kempiness Between Age Groups.

The practical usefulness of knowing which age groups show the most kempiness is important in selection. An endeavour was made therefore, to determine the degree to which each age group shows kempiness.

The analysis of variance (Table 14) of the two and three-year-olds established that there were no significant differences in total kempiness (the sum of the four positions) between the two age groups. However, Tables 11 and 27, using data from position A for more sheep, showed that there were significant differences (5% level) in kempiness between age groups. This fact implies that there were too few sheep included in the analysis (Table 14) involving total kempiness to show up existing differences between age groups. It might also be interpreted as indicating that differences in age groups, as indicated by position A are not representative of total kempiness. However, this is unlikely as it already

TABLE 30

The logarithm means, the antilogarithms of the means and the standard errors of the logarithm means for data from position A in each age group.

Method of measurement of kempiness: Total kemps per square centimetre

Logarithm Means

Sampling Time	1	s.e.	2	s.e.	3	s.e.	4	s.e.	Total	
Age Two-year-olds	2.389	± 0.70	2.444	±0.71	2.407	±0.58	2.366	±0.65	2.402	±0.32
Three-year-olds	1.580	± 0.46	1.832	±0.52	1.996	±0.49	1.781	±0.46	1.797	±0.24
Four-year-olds	2.203	± 0.46	2.194	±0.54	2.289	±0.56	2.271	±0.51	2.239	±0.26
Five-year-olds	1.799	± 0.54	2.047	±0.60	1.932	±0.47	1.986	±0.50	1.941	±0.26
Over all ages	1.993	± 0.09	2.129	±0.10	2.156	±0.06	2.101	±0.09		

log 2.0 = antilog 10.0

Antilogarithms of Means

Sampling Time	1	2	3	4	Total
Age Two-year-olds	24.49	27.80	25.53	23.23	25.23
Three-year-olds	3.80	6.79	9.91	6.04	6.27
Four-year-olds	15.96	15.63	19.45	18.66	17.34
Five-year-olds	6.30	11.11	8.55	9.68	8.73
Over all ages	9.84	13.46	14.32	12.62	

TABLE 31

Multiple range test: Testing the differences in mean kempiness of four age groups at the 5% level.

Method of measurement of kempiness: Total kemps per square centimetre.

Age (years)	Three	Five	Four	Two
log Mean	1.797	1.941	2.239	2.402

log 2.0 = antilog 10.0

Results: Any two means not underscored by the same line are significantly different at the 5% level.

Any two means underscored by the same line are not significantly different at the 5% level.

TABLE 32

The logarithm means, the antilogarithms of the means and the standard errors of the logarithm means for data from position A in each age group.

Method of measurement of kempiness: Shed kemp per square centimetre.

Logarithm Means

Sampling Time		1	s.e.	2	s.e.	3	s.e.	4	s.e.	Total	s.e.
Age	Two-year-olds	2.166	±0.74	2.391	±0.69	2.388	±0.57	2.341	±0.65	2.322	±0.33
	Three-year-olds	1.465	±0.37	1.713	±0.48	1.904	±0.49	1.658	±0.45	1.685	±0.23
	Four-year-olds	2.033	±0.40	2.024	±0.54	2.207	±0.55	2.205	±0.48	2.117	±0.25
	Five-year-olds	1.656	±0.50	1.886	±0.53	1.886	±0.47	1.948	±0.49	1.844	±0.25
	Over all ages	1.830	±0.09	2.004	±0.04	2.096	±0.09	2.038	±0.09		

log 2.0 = antilog 10.0

Antilogarithms of Means

Sampling Time		1	2	3	4	Total
Age	Two-year-olds	14.66	24.6	24.43	21.93	20.99
	Three-year-olds	2.92	5.16	8.02	4.55	4.84
	Four-year-olds	10.79	10.57	16.11	16.03	13.09
	Five-year-olds	4.53	7.69	7.69	8.87	6.98
	Over all ages	6.76	10.09	12.47	10.91	

TABLE 33

Multiple range test: Testing the differences in mean kempiness of four age groups at the 5% level.

Method of measurement of kempiness: Shed kemps per square centimetre

Age (years)	Three	Five	Four	Two
log Mean	1.685	1.844	2.117	2.322
	──────	──────	──────	──────
		──────	──────	

log 2.0 = antilog 10.0

Results: Any two means not underscored by the same line are significantly different at the 5% level.

Any two means underscored by the same line are not significantly different at the 5% level.

has been shown that kempiness in position A can be used to predict total kempiness although not very accurately.

The log means and the antilogs of the means for each age group are presented in Table 30 and show that the age groups fall into the following order of kempiness: two > four > five > three years of age (> indicates greater than). To test differences between these means Duncan's (1955) multiple range test was applied (Table 31). It was found that the two-year-olds differed significantly (5% level) from the five and three-year-olds but not from the four-year-olds while the four-year-olds were significantly different from the three-year-olds but not the five-year-olds.

The analysis of variance using data for shed kemps per g of wool (Table 28) indicated that there was a highly significant difference between the means of each age group (Table 32). The order of kempiness of the log means or the antilog of the means of each age group for data involving shed kemps (Table 32) is the same as the order of kempiness of the means of each age group for data involving total kemps (Table 30). The multiple range test (Table 33) again shows that the two-year-olds differ significantly from the five and three-year-olds but not the four-year-olds while the four-year-olds differ significantly from the three-year-olds but not the five-year-olds. This suggests that shed kemps vary similarly to total kemps. Further evidence from Tables 27 and 28 is gained from the F values of the between ages variation. The F values suggest that there is not a marked difference in the variance of measures involving shed kemps and total kemps. It has already been shown that shed kemps comprise the greater proportion of total kemps per sq. cm. This evidence strongly suggests, therefore, that the major part of the differences in kempiness between ages is due to shed kemps.

Examination of figures 12, 13, 14 and 15 suggest that some part of the difference in kempiness between ages may be due to a few sheep in the two-year-old group departing considerably from the mean. That this is so, is further indicated by a comparison of the variation in kempiness in each age group, (Table 29), where it is obvious that the logarithmic transformation has not completely stabilised the variance between age groups.

F. The Variation of Kempiness at Different Sampling Times

The variation in kempiness between seasons was analysed in order to gain information on changes in the kemp population with time and to obtain some information on the time that kemps grow into the fleece.

As previously stated, the kemps in any sample were divided into the following kemp types:

a. Shed kemps.

b. Growing kemps, i.e. kemps showing a cut basal end.

The assumption was then made that the mean kemp length is similar for all ages. Thus, a growing kemp being shorter should weigh less than a shed kemp. If the fleece contains

TABLE 34

The regressions and standard errors of estimate of weight of kemps per square centimetre on total kemps per square centimetre for position A at all sampling times for each age group.

a. Two-year-olds 17 ewes

Sampling	1	2	3	4
b	0.87^{**}	0.99^{**}	0.92^{**}	0.97^{**}
s.e.	0.07	0.02	0.03	0.03

** p less than .01

b. Three-year-olds 17 ewes

Sampling	1	2	3	4
b	0.93^{**}	1.03^{**}	0.99^{**}	0.92^{**}
s.e.	0.06	0.03	0.03	0.08

** p less than .01

c. Four-year-olds 17 ewes

Sampling	1	2	3	4
b	0.98^{**}	0.96^{**}	0.95^{**}	0.89^{**}
s.e.	0.02	0.03	0.02	0.05

** p less than .01

d. Five-year-olds 17 ewes

Sampling	1	2	3	4
b	0.91^{**}	0.95^{**}	0.93^{**}	0.94^{**}
s.e.	0.06	0.03	0.03	0.03

** p less than .01

TABLE 35

The test for differences between sampling times of the regression lines in Table 34 for each age group.

a. Two-year-olds

Source	d.f.	dyx^2	m.s.	F
Within Samples	60	0.873	14.6	F_1 = 2.47 n.s.
Between Regression Coefficients	3	0.109	36.0	
Common Regression	63	0.982	14.7	F_2 = 1.47 n.s.
Adjusted Means	3	0.310	10.0	
Total	66	1.013		

n.s. p greater than .05

b. Three-year-olds

Source	d.f.	dyx^2	m.s.	F
Within Samples	60	2.851	47.5	F_1 = 0.4 n.s.
Between Regression Coefficients	3	0.057	19.0	
Common Regression	63	2.908	46.2	F_2 = 0.5 n.s.
Adjusted Means	3	0.07	23.0	
Total	66	2.978		

n.s. p greater than .05

c. Four-year-olds

Source	d.f.	dyx^2	m.s.	F
Within Samples	60	1.094	18.2	F_1 = 0.60 n.s.
Between Regression Coefficients	3	0.032	11.0	
Common Regression	63	1.126	17.9	F_2 = 1.45 n.s.
Adjusted Means	3	0.078	26.0	
Total	66	1.204		

n.s. p greater than .05

d. Five-year-olds

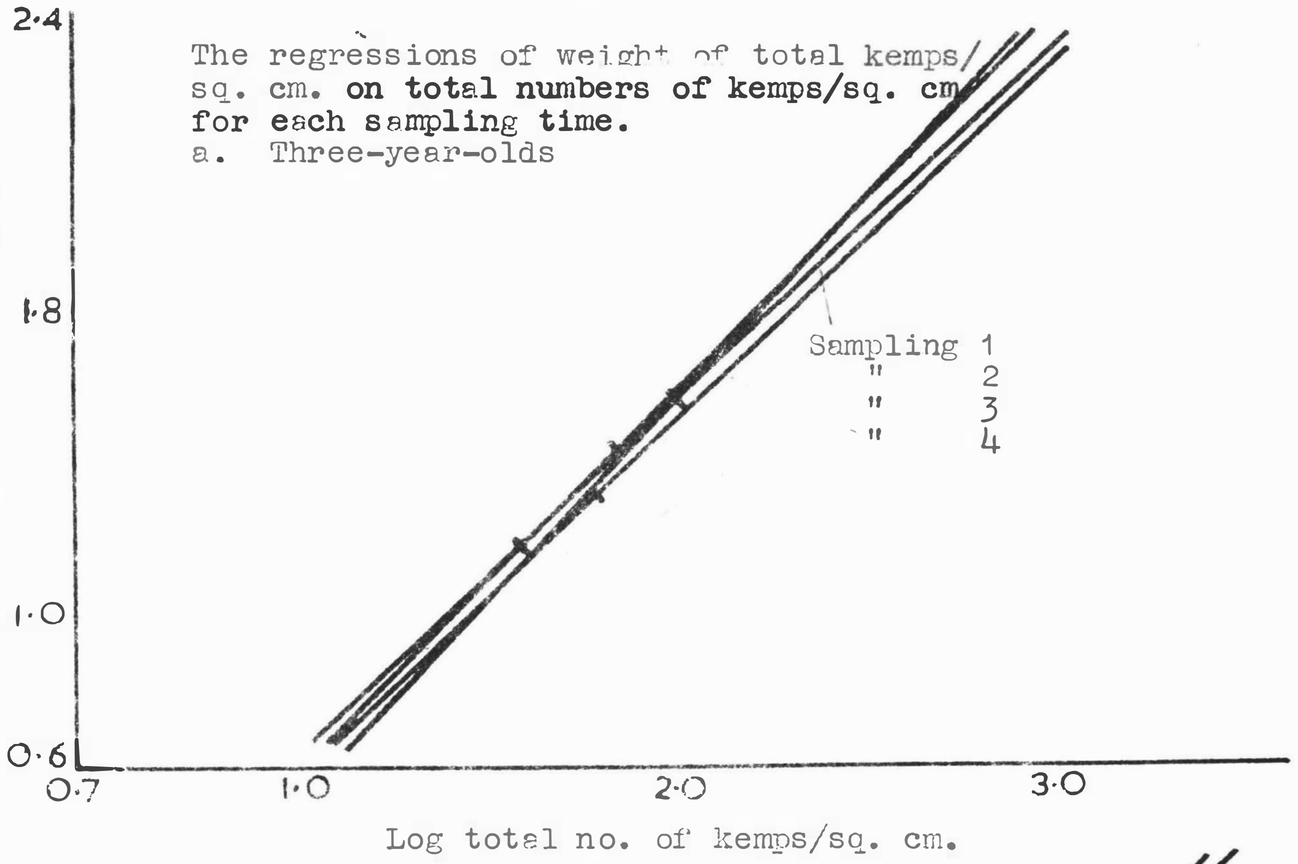
Source	d.f.	dyx^2	m.s.	F
Within Samples	60	1.584	26.4	F_1 = 0.04 n.s.
Between Regression Coefficients	3	0.004	1.0	
Common Regression	63	1.588	25.2	F_2 = 0.44 n.s.
Adjusted Means	3	0.033	11.0	
Total	66	1.621		

n.s. p greater than .05

many growing kemps, a regression of the weight of kemps on the number of kemps will not have as steep a slope, i.e. it will show a smaller change in weight for a given change in number of kemps, as when the fleece contains many shed kemps. The slope of the regression lines of the weight of kemps per sq. cm. on the number of kemps per sq. cm. at different sampling times in the same age group may, therefore, indicate whether there is a high proportion of growing or shed kemps in the fleece. Some indication of whether shedding or growth of kemps is taking place can be gained from this information.

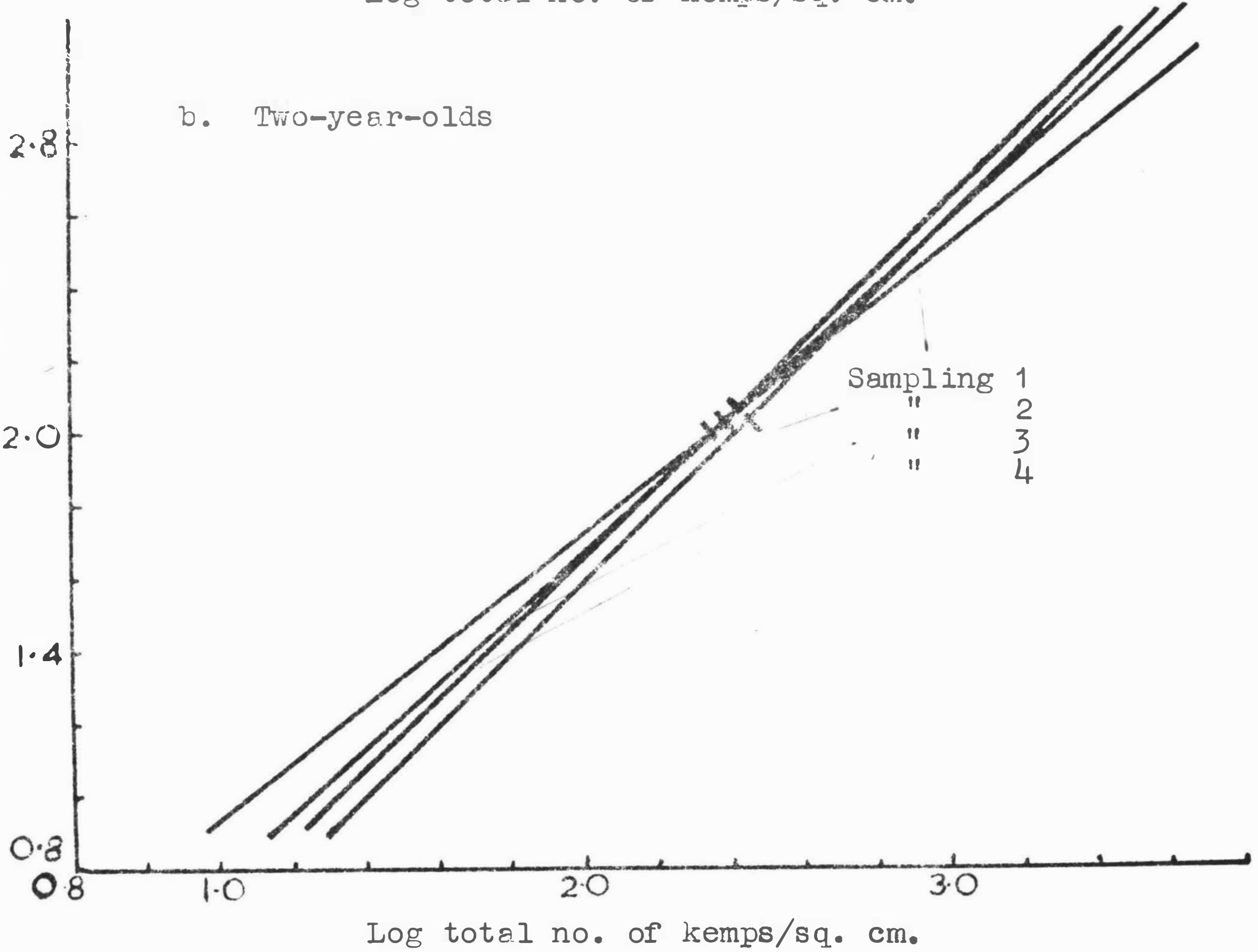
The regression coefficients of weight of kemps per sq. cm. on total kemps per sq. cm. and their standard errors of estimate are presented in Table 34. All regressions are highly significant and the table shows that the change of weight relative to a change in the total numbers of kemps is of the order of 1:1 for most sampling times. The test for significant differences between sampling times of the regression lines for each age group is presented in Table 35. The results of this test indicate that the regression lines of the two-year-olds were not parallel but that the departure did not reach significance. The other age groups were found to have regression lines in which differences between slopes and means were not significant (figures 9 and 10). This being the case, it appears that a given increase in number of kemps is associated with a similar increase in weight of kemps at all sampling times and in all age groups except the two-year-olds. The regression lines give no indication, therefore, of shedding or growth of kemps

Fig. 9



The regressions of weight of total kemps/sq. cm. on total numbers of kemps/sq. cm for each sampling time.

a. Three-year-olds

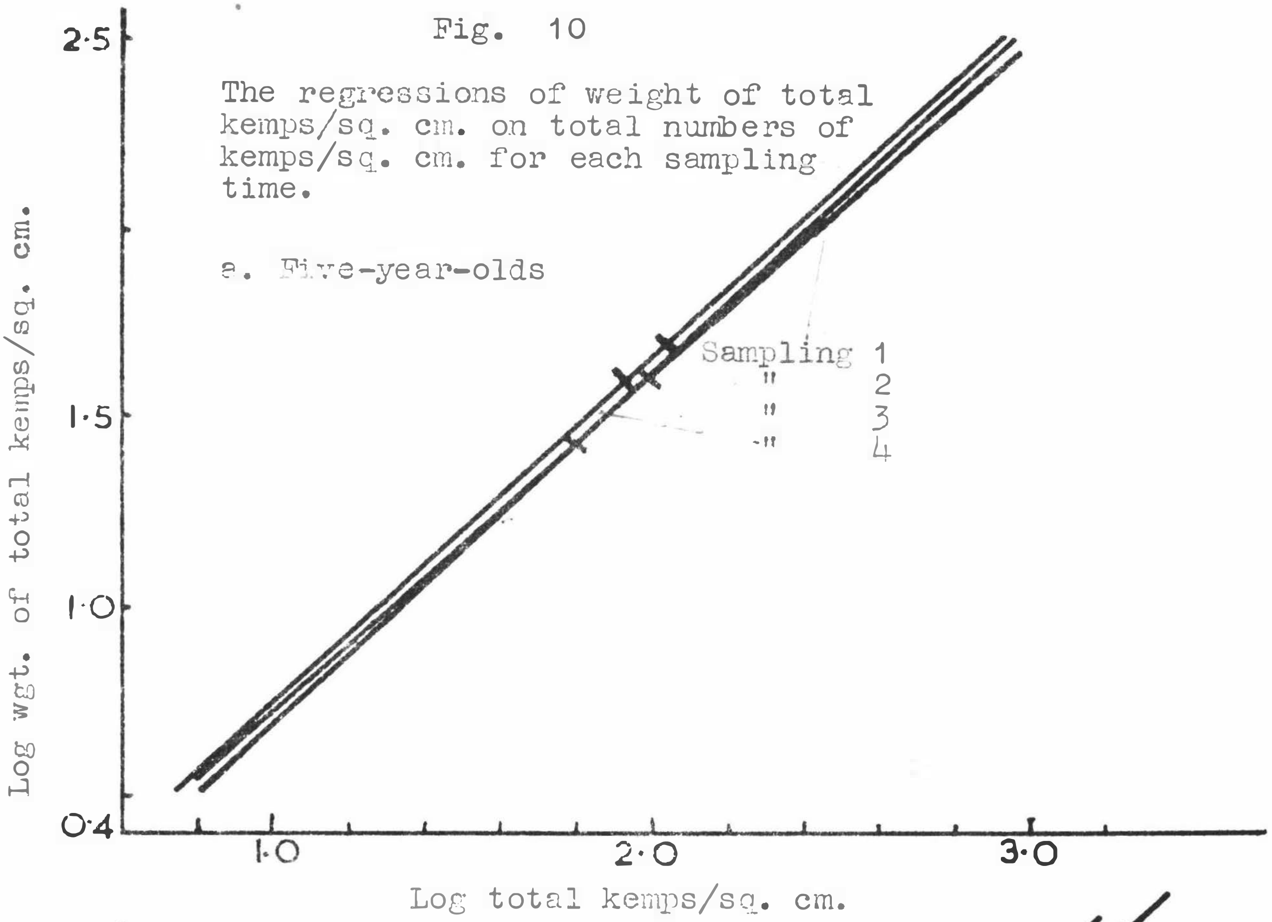


b. Two-year-olds

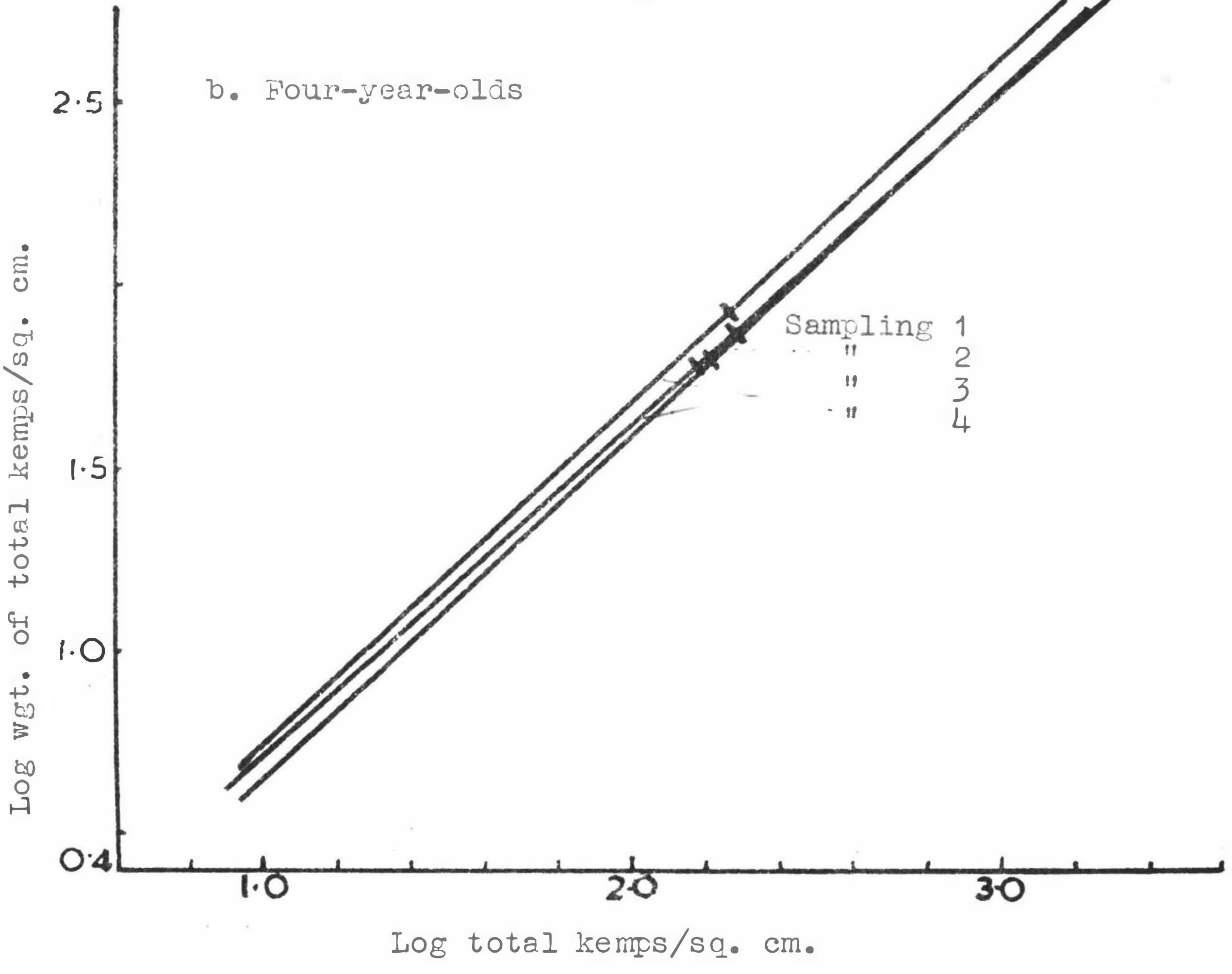
Fig. 10

The regressions of weight of total kemps/sq. cm. on total numbers of kemps/sq. cm. for each sampling time.

a. Five-year-olds



b. Four-year-olds



except in the two-year-olds. However, there might be non-detectable variations in shed and growing kemps throughout the year (figure 11).

The two-year-olds show some variation in the slope of the regression lines. Figure 9 shows that the regression line for sampling I is not as steep as the regression lines for the other sampling times. Although random variations in kempiness may have caused the departure from parallelism, the regression line for sampling I indicates that for a given increase in number of kemps there is a smaller increase in weight of kemps than is the case at other sampling times. This suggests that a wave of kemp growth is commencing or finishing at this time. Figure 11 supports this contention.

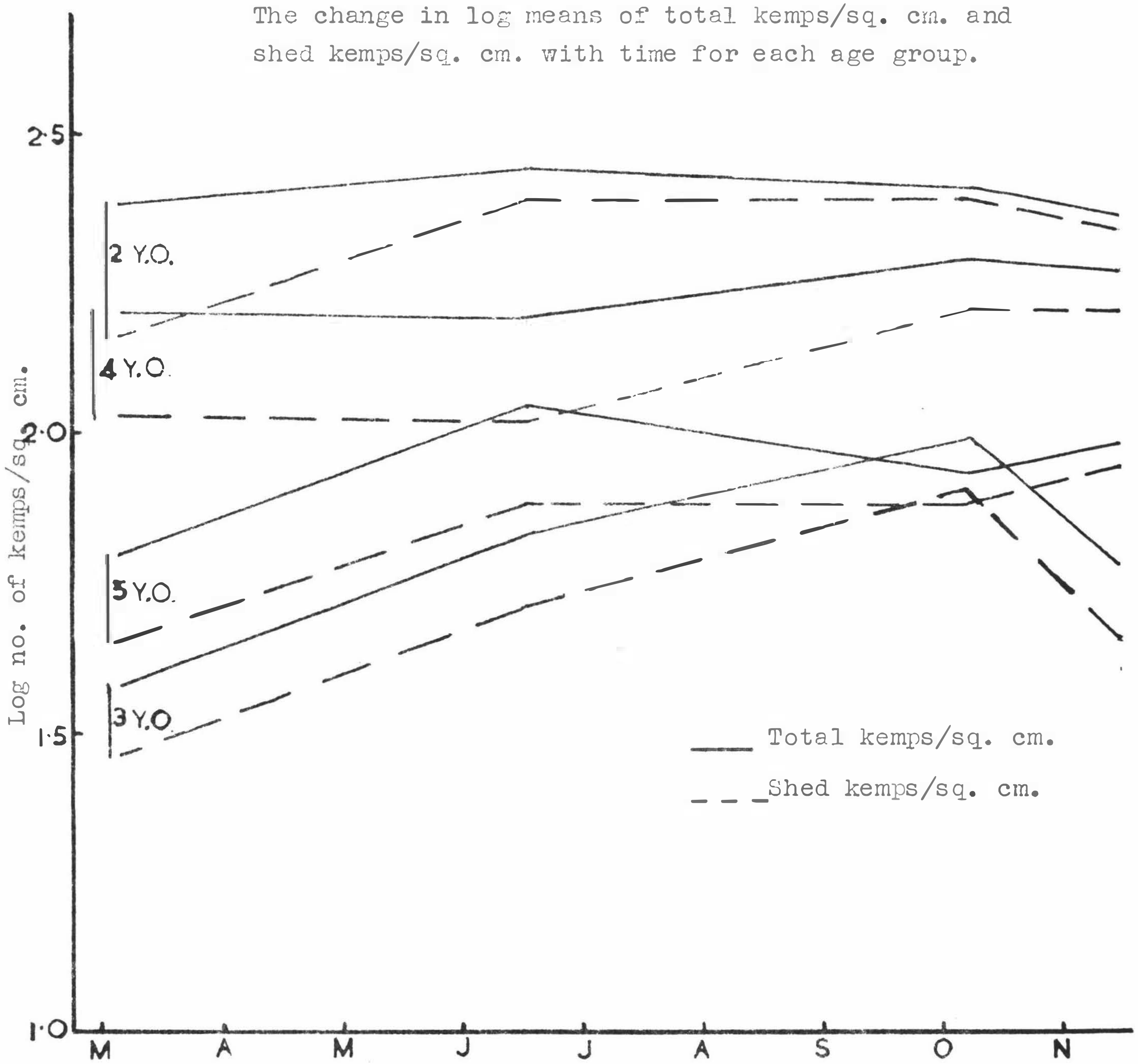
The differences in total kempiness between sampling times were found to be non-significant (Table 14) and this was confirmed in data for position A for all sheep (Table 27). However, these results may be influenced by several factors.

It has already been mentioned that the indicated loss in body weight over the winter and inaccuracies of estimating the total numbers of kemps in a sample in the three-year-olds at samplings I and IV will affect differences between sampling times.

The use of the method of measurement, the total number of kemps per g of wool (Table 14) will cause a decrease in kemp population to be further reduced and the magnitude of an increase in kemps to be reduced as the experiment progresses. The reason for this is that as the wool grows, fewer fibres

Fig. 11

The change in log means of total kemps/sq. cm. and shed kemps/sq. cm. with time for each age group.



go to make up one g of wool. Thus fewer follicles (and hence kemps) are sampled as the experiment progresses with the previously mentioned consequences.

Whether these factors influence the results of tables 14 and 27 to any great extent is not known. However, they were assumed not to have any major effect. Therefore, it is concluded that there are no significant differences between sampling times in total kemps per sq cm.

The graphical representation of changes in kempiness in individual sheep at each age group with time is presented in figures 12, 13, 14 and 15. Some explanation of these graphs is needed as it appears as if the non-significant differences in kempiness between sampling times are due to the individual sheep in each age group following one of four conflicting patterns of kemp population change with time. However, these patterns can be attributed to differences in kempiness in the four areas comprising position A (section IV B 2) and the randomisation of the serial order in which they were sampled. Therefore, the four patterns will be determined by the kempiness of the area sampled first and will show maximum kempiness at the samplings when the more kempy areas (areas two and three) are sampled. Evidence for this conclusion is presented in Appendix 1. Under these circumstances the randomisation of the serial order of sampling the areas in position A will ensure that the log means at each sampling time will be a random sample of the areas of position A. Thus, there should be little difference in the log means of kempiness at each

Fig. 12

The change in the total number of kemps/sq. cm. in position A with time for individual two-year-old sheep.

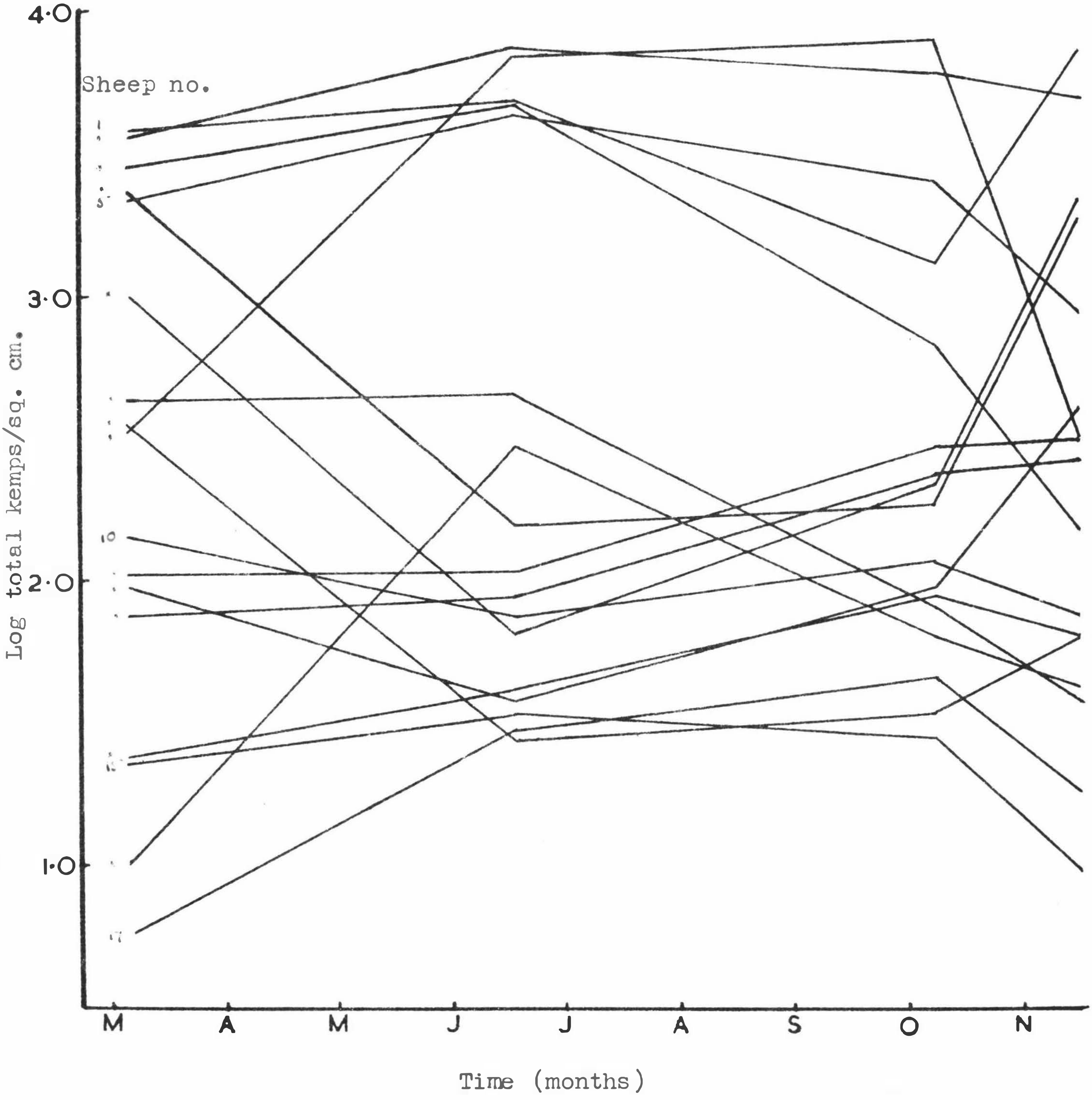


Fig. 13

The change in the total number of kemps/sq. cm. in position A with time for individual three-year-old sheep.

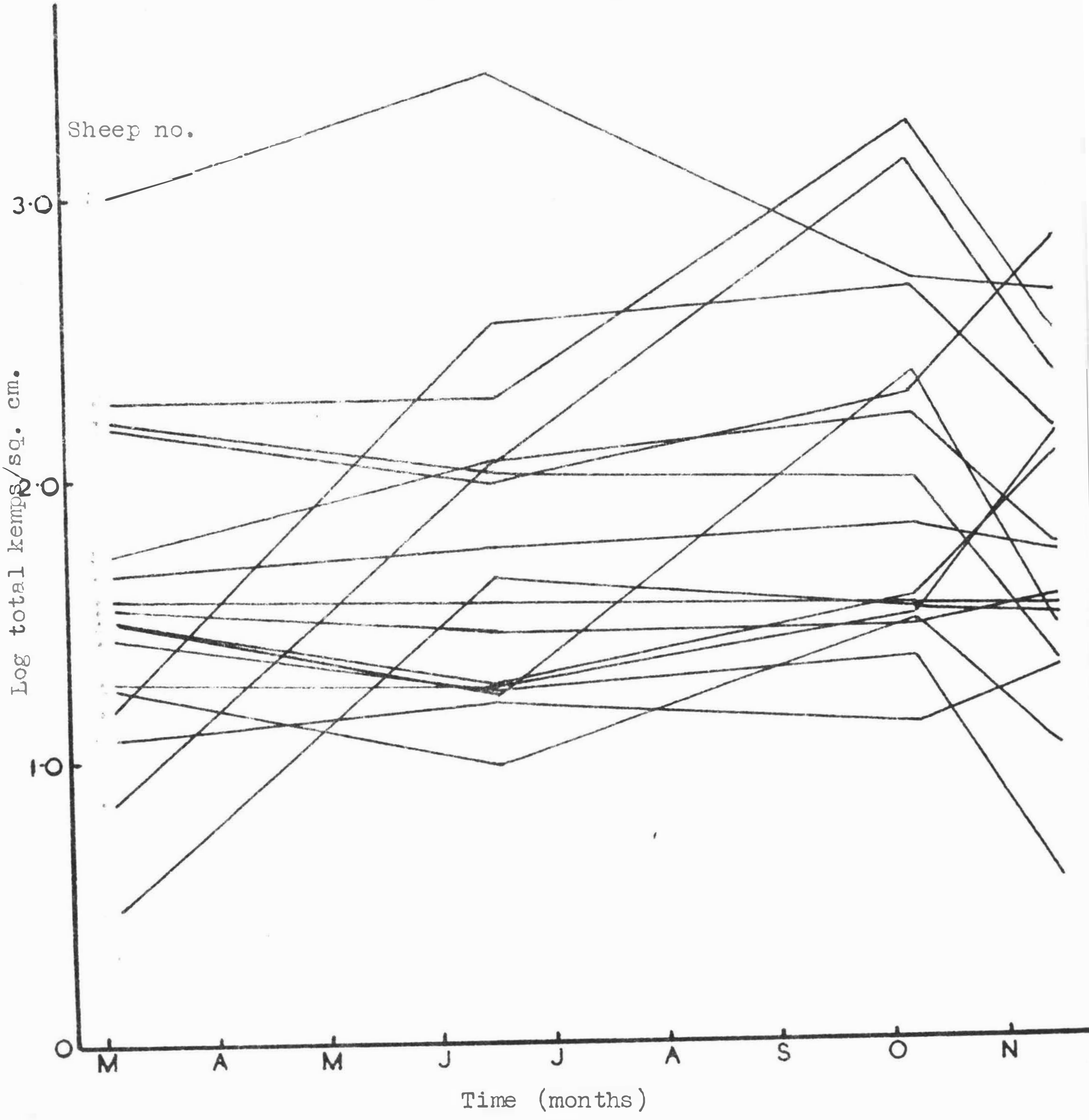


Fig. 14

The change in the total number of kemps/sq. cm. in position A with time for individual four-year-old sheep.

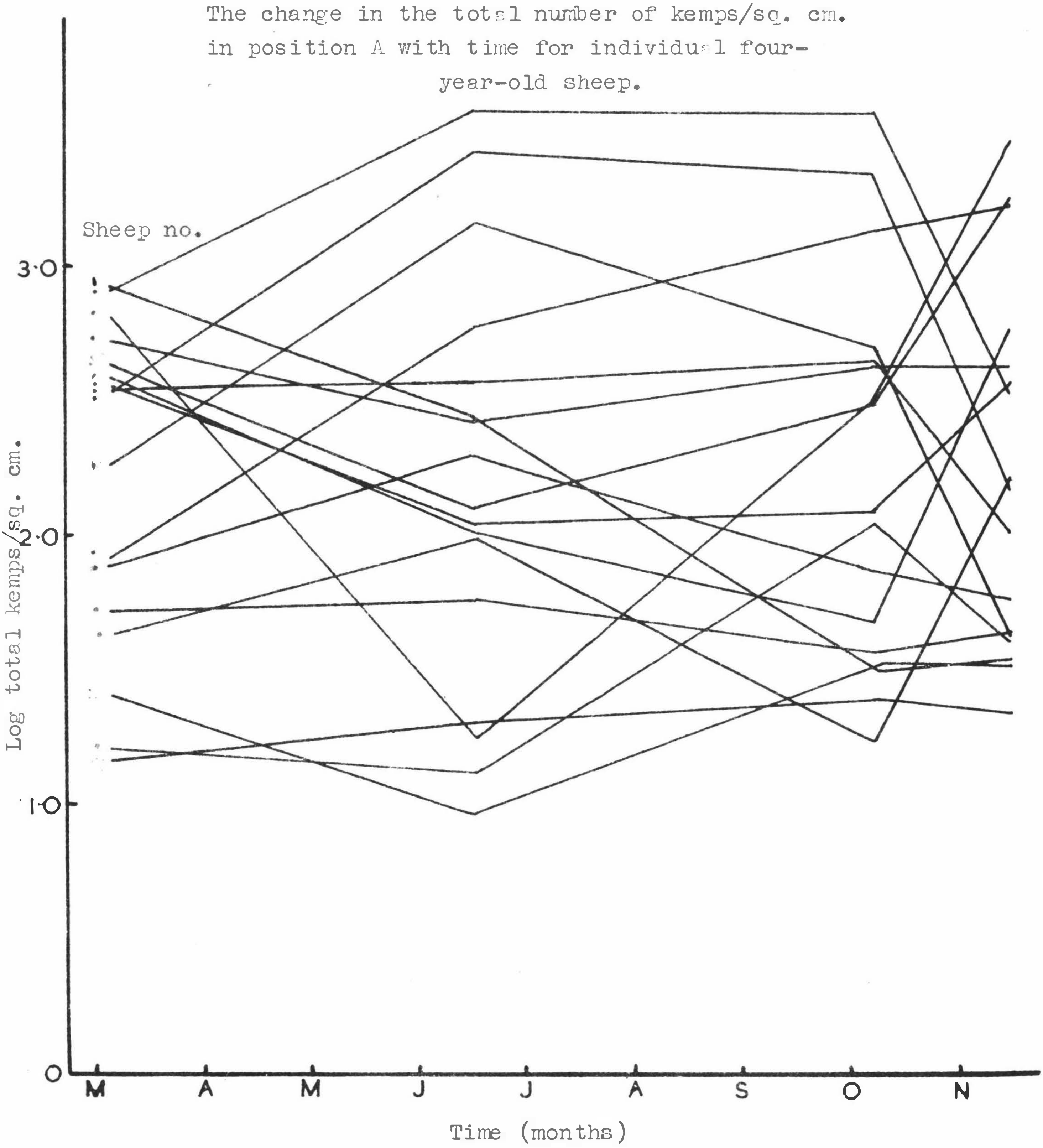
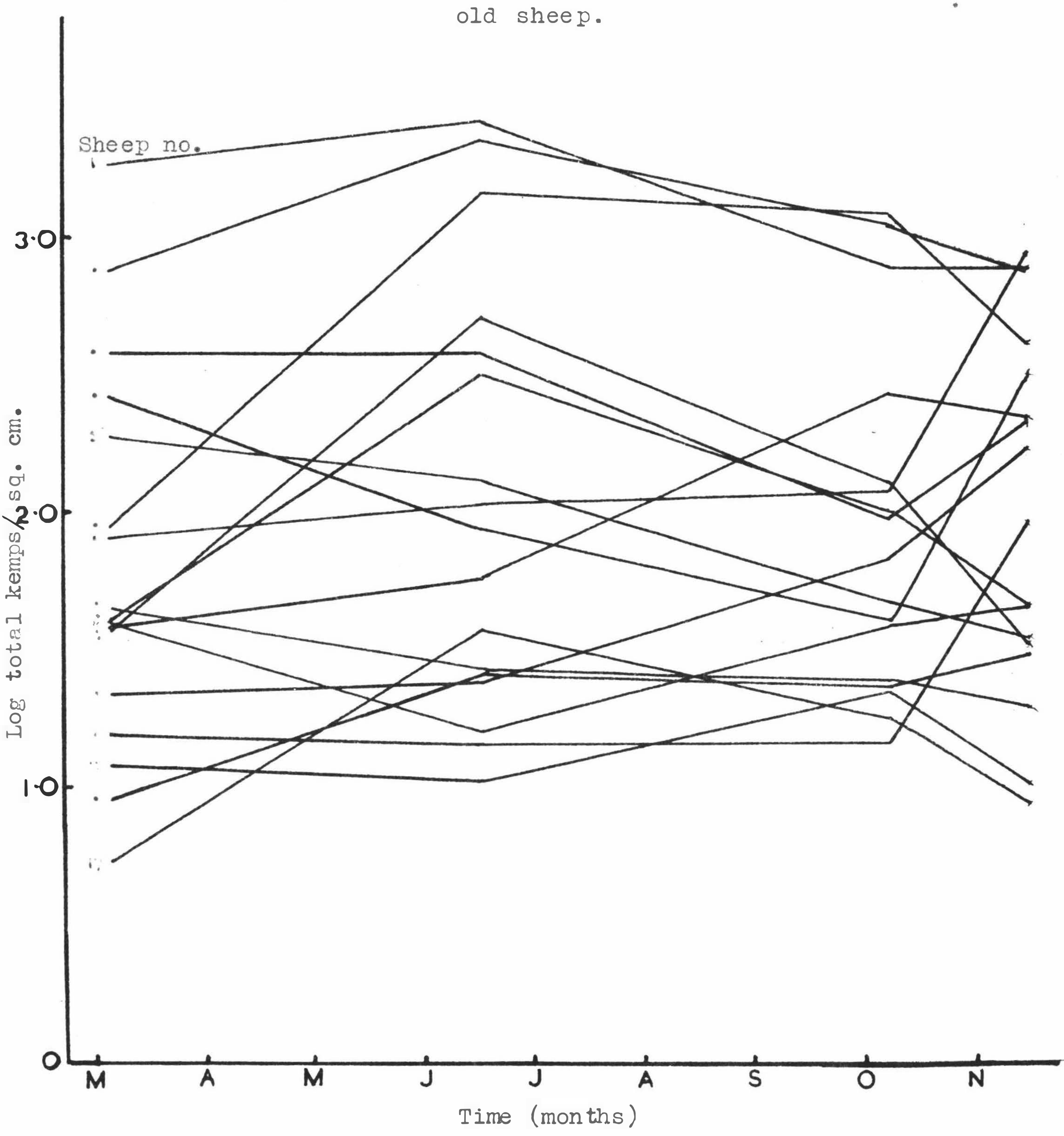


Fig. 15

The change in the total number of kemps/sq. cm. in position A with time for individual five-year-old sheep.



sampling time provided that there is little change in the kemp population with time. This contention is confirmed on inspection of the log means of all age groups at each sampling time in Table 30, and the analysis presented in Table 27.

The importance of shed kemps as the major proportion of total kemps is again demonstrated in Tables 28 and 32 and figure 11. Furthermore, the F values in tables 27 and 28 suggest that shed kemps per sq. cm. vary similarly to total kemps per sq. cm. In both cases non-significant differences occur between sampling times. This in turn implies that either few shed kemps are lost from the fleece between sampling times or that the rate of growth, shedding and loss of shed kemps is similar between sampling times.

Although there is evidence to support the former hypothesis, it is inconclusive and must be regarded with caution.

The retention of shed kemps in longer wool has been indicated in the section on recutting previously sampled areas (IV, A, 3). Presumably, there is some threshold length of wool which will cause the retention of shed kemps in the staple. As there are no significant differences in shed kemps per sq. cm. between sampling times, it must be assumed that this length was attained some time before sampling I. The results from this section (IV, A, 3) also indicate that there is a cycle of kemp growth occurring about sampling I. Further evidence of this growth cycle of kemps is demonstrated in figure 11 and Tables 30 and 32 in which growing kemps, i.e. the difference between total and shed kemps per sq. cm. are at a maximum at samplings I and II except in the two-year-olds. As there are fewer growing kemps on the average, at samplings III and IV in each age group, it may be implied that shedding has taken place. Therefore, as there are no significant differences between sampling times, the kemps growing at samplings I and II and shed during samplings III and IV may be assumed to remain in the fleece.

The evidence suggests, then, that the major part of the kemp population has pierced the skin and is either growing or has shed by the first sampling time.

The length of wool when shedding commenced must be assumed to have been long enough to retain most of the shed kemps. Thus, most of the kemp population is retained in the fleece until sampling IV at least.

However, the means in Tables 30 and 32 show that growing kemps occur at all sampling times. This may be interpreted as indicating that there is a "base" growth and shedding of kemps and that shed kemps are lost at a similar rate at each sampling time. As the sampling intervals were too long to determine whether growing kemps occurred at all times during the experimental period this hypothesis must be regarded with caution.

However, it is obvious that more work is needed to determine the factors causing retention of shed kemps in the fleece and the rate of loss of shed kemps from the fleece.

The variance at each sampling time for each age group is presented in Table 29. The table demonstrates that the most variation occurs at sampling II while the least variation in the three and four-year-olds occurs at sampling I and in the two and five-year-olds at sampling III.

These findings show that there are non-significant differences between sampling times in total kemps per sq. cm. and shed kemps per sq. cm. This was thought to signify that either the major part of the kemp population had grown before sampling one and was retained in the fleece for the experimental period or that kemps were being lost from the fleece and replaced at a similar rate at each sampling time.

There was some evidence which suggested that more growing kemps occurred at samplings I and II than at samplings III and IV although as previously pointed out this difference is small. The variances in each age group were found to be greatest at sampling II.

G. The Relationship Between Percentage Medullation and Kempiness.

The estimation of kempiness from hairiness could be a useful tool in the selection of non-kempy sheep if a strong positive relationship exists between kempiness and hairiness. This relationship was investigated.

The correlation coefficients of the number of kemps per unit area and the percentage medullation (as measured by a medullameter) for each sampling time, for each age group over all sampling times and over all age groups and all sampling

TABLE 36

The correlations of percentage medullation and number of kemps per square centimetre over all sampling times and all age groups.

Age (years)		2	3	4	5
Sampling	1	0.056 n.s.	0.364 n.s.	-0.085 n.s.	0.077 n.s.
	2	0.113 n.s.	0.253 n.s.	-0.108 n.s.	0.160 n.s.
	3	-0.096 n.s.	0.294 n.s.	-0.009 n.s.	0.247 n.s.
	4	-0.469 n.s.	0.515 *	-0.165 n.s.	0.113 n.s.
Over all Samplings		-0.14 n.s.	+0.355**	-0.068 n.s.	+0.146 n.s.
Over all Ages			+0.083 n.s.		

n.s. p greater than .05

* p less than .05

** p less than .01

times are presented in Table 36.

Percentage medullation was estimated from the non-kemp portion of each sample. The percentage medullation data was subjected to a logarithmic transformation; the need for which has been indicated by Goot (1945).

The results demonstrate that the relationship between the two variables at each sampling time is very low and in many cases negative. Only once does the correlation reach significance, i.e. at sampling IV in the three-year-olds.

The correlations over all sampling times show the same degree of relationship except that the correlation for the three-year-olds is significant.

The correlation coefficient over all sampling times and all ages is non-significant and again shows a very poor relationship between the two variables.

Data for mean fibre diameter were obtained for position C at the fourth sampling time for 10 two-year-old and 5 three-year-old ewes. The mean fibre diameter was calculated from the fibre diameters of the fibre types measured at three levels in the staple.

The correlation of kempiness with mean fibre diameter $r = -0.495$ just fails to reach significance at the 5% level ($r = 0.514$). This result should be confirmed for more sheep.

V DISCUSSION

The results in this experiment represent an initial investigation of kemp variability in the fleece of Cheviot ewes and raise problems requiring further research.

The first problem investigated was the suitability for this experiment, of several methods of measurement of kemp variability.

This problem was approached by trying to determine which measure gave the most accurate assessment of kempiness in the fleece. Other methods of measurement of kempiness, i.e. percentage weight of kemps and percentage number of kemps, used by Fraser Roberts (1926), Darling (1932) and Bryant (1933) have already been criticised in the light of Ryder's (1957) work. Nevertheless, as percentage weight was included in this investigation, some idea can be gained of the relationship between the previous workers' investigations and the present one.

The relationship between the measures of kempiness used in this study is such that there is probably little loss of accuracy in measuring kempiness with any one of them. Thus, the results obtained by Fraser Roberts (1926), Darling (1932) and Bryant (1933) can be assumed to be comparable to the results obtained in this experiment, other things being equal. The relationship between percentage number and percentage weight of kemps suspected by Darling (1932) is, on this evidence, probably real also.

The reasons for the selection of the measures of kempiness used in this study have been mentioned previously. (p. 58). Hence, the differences in the number of kemps in a sq. cm. or in a g of wool were considered to give the most useful information of kemp variability in this study.

The variability of the data collected for these measures suggested that the mean and the variance were correlated i.e. the populations did not fulfil the requirements of tests of significance. This is indicated by the marked skewness of the data collected by Darling (1932) and Bryant (1933) in their work on the Scottish Blackface and the skewness of the data collected in this investigation. However, a logarithmic transformation was found to bring about homogeneity of variance so that the use of tests of significance was justified. There is some suggestion in the two-year-olds that the transformation did not completely stabilise the variability in kempiness. Future research on kemp variability with the methods of measurement of kempiness used in this experiment will therefore, entail the application of a transformation to the data to justify the use of tests of significance.

Past workers have given scant consideration to the errors involved in obtaining data for the measures of kempiness. Until these errors have been estimated the value of their work remains in doubt. Most errors are introduced by the failure of the method of measurement of kempiness to sample the same follicle populations on different sheep and on different sampling occasions. This is understandable in view of the indirect methods used to maintain the follicle population constant. By an indirect method, it is meant that the actual follicles themselves are not counted but that some other related measure such as the number or weight of fibres or an area of skin is used to maintain follicle numbers constant.

The use of skin area to keep the follicle population constant is subject to errors caused by differences in follicle density between sheep, the measurement and calculation of skin area and changes in area due to stretching of the skin or changes in body weight. As skin area was used in this experiment, the effect of some errors on the results was determined.

The differences in follicle density between sheep were not measured in this experiment so that their effects on the results are not known. The errors involved in measuring and calculating the areas from which the position A samples were cut probably have little effect on the results as they are of insufficient magnitude to mask the large differences in kempiness between sheep. Nevertheless they require some consideration. The method of calculating area which has been intimated by Cockrem (personal communication) as losing little in accuracy as compared with the more laborious method of calculating true area, was shown to cause considerable deviations from true area. The mean value of these deviations, however, supports Cockrem's contention of there being little loss in accuracy from the use of this method.

The errors of measuring the sides of the sampled area were found to be small and unimportant as judged by the differences in areas. Although the relationship between repeat areas was significant, it was not very high possibly because of errors introduced in the calculation of area. This probably explains why the results were not strictly comparable with those achieved by Morely, Lockart and Davies (1955). They found a correlation of r = 0.96 between repeat measurements. These results do suggest, however, that the method of holding the sheep for sampling sufficiently stabilises its position to allow repeatable measurements to be made after short periods of time.

The cutting of different sized areas on different sheep assumes some importance in view of the marked variation in kempiness over small regions of the body. The larger the area cut, the more likely are significant differences in kempiness to occur. Hence, when the total number of kemps is estimated from one subsample, the estimated value of the total number of kemps in the area may not agree closely with the true number of kemps in the area. This applies particularly at Samplings I and IV when the size of subsample was found to be inadequate. The same problem arises when sampling at different sampling times. The different size of areas sampled indicates that the same follicle population is not sampled at different sampling times. However, this was obscured in this case by a probable loss in body weight which caused skin area to be reduced, i.e. follicle density increased.

The evidence indicates that the major problem to be overcome when sampling by the methods used in this experiment is the sampling of a different follicle population on different sheep and at different sampling times. In the latter case, it is suggested that a method of maintaining the follicle population constant between sampling times would be to sample the same area at all times. However, if the area is sampled frequently this method will increase the problems of distinguishing kemps from coarsely medullated fibres, due to the absence of easily discernible characteristics such as the tip and brush-ends from the kemps in the sample.

From a practical viewpoint, some knowledge of the variability of kempiness over the body of a ewe is important if one is trying to estimate the kempiness of the fleece.

Kempiness in the regions sampled in position A was found to be very variable. In other body regions, however, such variability was not apparent. On their face value, these results suggest that the mid-back region shows more variability than positions along the mid-line of the body. It is difficult to perceive why the follicles in one body region should show such variability in the number of kemps they produce. A possible alternate explanation of this occurrence is that the number of subsamples taken from the position A samples and the larger area from which position A samples were cut may have allowed differences in kempiness to be detected in the mid-back region and not the other body regions. Such variability over small regions of the body confirms Bryant's (1933, 1936) contention for the Blackface, that outside a region along the mid-line of the back there is much variability in kempiness. The variability of kempiness in Bryant's mid-back position could not be determined as the position was not sampled.

Although there is much variability in kempiness over small regions, gradients in kempiness were found to occur over the body in two age groups. As these gradients were determined from four positions only they need to be confirmed for more intensively sampled fleeces and for the older age groups studied. However, there is a considerable amount of evidence in the literature to support this finding.

The fibre type array gradients first described by Galpin (1934, 1936) and studied intensively by Stephenson (1952, 1956), imply that more primary follicles will be producing halo-hairs in the britch than in the shoulder regions. There is probably a genetic basis for these gradients as Stephenson (1952, 1956) has found that with increasing N-gene dosage, the least heavily checked regions showed an increase in halo-hair numbers before the most heavily checked regions. If the degree of shedding of halo-hairs in different regions occurs as described by Goot (1940) and if they are succeeded to any great extent by kemps, which is probable (Dry, 1940; Ross, 1945), then gradients over the body in kempiness are expected.

Darling (1932) has found similar gradients in adult Blackface sheep and this has been confirmed by Bryant (1933) and Burns (1953). Bryant, however, found much variability between sheep in the pattern of kempiness over the body. In this experiment, only minor variations of the pattern of kempiness over the body were indicated.

Further evidence of the existence of gradients can be interpreted from the coefficients of variation of subsamples taken from all positions at sampling I. It is logical to assume that the fewer kemps there are in a region, the greater are the errors in subsampling. Therefore, a higher coefficient of variation is expected in regions of least kempiness. As the results indicate the coefficients of variation decrease as the regions became more kempy.

It may be intimated from the foregoing evidence that the gradients indicated by the results are probably real and that they probably occur in all age groups.

In view of the variability of kempiness over small regions of the body, one does not expect the gradients to follow an orderly pattern down the body. That reversals of the gradient can occur, has been shown in the areas comprising position A for each age group. However, it should be pointed out that the antero-posterior gradient was only demonstrated in the region along the mid-side of the body which does not necessarily mean that the same gradient occurs along the back.

Nevertheless, the mere fact that such variation does exist between small areas suggests that the gradients only indicate general trends in kempiness over the body.

There is a paucity of information regarding the fundamental causes of gradients. However, an explanation of the gradients could be provided by a genetic situation similar to that described by Stephenson (1956) for his N-type Romney lambs. Other possibilities such as differences in the follicle blood supply of different body regions or differences in the rate of loss of shed kemps from the staples in different body regions might supply alternate explanations for the variability of kempiness in small regions and over the body. Unpublished data from Romney ewes, obtained by the Massey Agricultural College Metrology Laboratory, has indicated that the secondary follicle : primary follicle ratio increases toward the shoulder but that follicle density follows a reverse pattern and decreases toward the britch. Assuming that these patterns occur in the Cheviot a possible explanation of kemp gradients being due to differing primary follicle numbers in different body regions is not likely.

A problem raised by the variability of kempiness over the body of the ewe is the determining of the degree of kempiness in the fleece. In other words, can the degree of kempiness in a fleece be determined from the number of kemps in the wool at one easily identifiable region or does the whole fleece have to be examined? The practical significance of the answer to this problem lies in the ease with which kempiness in the fleece can be estimated for selection purposes.

This problem has received little attention by other workers. The results in this investigation showed that significant predictions of kempiness in the fleece (as indicated by the sum kempiness of the four positions) could be made at all sampling times from either the mid-back or mid-thigh regions sampled. On face value, the mid-thigh region gave best prediction of total kempiness. However, due to the way in which total kempiness was computed and the degree of kempiness of the mid-back and mid-thigh regions, there is probably little loss in accuracy from using the kempiness in either position for the prediction.

The variability of kempiness over the body suggests that only reasonable accuracy in the prediction of total kempiness would be obtained and this is verified by the size of the standard errors of estimate. Furthermore, the accuracy of prediction varied from sampling time to sampling time although not significantly so.

The ability of the kempiness in position A (mid-back) or position D (mid-thigh) to give a reasonable estimate of kempiness in the whole fleece is of some practical significance. Position D approximates very closely with position 5 which was found by Goot (1945) to give a good estimate of hairiness in the fleece of Romneys. If it can be assumed that the Cheviot has similar gradients in hairiness to Romneys, then both hairiness and kempiness can be estimated from the same region. If hairiness is not a problem, then it is usually easier to estimate kempiness from the mid-back region.

The overall pattern in the relationships between the kempiness of each region with kempiness in positions A or D is that the best relationships and prediction of kempiness occur between the most kempy regions. Conversely, the relationships and predictions of kempiness in regions showing little kempiness is generally poor.

A possible explanation of this situation is that, in regions of low kempiness, the greater error variance due to subsampling has resulted in a poor relationship with the most kempy regions. On the other hand, it may indicate that the extent to which kempiness spreads over the body, varies greatly. Thus sheep showing much kempiness in the mid-back or mid-thigh regions may or may not show much kempiness in the mid-shoulder region. Similarly, sheep showing little kempiness in the most kempy regions may show much kempiness in the mid-shoulder region. If this is the case, the mid-shoulder region is useful as Fraser Roberts (1926) found, in determining the extent of the spread of kempiness throughout the fleece.

The results also show that the prediction of kempiness in a region in the fleece becomes less accurate as the degree of kempiness in that region becomes less.

It follows from the foregoing evidence, that more efficiency in estimating the kempiness in the fleece would possibly be gained by predicting the kempiness of the fleece from either position A or D but to obtain a more accurate picture of the spread of kempiness over the body from position B. This method was considered the most useful for kemp estimation in the fleece of the Blackface by Darling (1932).

Another point of interest brought out by the results is that the accuracy of prediction for the same variables differs at different sampling times although in only one case were the differences significant. This case occurred in the three-year-olds. It should be pointed out that any conclusions reached for this age group must be regarded as tentative, as they are based on only five ewes. The conclusion reached in regard to the non-significant differences in accuracy of prediction, is that the accuracy of prediction of kempiness at any one sampling time is not very good. The use of position B as a check on the spread of kempiness throughout the fleece is, therefore, further vindicated.

The reason for such poor accuracy of prediction of kempiness is probably the variability of kempiness over the body and the differences in kempiness between sheep. Other factors such as differing rates of loss of shed kemps from differing body regions caused by differences in wool length, wool type, wind etc. may partly or wholly explain the results.

Significant differences in the accuracy of prediction at different sampling times suggests that at times when the accuracy of prediction is high, the changes in kemp population must be under the influence of the same factor. As the accuracy of prediction is significant at certain sampling times only, it may be that this factor has to reach a threshold value before the kempiness in the region (mid-shoulder) become predictable. This indicates that the factor may be of hormonal origin.

As the rate of progress in selection against kempiness will depend in part on the differences in kempiness between sheep, this is perhaps the most important finding of the investigation.

The considerable variation in kempiness between sheep indicated by research on the Scottish Blackface by Darling (1932) and Bryant (1933) was confirmed in this study for the Cheviot.

In the two-year-olds some part of the difference in kempiness between sheep was due to incomplete stabilisation of the variance by the logarithmic transformation. However, the major proportion of the differences between sheep were shown to be made up of shed kemps. Presumably, the presence of many shed kemps in the fleece in the mid-back region indicates that the sheep has the ability to produce many kemps. As this assumption depends on all or most of the shed kemps being retained in the fleece and no work has been published on this aspect, it is obvious that further research is needed to justify it.

There is some indirect evidence to show that length of wool grown may be the important fleece character determining whether kemps are retained in the fleece or not. The recutting of previously sampled areas indicated that the loss of shed kemps from short wool takes place within a relatively short time of shedding. It is possible therefore, for a sheep which grows many kemps, but does not retain them as the length of staple it grows is short, to miss selection as a kempy sheep. Whether this problem arises depends on the length of wool required to retain a shed kemp at the time when shedding occurs.

On this basis, an explanation of the extreme variability shown by the two-year-olds other than their greater capacity for kemp production, could be made on the fact that they were shorn some time previous to the other age groups. If a wave of kemp growth and/or shedding occurs during the autumn, as indicated by the results of this experiment and work on other breeds (Burns, 1953; Ryder, 1956), then the two-year-olds are better equipped by their longer length of wool grown, to retain shed kemps in the fleece.

Further evidence that shed kemps may be retained in the fleece for a considerable time is indicated by the non-significant differences in both shed and total kempiness between sampling times. Unless changes in the kemp population occurred unnoticed between sampling times, these results can be interpreted as indicating that the kemp population in the fleece remained relatively static over the experimental period.

The most important point arising from the preceding section is that although total kemps, i.e. growing and shed kemps, probably give a good indication of the ability of the sheep to produce kemps, it may not be the most accurate one as some fleece characteristics may influence the extent to which shed kemps are retained in the fleece. These factors will affect the kemp grading of the ewe.

Total kemps per sq. cm. as a measure of kempiness in the fleece, is however, of more practical significance to the manufacturer than shed or growing kemps per sq. cm. and is the easiest to estimate visually. Its use in future studies, therefore, would probably require some investigation into the rate of loss of shed kemps from the fleece or the factors causing kemps to be retained. Dry's (1934) method of using covers to retain shed birthcoat kemps in the lambs birthcoat may offer a possible solution to the problem of determining the rate of loss of shed kemps or retaining all shed kemps in the fleece.

It should also be pointed out that differences between sheep are really differences between position A on each sheep. Comparisons between sheep by means of other regions or with kempiness estimated for the whole fleece may give different results. However, as position A has been shown to have a reasonable relationship with total kempiness and with kempiness in each region but the mid-shoulder, the results are not likely to be markedly different.

Despite the lack of knowledge regarding the factors causing errors in the results, the extreme variability in kempiness between sheep must signify some difference in the kemp producing ability of sheep. If this contention is accepted, then the variability between sheep indicated in this investigation and others demonstrates the need for the inclusion of sufficient sheep in an experiment to allow valid conclusions to be drawn for the sheep population. Ryder's (1956) experiment on Masham sheep may be criticised for this defection.

The differences in kempiness between age groups are important as they indicate the age groups in which the greatest rate of progress in selection against kempiness will be obtained. The results indicated that the two and four-year-olds were the most kempy age groups. This is fortunate in that in many flocks, most intense selection for various factors is carried out on the two-year-olds.

These results do not agree closely with those presented in the literature. The kempiness in the age groups of the Cheviot follows a similar pattern to that described by Darling (1932) in the Blackface but in different age groups. Bryant's (1933) conclusions for the Blackface do not agree at all with the present results or those of Darling (1932).

It should be pointed out that these results are based on 17 sheep in each age group. The sampling of more sheep in each age group may give rise to different results, especially for the age groups showing the least kempiness. Insufficient numbers of sheep probably account for the non-significant differences in total kempiness in the fleece between the two and three-year-olds. Despite this, each age group ranked the same at each sampling time.

As the differences between age groups were shown to be mainly due to the presence of shed kemps in the fleece, it must again be assumed that the age groups showing the most kempiness are producing more kemps than the age groups of lower kempiness. That factors (such as longer wool) causing retention of shed fibres might be responsible for the differences between ages, has already been pointed out in the two-year-olds. Therefore these results should be confirmed.

The problem of determining the best time to distinguish kempy sheep from non-kempy sheep was confused by the non-significant differences in kempiness found between sampling times. This finding is contrary to the cycles of kemp growth and shedding indicated by the literature for various breeds. Thus, the cycles of kemp population change have been described as varying from all year round in the Karakul (Frölich et al 1929) to twice yearly cycles in the Blackface, Herdwick and Masham breeds (Burns, 1953, 1954b; Ryder 1956) to yearly cycles in the Welsh Mountain, Blackface and Limousin breeds (Fraser Roberts, 1926; Darling, 1932; Bryant, 1933 and Rougeot 1957).

The growth of kemps in the one cycle breeds has been reported as occurring over the summer and early autumn. Shedding occurs in the late autumn or winter. Sheep showing two cycles of kemp growth undergo one cycle of kemp growth over the summer which is shed in autumn and a further cycle in the late autumn-winter period which is shed in spring. Burns (1953, 1954b) considered that in the Blackface and

Herdwick breeds, these two cycles arose from the same physiological moult in autumn but that many shed fibres were held in the follicles until they shed in the spring.

As the Cheviot is classified by Lang (1942) with the Welsh Mountain breed in the evolution of British breeds, it may be expected to have only one cycle of kemp growth per year.

As there was little difference in kempiness between sampling times, the use of the variability of kempiness between sheep of different age groups at different sampling times was made use of to determine the best time for distinguishing kempy sheep from non-kempy sheep. The variance was found to reach a maximum at sampling II in all age groups. However, this is not necessarily the best time to make the most accurate predictions of kempiness in the fleece from the mid-back region. Nevertheless, any loss in the accuracy of prediction of fleece kempiness is likely to be made up by the more kempy sheep being more easily distinguishable.

The assumption that sheep showing more kempiness at one time have produced more kemps at that time than at other times, may not be valid in this case. The importance of shed kemps in making up the higher proportion of total kemps was again demonstrated. As there were no significant differences in shed kemps between sampling times, a possible conclusion is that the major part of the kemp population has grown and shed before the first sampling time and that most kemps were retained in the fleece for the experimental period.

However, changes in kemp population could have occurred unnoticed between samplings.

Conversely, as growing kemps were found at all sampling times, the rate of loss of shed kemps from the fleece and their replacement may be similar at all sampling times. Work by Wildman (1958) supports this, as he has found that there is a "base" growth and shedding of kemps. However, in the present investigation, the period elapsing between sampling times is too long to determine whether growing kemps occurred at all times in the experiment. Therefore, until the rate of loss of shed kemps from the staple has been determined and fuller investigations of changes, in total kemps per unit area over a year have been carried out the use of sampling II as the best time to distinguish kempy sheep, must be regarded with caution.

Another point arising from the results is that if the number of kemps in a fleece in the wool of the mid-back region remain relatively static over the experimental period, they could probably be expected to remain in the fleece until shearing. This finding is of some practical significance to the manufacturer.

As previously mentioned, the results suggest that the major part of the kemp population had grown before the first sampling time. Some evidence obtained in this study concerning this point is inconclusive but on the whole supports the above hypothesis.

The use of the regression of the weight of kemps per sq. cm. on the number of kemps per sq. cm. gave little indication that there were any great changes in growing or shed kemps in all age groups over the experimental period. There was some indication in the two-year-olds that a cycle of kemp growth was concluding about sampling I.

Further ratification of a cycle of growth during the autumn period is derived from the mean number of growing kemps at each sampling time. More growing kemps were found at samplings I and II than at samplings III and IV. However, as previously pointed out, this difference was small. The cycle of kemp growth indicated by these results about the time of sampling I (autumn) would agree well with work by other investigators of British breeds (Fraser Roberts, 1926; Darling, 1932 and Bryant 1933). This cycle is probably of hormonal origin as indicated by the work of Rougeot (1957) and may be super-imposed on the previously mentioned "base" kempiness. However, this "base" of kemp growth may have been the result of errors in the determination of growing kemps. It is possible for the kemps to shed yet be retained in the follicle as found in the Blackface by Burns (1953). As the brush-end or normal shedding (Dry, 1926; Frölich <u>et al</u>, 1929) was used to differentiate shed kemps from growing kemps, the cut ends of these kemps would be taken to indicate that they were growing. Furthermore, fibres shed as a result of some abnormality of the follicle (Burns and Auber, 1951; Auber and Ryder, 1955) or abnormal types of shedding (Rudall 1934) could also have resulted in undetermined errors of estimation of the numbers of growing kemps.

The recutting of previously sampled areas also provided some inconclusive information on the time that kemps grow into the fleece. The trends in the age groups studied showed that most sheep were increasing their kemp populations during the autumn and shedding them over the winter. A new cycle of kemp growth started growing during the spring. On this evidence, the period when most kemps are likely to be growing is the summer, i.e. if the Cheviot can be assumed to have one cycle of kemp growth per year (Fraser Roberts, 1926; Lang, 1942). Unfortunately, samples were not taken over this period so that no conclusions can be drawn regarding kemp growth during the summer.

There appears to be considerable individual variation in the growth and shedding of these fibres. This may be partly explained by waves of kemp growth or shedding passing down the body. Burns (1953) found some evidence of this in the Blackface. Such waves may start at different times in different animals so that although all animals are growing or shedding kemps, the sample may not show this, as it has been cut either before or after the wave has passed down the body. No evidence of such waves of kemp population change was obtained in this investigation. This does not preclude the possibility of waves of kemp growth or shedding passing down the body at intervals shorter or longer than the experimental ones.

A point of interest arising from this section is that growing kemps are probably a better indicator of cycles of kemp growth than shed and growing kemps, as the evidence suggests that growing kemps, when shed, are retained in the fleece for a considerable time. It is obvious that a definite decision can not be made as to the best time for the selection of kempy sheep until kemp population changes with time have been investigated more fully.

Few investigations have been made on the relationships of kemp and other fleece characteristics. Lockner (1931) reported a highly significant negative relationship between kemp and long hair in the Blackface ($r = -0.96$). Darling (1932) also investigating the Blackface, considered that the lack of hairiness in sheep showing much kempiness was not related.

Experimental results in this case have shown that kempiness is not correlated with the percentage medullation of the non-kemp portion of the sample. Only once did the correlation reach significance. This evidence implies that a kempy fleece is associated with little non-kemp hairiness. This conclusion is further substantiated by a negative correlation of mean fibre diameter with kempiness obtained for a very limited number of sheep. Thus the evidence confirms Lockner's (1931) findings.

In one sense, these findings support the theory (Fraser, 1952; Fraser and Short, 1952 and Fraser, 1953) that the earlier a follicle develops the more efficient it is. This efficiency enables it to compete effectively with other follicles for the wool substrate available and produce a hairier fibre. Since kemp fibres have been shown to be produced from the early formed follicles, i.e. follicles producing halo-hairs (Dry, 1935; Fraser, Ross and Wright, 1954, Wickham, 1958) it has been assumed that kemps are produced by the more efficient follicles. This results in the surrounding follicles being much less efficient so that they produce fibres of smaller diameter and, presumably, less medullation.

Other possible explanations are that kemps may be regarded as the extreme form of medullated fibres. As medullated fibres tend to grow in certain follicle types depending on the genotype, the higher the proportion of kemps, the fewer follicles are available for growth of non-kemp medullated fibres.

In the Cheviot, fleeces showing much medullation have many fibres showing fine medullation rather than a few fibres showing coarse medullation (Wickham, personal communication). This is further borne out by the estimation of numbers of medullated fibres which are sufficiently high to indicate that, in many cases, medullated fibres must be grown in secondary follicles. If the evidence that kemps are grown in primary follicles is correct, one may suppose that many medullated non-kemp fibres will be grown in secondary follicles. If this is the case, then a good relationship between the fibres produced by the two types of follicles is not necessarily expected. Similarly, changes in the primary follicle fibre population need not necessarily be related with changes in the secondary follicle fibre population in this breed. Ryder (1956) has demonstrated this in the Masham breed.

VI SUMMARY AND CONCLUSIONS

1. A preliminary investigation of kemp variability in the fleece of the Cheviot was carried out on two, three, four and five-year-old ewes. The 17 sheep in each age group were sampled in the mid-back region while 10 two-year-olds and five three-year-olds were sampled in the mid-shoulder, mid-side and mid-britch regions. All ewes were sampled four times over a period of nine months.

2. Four methods of measurement of kempiness were compared in an effort to determine the most suitable ones for the purposes of the experiment. These measures were:
   The number of kemps per unit area (sq. cm.)
   The weight of kemps per unit area (sq. cm.).
   The percentage weight of kemps.
   The number of kemps per gramme of wool.

3. The methods of measurement of kempiness were found to be comparable.

4. The measures selected were the number of kemps per sq. cm. and the number of kemps per g of wool.

5. It was shown that a logarithmic transformation of the data was necessary to justify the use of tests of significance.

6. Some errors associated with the collection of data for the measures were examined.

7. The mid-back regions on both sides of the body of three-year-old ewes were found to show comparable degrees of kempiness.

8. It was established that there was much variability in kempiness in different areas of the mid-back region.

9. An examination of the four positions sampled in some two and three-year-olds revealed dorso-ventral and antero-posterior gradients in kempiness. As reversals of the gradients were found to occur in the mid-back regions, the gradients can only be regarded as trends in kempiness.

10. The kempiness of the fleece, i.e. the sum of the four positions sampled was predicted equally well from either the mid-thigh or mid-back regions.

11. The accuracy of prediction was not found to be good, especially in regions of low kempiness. Therefore, a more accurate method of prediction, involving the inspection of either the mid-thigh or mid-back regions and the mid-shoulder region was suggested.

12. Significant differences in kempiness were found between the sheep in each age group and between age groups. The age groups showing the most kempiness were found

to be the two and four-year-olds.

13. The differences between sheep and between age groups were found to be mainly due to shed kemps being retained in the wool. The significance of this finding is discussed.

14. The largest differences in kempiness between sheep were found to occur at sampling II (late autumn)

15. Although significant differences in total kemps per sq. cm. at different sampling times did not occur, the number of growing kemps per sq. cm. indicated that more kemps were growing in the autumn and spring than in the winter. The summer period was not investigated. This conclusion must be regarded as tentative, however, until confirmed by further research.

16. A poor relationship was obtained between kempiness and medullation in the non-kemp portions of the samples. Furthermore, in a limited number of sheep, a negative relationship was found between the mean fibre diameter and kempiness.

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Appendix I (cont.)

Age (yr.)	Sheep No.	Sampling Order of sampling areas	I	II	III	IV	Mean	Antilog of Mean
Four			Area 1	2	3	4		
	2		2.900	3.576	3.572	2.524	3.143	139
	8		2.533	3.427	3.382	2.165	2.876	75
	9		2.546	2.585	2.641	2.005	2.444	28
	10		2.263	3.167	2.696	1.631	2.439	28
	15		1.416	0.965	1.509	1.509	1.350	2
			Area 2	3	4	1		
	1		2.938	2.444	1.507	1.540	2.107	13
	4		2.719	2.416	2.615	2.623	2.593	39
	7		2.562	2.051	2.093	2.556	2.316	21
	13		1.725	1.775	1.568	1.635	1.676	5
			Area 3	4	1	2		
	3		2.825	1.254	2.498	3.265	2.461	29
	5		2.649	2.106	2.487	3.249	2.622	42
	6		2.570	2.002	1.681	2.769	2.256	18
	14		1.632	1.994	1.229	2.203	1.765	6
			Area 4	1	2	3		
	11		1.905	2.776	3.130	3.224	2.758	57
	12		1.893	2.308	2.865	2.768	2.459	29
	16		1.207	1.124	2.037	1.601	1.492	3
	17		1.160	1.320	1.398	1.343	1.305	2

Age (Yr)	Sheep No.	Sampling Order of sampling areas	I	II	III	IV	Mean	Antilog of Mean
Five			Area 1	2	3	4		
	6		1.947	3.176	3.092	2.603	2.705	51
	9		1.605	2.505	2.000	1.665	1.944	9
	12		1.566	2.717	2.111	1.526	1.980	10
	14		1.196	1.157	1.159	1.964	1.369	2
	17		0.716	1.578	1.258	0.934	1.122	1
			Area 2	3	4	1		
	1		3.276	3.414	2.887	2.898	3.118	131
	2		2.872	3.352	3.043	2.885	3.038	109
	3		2.578	2.572	1.975	2.325	2.363	23
	5		2.290	2.124	1.673	1.541	1.907	8
	8		1.656	1.431	1.389	1.281	1.439	3
			Area 3	4	1	2		
	4		2.433	1.936	1.607	2.500	2.119	13
	7		1.908	2.036	2.075	2.927	2.237	17
	10		1.606	1.211	1.589	1.657	1.516	3
	15		1.080	1.014	1.354	1.005	1.113	1
	16		0.947	1.420	1.372	1.482	1.305	2
			Area 4	1	2	3		
	11		1.566	1.772	2.428	2.342	2.027	11
	13		1.343	1.381	1.825	2.231	1.695	5

Note: log 2.0 = antilog 10.0

APPENDIX I

Data for individual sheep in each age group for:

a. The order of sampling the areas in position A

b. The kempiness at each sampling time

c. The log mean kempiness and the antilog of the mean.

Method of Measurement of Kempiness: Total kemps per sq. cm.

Age (yr)	Sheep No.	Sampling Order of sampling areas.	I	II	III	IV	Mean	Antilog of Mean
Two			Area 1	2	3	4		
	2		3.564	3.877	3.785	3.701	3.731	538
	5		3.339	3.644	3.411	2.940	3.333	215
	9		2.525	3.850	3.905	2.513	3.198	158
	15		1.367	1.537	1.452	0.909	1.316	2
	16		1.009	2.489	1.806	1.623	1.732	5
			Area 2	3	4	1		
	3		3.446	3.667	2.835	2.188	3.034	108
	7		2.637	2.669	1.912	1.579	2.199	16
	10		2.162	1.886	2.072	1.888	2.002	10
			Area 3	4	1	2		
	1		3.590	3.686	3.128	3.861	3.566	368
	4		3.366	2.200	2.271	3.275	2.778	60
	6		3.022	1.833	2.344	3.336	2.633	43
	8		2.549	1.436	1.537	1.802	1.831	7
			Area 4	1	2	3		
	11		2.029	2.040	2.475	2.494	2.260	18
	12		1.986	1.578	1.981	2.607	2.038	11
	13		1.874	1.947	2.382	2.426	2.157	14
	14		1.386	1.629	1.949	1.813	1.694	5
	17		0.763	1.582	1.674	1.263	1.321	2

Age (yr.)	Sheep No.	Sampling Order of sampling areas.	I	II	III	IV	Mean	Antilog of Mean
Three			Area 1	2	3	4		
	2		2.282	2.911	3.238	2.500	2.732	54
	3		2.215	2.017	1.995	1.330	1.889	8
	5		1.742	2.447	3.114	2.351	2.414	26
	10		1.501	1.333	2.363	1.462	1.665	5
	16		0.668	2.061	2.209	1.738	1.719	5
			Area 2	3	4	1		
	1		3.005	3.436	2.690	2.626	2.939	87
	7		1.583	1.574	1.543	1.529	1.557	4
	11		1.444	1.241	1.347	0.556	1.147	1
	13		1.257	0.982	1.494	1.030	1.191	2
			Area 3	4	1	2		
	4		2.190	1.934	2.295	2.823	2.311	21
	8		1.546	1.463	1.461	1.456	1.482	3
	9		1.493	1.274	1.565	2.060	1.598	4
	15		1.089	1.249	1.116	1.303	1.189	2
	17		0.486	1.655	1.522	1.497	1.290	2
			Area 4	1	2	3		
	6		1.673	1.757	1.820	1.733	1.746	6
	12		1.293	1.259	1.512	2.135	1.550	4
	14		1.188	2.551	2.651	2.149	2.135	14

Note: log 2.0 = 10.0