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WINTER HAIR COAT PARAMETERS OF PREGNANT BEEF COWS FROM BRITISH AND EXOTIC ORIGIN

BY

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A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
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ABSTRACT

Insulation afforded by the pelage is thought to be a factor influencing the winter maintenance requirements of pregnant beef cows. Two experiments were conducted in consecutive winters to determine if there were differences in pelage characteristics among breed crosses.

Hair weight per unit area, hair length, and hair depth were measured throughout the winter on pregnant beef cows from fifteen breed crosses, which varied in their proportions of British (Hereford, Angus, or Shorthorn) and exotic (Charolais or Simmental) parentage. Ultrasonic determinations of subcutaneous fat thickness were also measured monthly.

In both experiments, the standard breed cross, Hereford x Angus, had shorter hair length (p=0.04), coupled with thicker subcutaneous fat (p=0.0001), than all other breed crosses. Breed crosses of predominantly exotic origin had longer hair length (p=0.0001), deeper pelage depth (p=0.0001), heavier hair weight (p=0.05), and thinner subcutaneous fat depth (p=0.0002) at the beginning of the winter than British breed crosses and Hereford x Angus. Exotics may have commenced growth of the winter pelage earlier than British breed crosses because of low condition as suggested by low ultrasonic subcutaneous fat measurements.

Younger cows had longer hair length, greater hair weight, and thinner ultrasonic subcutaneous fat depth at the beginning of the winter than older cows. The difference in hair weight between ages may be strictly a consequence of a difference in body size coupled with a stable hair follicle population, but the differences between ages in hair length and ultrasonic subcutaneous fat depth suggest that younger cows commenced growth of the winter pelage earlier than older cows.

The experiments did not extend late enough into the spring to compare the time of cessation of winter hair growth and the onset of spring shedding in the different breed crosses.

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GENERAL INTRODUCTION

The role of the pelage in climatic adaptation of beef cattle suited to production in the tropics has been well established, but relatively few comparative studies have been conducted on pelage differences among beef cattle selected for production in Western Canada.

Hereford, Angus, and Shorthorn breeds have long been the mainstay of the Canadian beef industry, and the Hereford x Angus cross, noted for its lifetime reproductive capabilities, overwinters well even under harsh range conditions.

The introduction of rapidly-growing, lean-carcassed European breeds in the 1960's and early 1970's spawned a new interest in crossbreeding to enhance production. Various crosses of the new European and the traditional British breeds have been previously evaluated in the initial phases of the Foreign Cattle Breed Evaluation (F.C.B.E.) program, in terms of reproductive capability (Fredeen _et al_. 1981), performance of calves (Fredeen _et al_. 1982), and carcass characteristics (Rahnefeld _et al_. 1985), but, to date, a large scale study of the comparative winter hardiness of these breed crosses has not been completed.

Fifteen breed crosses of pregnant beef cows, varying in their proportions of British (Hereford, Angus, or Shorthorn) and exotic (Charolais or Simmental) parentage, were assessed for comparative winter maintenance requirements in phase IV of the F.C.B.E. program. The purpose of the present study was to examine pelage parameters which estimate insulative quality of these breed crosses over the winter, and to determine the effect of breed cross upon pelage parameters and upon the time of spring shedding, which appears to be dependant upon the degree of cold stress. The study consisted of two experiments, conducted during consecutive winters, on cows penned under feedlot conditions. The pelage parameters measured at monthly intervals throughout the winter were hair weight per unit area, hair fibre length, and pelage depth.

LITERATURE REVIEW

1.1 INTRODUCTION

The ability of an animal to seasonally adapt to a cold environment is determined in part by the extent to which heat loss can be reduced by an increase in insulation (Scholander et al. 1950). Thermal insulation can be discussed in terms of internal and external insulation.

1.1.1 Internal Insulation

Internal insulation is composed of the outer tissues of the body, the skin and the subcutaneous fat. The insulation offered by sparsely-haired skin can be altered by vasomotor control of capillary blood flow (Goodall 1955). Nay and Hayman (1963) found that there were highly significant differences in skin thickness of dairy cattle between summer and winter. The actual thickness of the skin layer itself may afford some small degree of insulation.

The thickness of the subcutaneous fat layer also plays a role in insulation (Mount 1979). Subcutaneous fat is of particular importance in arctic marine mammals, where it is the principal insulating material (Scholander et al. 1950), but in terrestrial mammals it is thought to be primarily an energy source (Folk 1974).

Dowling (1955) reported that certain strains of cattle, such as the early maturing Bos indicus, are disposed to lay down more subcutaneous fat than others, which acts as passive insulation and is of importance in cold adaptation. Webster et al. (1970), however, found no differences in skin and subcutaneous fat insulation among heifers housed indoors at 20°C, housed throughout the winter in outdoor pens with shelter, and housed throughout the winter in outdoor pens without shelter, even though the winter was severe. In this study, heifers consumed an average of 9.0, 11.3, and 10.9 g hay per kg body weight in the control, sheltered, and exposed groups, respectively, while all heifers were offered a standard amount of grain daily.

1.1.2 External Insulation

External insulation is provided by the pelage. Seasonal pelage changes to alter insulative quality are usually quite conspicuous (Gessaman 1979).

The degree to which the volume of the pelage can be increased in the winter is limited by the relative body size of the animal (Scholander et al. 1950; Herrington 1951; Hart 1956; Folk 1974). Scholander et al. (1950) demonstrated that in mammals smaller than a fox, a thick pelage would severely hamper mobility. The limit of effective insulation per unit thickness is reached rapidly in animals with a large relative surface area, and may actually contribute to heat loss (Herrington 1951; Folk 1974). Thus, small animals, which have a large ratio of surface area to body size, are unable to greatly increase their pelage (Herrington 1951). In larger mammals, however, the relative contribution of pelage insulation increases as the absolute size of the animal increases (Scholander *et al*. 1950; Hart 1956).

The maximum insulative capacity of the winter pelage is dependent upon physiological regulation of the pelage in response to photoperiod or the need to conserve heat (Turner 1964), and upon genetic capacity for hair growth (Bianca *et al*. 1974). This is clearly evident in the inherent pelage growth differences between the temperate *B*. *taurus* type of cattle and the tropical *B*. *indicus* (Turner 1964; Bianca *et al*. 1974; Mount 1979). Brody (1956) referred to the Wilson rule which states that there exists a gradient from thick, wooly coats in cold climates to short, smooth coats in tropical climates. Differences in inherent coat qualities among breeds within a species have also been observed (Schleger and Turner 1960; Bianca *et al*. 1974; Dragnev and Zdravkov 1977).

The following sections include a review of hair coat growth characteristics, physiological regulation of hair coat in response to environmental conditions, and methods used to assess hair coat insulative quality.

1.2 HAIR FOLLICLE CYCLE

1.2.1 Morphology

Histological studies of the skin of Ayrshire cattle (Findlay and Yang 1950), beef cattle of the Aberdeen Angus, Devon, Hereford, and Shorthorn breeds (Carter and Dowling 1954), various crosses of *B. taurus* cattle (Lyne and Heideman 1959), as well as over 1300 cattle of twenty different breeds from various regions of Europe (Jenkinson and Nay 1972), have firmly established the presence of a single type of hair follicle that is common to all cattle. While the formation of both primary and secondary hair follicles is observed in other domestic mammals, such as sheep (Lyne and Heideman 1959), in cattle, only a primary hair follicle is found (Findlay and Yang 1950).

The hair follicle in cattle is always associated with an apocrine (sweat) gland, a holocrine (sebaceous) gland, and arrector pili muscle (Findlay and Yang 1948, 1950; Carter and Dowling 1954; Lyne and Heideman 1959; Jenkinson and Nay 1972). The medulla of the hair fibre is usually narrow (Ryder 1973), and is more apparent in hair fibres of the summer, compared to the winter, pelage (Dowling 1959a). No branching of follicles (Lyne and Heideman 1959) or grouping of follicles (Carter and Dowling 1954), as found in sheep, has been observed in cattle.

1.2.2 Hair Growth Cycle

Individual hair follicles and their associated hair fibres experience phases of growth and rest in a cyclical fashion (Dowling and Nay 1960; Ebling and Johnson 1964; Roth 1965; Schleger 1966; Meyer et al. 1980), which allows for the replacement of worn hairs and the provision of morphologically distinct coats for summer and winter (Ryder and Kay 1973).

The phases of the hair follicle growth cycle are widely viewed as three-fold: anagen, which involves the regeneration of the follicle after the shedding of the old hair fibre and the active growth of the new hair fibre; catagen, the transitional phase which allows for the retrogression of the follicle and keratinization of the hair root; and telogen, which is the inactive, resting phase (Ebling and Johnson 1964; Roth 1965; Ryder 1973). Others authors have further subdivided these three main phases into either six (Neurand et al. 1980), or eleven (Schleger 1966) phases, or have proposed renaming the phases of the follicle cycle (Chase 1965).

The growth of cattle hair occurs in a diffuse manner, in that there is never complete synchrony of follicular activity in the entire pelage (Ebling 1965). The average rate of growth is two complete cycles per follicle each year (Hayman and Nay 1961; Turner and Schleger 1970). The cyclical nature of hair follicle growth is seasonally-regulated (Turner and Schelger 1970). The nature of the relationship between season and follicular cyclical activity is discussed in detail in the next section.

1.3 SEASONALITY OF THE PELAGE

1.3.1 Effect of Season Upon Follicle Activity

The average rate of hair production of two hairs per follicle per year is not constant throughout the year, but rather, varies markedly with the season. Dowling and Nay (1960) reported a variation in the percent of active follicles from an average of 27% in winter and 36% in summer, to an average of 47% in spring and 72% in autumn. Ebling (1965) reported that, although never quiescent in cattle, the hair coat is most stable in winter, when the majority of follicles are in the resting phase, while the summer coat contains a high proportion of active follicles.

Turner and Schleger (1970), by measuring the percentage of new hairs as opposed to previously-grown hairs on shaved cattle skin, quantitatively determined the rate of hair replacement and the length of the hair cycle throughout the year. They found that the rate of replacement of hairs was highest in spring and summer and that the length of time during which each hair grew was shorter in summer than in autumn. Hairs initiated during the late summer to early autumn had a growth phase two-and-a-half to four times longer than that of those initiated during the late winter and spring (Turner and Schelger 1970). Besides having a longer growing phase, the hairs initiated during autumn were found to be morphologically different from those initiated during spring (Dowling 1958; Neurand et al. 1980). Follicles produced a thick hair fibre in spring, which grew for a short period, while in late summer to early autumn follicles produced a thinner hair fibre with a longer actively-growing phase (Dowling and Nay 1960). Two distinct pelages are thus found during the year: summer pelage with short, thick hair and winter pelage with long, thin hair.

1.3.2 Photoperiodic Control of Hair Growth and Shedding

Yeates (1955) demonstrated that photoperiod was the major regulating factor of the hair coat cycle of cattle by reversing daily photoperiodic patterns to simulate the decreasing daylength of the opposite hemisphere, which was approaching winter. The animals exposed to this light regime developed coats which were characteristic of winter pelage, despite the onset of warm environmental temperatures.

By eliminating the effects of photoperiod, first through the imposition of a light regime simulating equatorial regions (Yeates 1957), then by performing experiments under actual equatorial conditions (Yeates 1977), it has been demonstrated conclusively that changes in photoperiod are necessary to induce cyclicity in the hair coat of cattle.

Equatorial photoperiod eliminated the natural coat cycle of the cattle. Instead, a short-term change in coat type occurred, and the change observed depended upon the time of year that the cattle were subjected to the equatorial photoperiod. The short-term change in coat was followed by the retention of an intermediate length pelage (Yeates 1957).

The increase in the insulative quality of the pelage during the winter is a function of both a longer growth cycle and reduced shedding. Although there is continuous shedding of hair throughout the year, in temperate climates cattle undergo cycles of diffuse shedding interspersed with periods of profuse shedding (Yeates 1955). The seasonal cycle of pelage changes is characterized by two major peaks of shedding, in the spring and in the autumn (Dowling and Nay 1960). During these peaks, the entire pelage is almost completely replaced (Hayman 1965).

Lengthening photoperiod stimulates the spring shed (Yeates 1955), while decreasing photoperiod triggers the less dramatic autumn shed (Hayman and Nay 1961). The onset of spring shedding has been reported to occur ten to twelve weeks (Yeates 1955), five to ten weeks (Hayman and Nay 1961), and six to nine weeks (Neurand et al. 1980) following the winter solstice in a temperate environment. The duration of the spring shed, the time during which the change from full winter to full summer pelage occurs, is approximately four months (Hayman and Nay 1961). Less time is required for the autumn shed (Hayman and Nay 1961). Autumn shedding has been reported to begin in mid-August and to end in October (Neurand et al. 1980).

1.3.3 Influence of Temperature on Pelage Cycle

Although photoperiod is the major controlling factor in hair coat cyclicity, the modifying role of ambient temperature upon the hair shedding mechanism has been emphasized (Meyer et al. 1980; Blaxter 1982). A study by Webster et al. (1970) showed that environmental temperature had no influence upon rate of hair growth, but the results did indicate that low environmental temperatures reduced shedding. Control heifers were kept indoors at 20°C, while sheltered and exposed groups of heifers were kept outdoors at a mean ambient temperature of -28°C. All groups were exposed to natural photoperiod. Rate of growth of new hair was measured on skin that was clipped repeatedly, while total hair cover was determined from previously unclipped areas of the skin. The rate of growth of new hairs was similar in all groups, but the total hair cover of the cattle kept outdoors was twice that of controls. This increase was attributed to reduced shedding due to exposure to the cold.

McDowell et al. (1960) found that a group of Shorthorn heifers exposed to 32.2°C under conditions of natural photoperiod shed the winter pelage in January and again in April, while the control heifers exposed to prevailing Maryland temperatures shed once in April.

Berman and Volcani (1961) and Murray (1965) independently studied the effect of temperature upon shedding in cattle under conditions of equal daylength but different temperatures. Murray (1965) maintained two groups of Aberdeen Angus at two locations of equal latitude (equal daylength), but differing seasonal temperatures. Cattle maintained in the warmer locality shed the winter pelage three months earlier than those maintained in the cooler locality. Both groups were fed to achieve comparable weight gains. Berman and Volcani (1961) measured differences in hair weight per unit area and hair coat thickness in dairy herds kept within one small geographical area, but in regions of differing climates. Mean hair weight and pelage thickness were significantly lower in the hot valley region, as opposed to the moderate coastal plain and the cool mountainous region.

Bianca *et al*. (1974) found that the development of a short summer coat which was noted in stall-housed cattle was not apparent in cattle kept on alpine pasture. This may have been the result of lower environmental temperature or possibly poorer nutrition in the alpine environment.

1.3.4 Influence of Nutrition Upon Seasonality of Pelage

The level of nutrition provided to cattle is thought to influence hair growth and shedding. Yeates (1958) found that Shorthorns which were fed a restricted ration of twenty-five percent of the quantity of lucerne hay which was fed to controls, as well as enough wheat straw to maintain body weight, retained their winter coats throughout the summer. When the cattle were returned to full feed, the spring shedding was completed normally. Hayman (1965) induced an early commencement of winter hair growth in cattle by restricting energy intake. Control cattle were fed lucerne hay and crushed grain *ad libitum*, while test cattle were fed a restricted ration of lucerne hay to induce a steady weight loss. The winter pelage of these animals was both longer and coarser than that of the control cattle and was retained into the late spring. Thus restricted feeding influenced both growth and shedding.

Yeates (1958) reported that retention of the winter pelage, caused by low energy intake, was characterized by a dull-lustred pelage and suggested that, although the hair was mechanically retained in the follicle, it may have been functionally severed. Although the physiological effect of nutrition upon hair coat cyclicity is not clear, Yeates (1958) speculated that the shedding process may have two components: a photoperiodically-regulated hair fibre severance, followed by a nutritionally-controlled release from the follicle.

The influence of temperature and nutritional status upon the hair shedding mechanism of cattle would appear to be important modifiers of the photoperiodic control of pelage cyclicity and may play a critical role in the adaptation of cattle to cold climates.

1.4 INSULATIVE QUALITY OF THE PELAGE

The hair coat acts as a physical barrier between an animal and the environment to impede heat loss from the animal. The amount of protection against heat loss that the hair coat offers the animal is determined by the inherent thermal insulation of the pelage (Mount 1979). Total thermal insulation of a barrier is the total resistance to heat transfer from one surface to another, and is equal to the reciprocal of thermal conductance, or the ability of a barrier to transfer heat from one surface to another (Berry and Shanklin 1961).

1.4.1 Physical Processes of Heat Transfer

Heat is transferred from the body of an animal to the environment by four physical processes: conduction, convection, radiation, and evaporation. Since evaporative heat loss predominates under warm conditions and is negligible under cold (Mount 1979), non-evaporative heat transfer only will be discussed.

Non-evaporative heat transfer follows three processes: conduction, convection, and radiation. Heat loss by conduction depends upon the temperature gradient between the body and the surface with which it is in contact,surface area of conducting surfaces, and conduction coefficient (Hardy 1979). Convection, both natural and forced, is based upon differences in density in the air surrounding a body (Bligh and Johnson 1973). When cooler air comes into contact with a warm surface, it is rapidly warmed. As the warm air has a lower density, it then rises and is replaced by cooler air. This establishes convection currents and maintains the temperature gradient between the warm surface and the surrounding air (Hardy 1979). Radiant heat, in the form of electromagnetic waves, is exchanged freely between objects, with the net direction of the exchange dependent upon the temperature differences between the objects and the amount of effective radiating surface (Bligh and Johnson 1973; Hardy 1979).

1.4.2 Air Interface

The layer of still air between the surface of the coat and the environment (the air interface) offers resistance to heat transfer by convection and radiation. This resistance is determined from the temperature gradient between the coat surface and the environment (Finch 1986). The importance of the air interface is evident from the fact that forced convection, which destroys the interface, results in an increase in the rate of heat loss in cattle and sheep (Ames 1974; Ames and Insley 1975). Ames and Insley (1975) found a non-linear response in heat loss to increases in wind velocity in cattle and sheep. Low wind velocities destroyed the air interface, causing an increase in the rate of heat loss.

Higher wind velocities caused separation of the hair fibres and further increased the rate of heat loss.

1.4.3 Transfer Processes in Animal Coats

Gonzalez-Jimenez and Blaxter (1962) found that the insulative value of the hair coat of calves was at least half that of still air. Heat transfer processes through the pelage of hair-bearing animals are more complex than the processes employed in the absence of hair, which are simply convection from the skin to the surrounding air and radiative exchange (Cena and Monteith 1975). In the presence of pelage, heat may be transferred by: (1) conduction along individual hair fibres, (2) natural and forced convection of air between the hair fibres, (3) conduction through the air entrapped between the fibres of the pelage, and (4) radiative exchange between individual hairs and the environment (Hammel 1955; Cena and Monteith 1975; Cena and Clark 1978).

1.4.3.1 Conduction Along Fibres

The quantity of heat transferred by conduction along the hair fibres is relatively small (Davis 1972; Cena and Monteith 1975; Cena and Clark 1978), as the hair fibres are fairly randomly distributed and conduction depends upon contact between them (Davis 1972). Berry and Shanklin (1961) suggested that, as the number of hairs increases, conduction along the fibres is also increased due to the greater fibre to fibre contact.

1.4.3.2 Natural and Forced Convection

Hammel (1955) demonstrated that heat is transferred through the pelage by natural convection.

If pelage is disrupted by wind, insulative quality is reduced dramatically (Davis 1972; Ames 1974; Ames and Insley 1975). Ames and Insley (1975) found that at wind speeds of greater than 40 $km.h^{-1}$, the pelage fibres are separated, resulting in greatly increased heat transfer. Thus, insulation of the pelage is highly dependent upon a low degree of forced convection within the coat.

1.4.3.3 Conduction Through Trapped Air

Davis (1972) felt that heat transfer through the pelage occurs primarily via conduction through the air among the fibres, but others (Hammel 1955; Cena and Monteith 1975; Cena and Monteith 1978) feel that natural convection plays a more important role than conduction.

1.4.3.4 Radiative Exchange Between Hairs

The role of radiative transfer between hair fibres has been deemed negligible by some researchers (Hammel 1955; Davis 1972), but has been found by others (Cena and Monteith 1975; Cena and Clark 1978) to be significant. Dowling (1959a) suggested that the prominently medullated hair fibres of the summer pelage reflect solar radiation more effectively than the less medullated hair fibres of the winter pelage.

1.4.4 Mechanisms for Reducing Heat Transfer by the Pelage

The stagnant air that is stabilized among the hair fibres, by nature of the highly insulative quality of still air, provides the pelage with its thermal capacity (Herrington 1951; Dowling 1958). Finch (1986) reported that, at a depth of one centimeter, the greater number of fine wool hairs in sheep pelage compared to cattle pelage allowed for more air spaces among the hairs. This resulted in a two- to three-fold greater insulation value of sheep, compared to cattle, pelages. Variation in hair length may help to stabilize insulating air. Dowling (1958) postulated that the high insulative quality of the winter coat of cattle is due to a high degree of variation in fibre lengths in autumn and early winter coats.

Davis (1972) found that the structure of the pelage, specifically the arrangement of the hair fibres within the pelage, contributed to the thermal characteristics of the coat presumably by the influence that fibre arrangement has upon the air spaces within the pelage.

The effectiveness of the pelage can be controlled to a certain extent by altering the angle of the hair fibres relative to the skin, thereby increasing the thickness of the trapped air layer (Hardy 1979). Hammel (1955) estimated that piloerection of the fur of various species of mammals decreased the insulation per unit thickness of the pelage by ten to fifteen percent, but increased the total insulation by ten to fifteen percent. He speculated that piloerection increased the thickness of the pelage and thereby increased the total insulation, while simultaneously increasing the opportunity for convection, thereby increasing thermal conductivity.

Findlay and Yang (1948) noted that, in skin sections of Ayrshire cattle, the arrector pili muscle was located at an obtuse angle, and suggested that contraction of the arrector pili muscle not only causes piloerection of the hair, but also exerted pressure on the capillaries. This could supplement cutaneous vasoconstriction to decrease heat loss.

1.5 CRITERIA FOR DETERMINING INSULATION OF THE PELAGE

External and internal insulation of live cattle can be determined according to the formulae used by Webster *et al.* (1969)

$$It = (Tr - Ts)/Hp$$

$$Ie = (Ts - Ta)/(Hp - 0.3)$$

where It = tissue insulation ($^{\circ}C.m^{2}.d.Mcal^{-1}$),

Ie = external insulation ($^{\circ}C.m^{2}.d.Mcal^{-1}$),

Tr = rectal temperature (°C),

Ts = the mean of skin temperature measured at eight sites (°C),

Ta = air temperature (°C),

Hp = heat production, determined by respiratory exchange (Mcal.m$^{2-1}$.d^{-1}),

0.3 = constant for evaporative heat loss in cold environments.

A more practical method to estimate the external insulation is by measurement of pelage physical parameters. The measurable qualities of the hair coat of live cattle are depth of the coat, length of the hair fibres, weight of hair per unit area of body surface, numbers of hairs per unit area of body surface, and diameter of hair fibres. These parameters have all been measured in attempts to estimate which parameters, if any, reflect the insulation of the pelage. Although an exhaustive amount of literature has been generated in the search for a definitive measurement which accurately reflects the insulation of the pelage, much contradiction remains as to which parameters and which locations on the animal yield the soundest estimate of pelage insulation. The following is a review of the pertinent hair coat parameters that have been quantitatively measured, the problems associated with obtaining these measurements, and the logic associated with relating these measurements to insulation. Only those parameters that can conceivably be measured _in situ_ or from hair samples obtained from live, unanaesthetized animals are considered.

1.5.1 Pelage Depth

Depth of the hair coat is a measure of a characteristic of the entire pelage as an integral whole, rather than a measurement of the individual hair fibres. Schleger and Turner (1960) described coat depth as a function of length of individual hairs, the curvature of the hairs, and their angle of attachment to the skin.

Depth measurements have been made on fresh or tanned hides (Scholander *et al.* 1950; Hart 1956; Bennett 1964; Davis 1972; Jacobsen 1980), or *in situ* by either reading from some type of ruled gauge held perpendicular to the skin (Schleger and Turner 1960; Berry and Shanklin 1961; Gonzalez-Jimenez and Blaxter 1962; Webster *et al.* 1970) or by using callipers (Berman and Volcani 1961).

The question of which location or locations on the live animal gives the best representation of the depth of the entire pelage continues to plague researchers. Mid-side (Schleger and Turner 1960), thigh (Berman and Volcani 1961), hip (Berry and Shanklin 1961), and mid-flank (Young 1969) have been used as locations for depth determination. Some researchers have made simultaneous depth measurements at numerous locations on the trunk (Gonzalez-Jimenez and Blaxter 1962; Webster *et al.* 1970; Davis 1972; Jacobsen 1980) and the extremities (Webster *et al.* 1970; Jacobsen 1980).

Ruminant pelage depth is greater in the winter than the summer (McDowell _et_ _al_. 1960; Berman and Volcani 1961; Jacobsen 1980). Hart (1956), in his classical experiment using summer and winter pelts of various mammals, concluded that the change in fur depth between seasons was the primary factor with respect to seasonal changes in coat insulative quality.

The direct measurement of heat transfer (the inverse of insulation) through the pelage, by use of a hot plate or similar apparatus, has shown insulation to be highly correlated with depth of pelage (Scholander _et_ _al_. 1950; Hart 1956; Bennett 1964) and the relationship was linear (Jacobsen 1980). The direct measurement of heat transfer through the pelage _in_ _situ_ with a heat flow meter also revealed a linear relationship between insulation and pelage depth (Berry and Shanklin 1961).

Although the nature of the measurement of coat depth makes it naturally quite arbitrary, many researchers agree that depth _per_ _se_ has a major influence on insulation (Hart 1956; Schleger and Turner 1960; Berry and Shanklin 1961; Bennett 1964; Mount 1979; Jacobsen 1980) presumably because a deep coat has the ability to stabilize more air.

1.5.2 Length of Hair Fibres

Length of hair fibres has been measured both *in situ* using a ruled gauge inserted parallel to the hair fibres (Berry and Shanklin 1961; Davis 1972; Jacobsen 1980) and with the aid of a microscope after removal of the hair from the animal (Dowling 1956, 1958, 1959a; Schleger and Turner 1960; Hayman and Nay 1961; Bennett 1964; Peters and Slen 1964; Pan 1964; Turner and Schleger 1970; Bianca *et al*. 1974). Measurements of hair length have been made at the mid-side location (Dowling 1956, 1958, 1959a; Hayman and Nay 1961), the last intercostal space (Schleger and Turner 1960; Turner and Schleger 1970), the hip (Berry and Shanklin 1961), and the left and right mid-rib (Peters and Slen 1964). Some researchers have made simultaneous length measurements at numerous locations on the trunk (Pan 1964; Davis 1972; Bianca *et al*. 1974; Jacobsen 1980) and the extremities (Pan 1964; Bianca *et al*. 1974; Jacobsen 1980). Pan (1964) critically examined the variation in hair fibre length over the body in Jersey cattle, and, of the twenty-one locations tested, found the hip location most representative of mean hair length.

The number of length measurements taken *in situ* ranged from four measurements at each of eleven locations (Jacobsen 1980) to twenty measurements at a single location (Davis 1972), while the number of hair fibre lengths determined with a microscope ranged from 130 hairs per location to 250 hairs from a single location (Dowling 1956, 1958, 1959a).

There has been no critical evaluation of the optimum number of hair fibres required for the microscopic determination of hair length, nor of the optimum number of measurements per location for *in situ* hair length determination, although Pan (1964) suggested using several locations spanning a line from the lower neck to the hip.

Researchers who measured differences in hair lengths between summer and winter coats discovered that winter coats were comprised of much longer hairs (Dowling 1958, 1959a; Hayman and Nay 1961; Bianca *et al.* 1974; Jacobsen 1980). Increases in hair length from summer to winter were reported as one-and-a-half (Jacobsen 1980) to three-fold (Dowling 1958). As well, when hair fibre length was measured in conjunction with the direct measurement of heat transfer through the pelage it was found that hair insulation was proportional to length (Berry and Shanklin 1961; Jacobsen 1980). This has been supported by the work of Bennett (1964) who reported a high positive correlation between pelage insulation and hair length.

1.5.3 Weight of Hair Per Unit Area

Weight of hair per unit area has often been measured to estimate insulative quality of the pelage, as it is a measurement which is a function of hair length, diameter, and number of hairs per unit area (Schleger and Turner 1960). Hair weight per unit area has been positively associated with hair length (Dowling 1956, 1958, 1959a; Schleger and

Turner 1960; Berry and Shanklin 1961; Hayman and Nay 1961; Bennett 1964; Peters and Slen 1964; Bianca _et al_. 1974) and with coat depth (Schleger and Turner 1960; Berman and Volcani 1961; Berry and Shanklin 1961; Bennett 1964; Webster _et al_. 1970), both of which are linearly related to insulation.

Berry and Shanklin (1961) and Bianca _et al_. (1974), using modified pliers, pulled the hair from an area of known size to determine the weight of hair per unit area. The hair has also been shaved from an area of known size (Dowling 1956, 1958, 1959a; Schleger and Turner 1960; Berman and Volcani 1961; Hayman and Nay 1961; Bennett 1964; Peters and Slen 1964; Pan 1964; Webster _et al_. 1970; Turner and Schleger 1970; Davis 1972). The location or locations on the animal which are most representative of the weight of the entire pelage has not been resolved. Hair weight per unit area has been measured at mid-side (Dowling 1956, 1959a; Hayman and Nay 1961), the last intercostal space (Schleger and Turner 1960; Turner and Schleger 1970), thigh (Berman and Volcani 1961), and hip (Berry and Shanklin 1961). Some researchers have made multiple hair weight determinations at locations on the trunk (Dowling 1958; Peters and Slen 1964; Pan 1964; Webster _et al_. 1970; Davis 1972; Bianca _et al_. 1974) and extremities (Bianca _et al_. 1974).

When hair weight per unit area of body surface has been measured in conjunction with direct measurement of heat transfer through the pelage, it has been found that weight of hair per unit area correlates highly with insulation (Bennett 1964) and the relationship is linear (Berry and Shanklin 1961).

Hair weight has been shown to increase at least two-fold from summer to winter (Dowling 1956, 1958, 1959a; Berman and Volcani 1961; Hayman and Nay 1961; Pan 1970). Hair weight per unit area depends upon hair length (Dowling 1958, 1959a; Schleger and Turner 1960; Hayman and Nay 1961; Peters and Slen 1964; Bianca et al. 1974), number of hairs (Schleger and Turner 1960; Peters and Slen 1964), hair fibre diameter (Dowling 1959a; Schleger and Turner 1960; Berman and Volcani 1961; Turner and Schleger 1970), and degree of medullation (Dowling 1959a; Turner and Schleger 1970; Bianca et al. 1974).

The relative importance of these factors in influencing hair weight per unit area is not clearly understood (Schleger and Turner 1960; Berman and Volcani 1961; Hayman and Nay 1961; Turner and Schleger 1970). There is some contradiction in the literature as to the effect of season upon the hair fibre diameter. Dowling (1959a), Berman and Volcani (1961), and Bianca et al. 1974) found that fibre diameter was greater in the summer than in the winter and Dowling (1959a) and Bianca et al. (1974) showed the increase in diameter to be associated with an increase in medullation. Dowling (1958) and Hayman and Nay (1961) found no change in diameter between seasons. Turner and Schleger (1970) found that in unmedullated hairs an increase in diameter was associated with an increase in hair weight per unit area, but at the same diameter medullated hairs reduced hair weight.

Hair fibre diameter has been measured, with the aid of a microscope, from hair samples removed from the mid-side (Dowling 1956, 1958, 1959a), the last intercostal space (Schleger and Turner 1960; Turner and Schleger 1970), and the thigh (Berman and Volcani 1961), as well as from unspecified locations (Berry and Shanklin 1961; Hayman and Nay 1961; Bennett 1964). Pan (1964), Peters and Slen (1964), Davis (1972), and Bianca et al. (1974) sampled from numerous locations. The number of hairs used to determine diameter varied from ten at a single location (Berman and Volcani 1961) to 130 from each of seven locations plus 100 randomly selected fibres from an additional fourteen locations (Pan 1964). Berry and Shanklin (1961) took twenty diameter readings on each of the twenty hair fibres selected for estimation of fibre diameter.

The correlation of hair fibre diameter with insulation, in tests that combined fibre diameter measurements with heat transfer measurements, was not highly significant or consistent, in one case (Berry and Shanklin 1961), and was negative, in the other (Bennett 1964).

1.5.4 Number of Hairs Per Unit Area

With some exceptions (Berry and Shanklin 1961; Peters and Slen 1964), the number of hairs per unit area of body surface was not found to be well or consistently correlated with coat depth, fibre length, or hair weight per unit area (Schleger and Turner 1960; Bennett 1964; Bianca *et al.* 1974). Dowling (1958) found no difference in number of hairs per unit area among seasons. In an experiment that combined counts of the number of hairs per unit area with the determination of heat transfer through the pelage, Bennett (1964) found insulation and number of hairs to have a correlation coefficient of only -0.19. Berry and Shanklin (1961) speculate that number of hairs per unit area could have a negative effect upon insulation by increasing the opportunity for conduction of heat along the hair fibres.

1.5.5 Conclusion

The best criteria for *in situ* live animal estimation of external insulation appear to be hair coat depth, hair fibre length, and hair weight per unit area.

1.6 BREED DIFFERENCES IN PELAGE INSULATION

Most previous research into breed differences in pelage characteristics of cattle has been focused upon breeds suited to production in the tropics. Dowling (1956) investigated the difference in heat tolerance between temperate Shorthorn and Australian Illawarra Shorthorn cattle as determined by measurement of rectal temperature. Coat characters that affected breed differences in heat tolerance were reported as fibre length and medullation. The degree of medullation, an indicator of the heat dissipation allowed by the pelage, was later studied in more detail in Brahman x Shorthorn, Australian Illawarra Shorthorn, and Shorthorn cattle (Dowling 1959a). The greater degree of medullation observed in the coats of Brahman x Shorthorn and Australian Illawarra Shorthorn cattle was highly correlated with the ability to regulate rectal temperature in a hot environment (Dowling 1959a). Dowling (1959b) studied the heat tolerance of Shorthorn cattle and Australian Illawarra Shorthorn cattle before and after complete clipping. Clipping improved temperature regulation in both breeds, but the improvement was most profound in the Shorthorn, which characteristically have long, unmedullated hair.

Turner and Schleger (1960) described a method of classifying coat types in Hereford, Shorthorn, Hereford x Africander, Hereford x Brahman, Shorthorn x Africander, and Shorthorn x Brahman cattle as a tool for selecting tropical beef cattle. Turner and Schleger (1970) then described the seasonal changes in hair coat characteristics among these different breeds. Dowling (1958) described the differences in seasonal pelage characteristics among beef and dairy breeds in both the *B. taurus*, *B. indicus* and *B. indicus* x *B. taurus* F1 crossbreds. Yeates (1977) conducted heat tolerance tests on Hereford and Santa Gertrudis heifers. Finch *et al.* (1984) reported differences in thermal balance, based on differences in coat colour, among Brahman, Brahman x Hereford-Shorthorn, and Shorthorn cattle in the tropics.

Relatively little research has been reported on the pelage differences among breeds selected for cold tolerance. Yeates and Southcott (1958) exposed groups of Hereford and Galloway heifers with intact coats and clipped coats to relatively mild Australian winters. Unclipped Herefords had slightly greater weight gains and significantly higher skin temperatures than did clipped Herefords. Unclipped Galloways had significantly higher skin temperatures than did clipped Galloways, but there was no difference in weight gains. Breeds were analysed separately and were not compared in terms of cold tolerance. Bianca *et al.* (1974) studied hair coat characteristics of Brown Swiss, Simmental, and Holstein heifers during the course of the year. Brown Swiss pelages had thin hair fibres with pronounced medullae; Simmental pelages were heavy and were made up of long fibres; and Holstein pelages were lightweight and were made up of short, thick fibres. In all breeds, hair fibres were shorter, thicker, and more medullated in summer, while in winter hair length and weight increased dramatically. Ames and Insley (1975) used Charolais, Hereford, and Angus hides to study the effect of differing wind velocities upon heat transfer through the pelage, but, in terms of breed differences, reported only that Charolais had deeper coats than the other breeds.

Limited research has been conducted on the pelage characteristics, in relation to cold tolerance, of the British and exotic breeds that are prevalent in Canada. Peters and Slen (1964) compared weight per unit area, length, and diameter of hair among Hereford, Angus, Shorthorn, Hereford x bison hybrid, Angus x bison hybrid, and Cattalo cows. Hereford, Angus, and Shorthorn cows did not significantly differ in weight of hair per unit area and had significantly lower hair weights than did the hybrids. Hair fibre length was also similar among the cattle breeds, whereas Herefords had the greatest mean fibre diameter. Webster et al. (1970) measured hair weight per unit area and coat depth of six Hereford and six Angus-Galloway-Charolais heifers penned over the winter in Edmonton at either 20°C, in the outdoors with shelter, or in the outdoors without shelter. With only six cattle per breed, no breed differences were apparent, and the effect of breed upon hair weight per unit area and upon coat depth was not discussed. There have been no comparisons of hair coat parameters throughout the winter among the

British and exotic breeds of beef cattle that predominate in the Western Canadian beef industry.

MATERIALS AND METHODS

1.7 EXPERIMENT ONE (1983/1984)

1.7.1 Animals and Management

Two hundred and fifty-six hybrid pregnant beef cows, ranging in age from one to three years, were used as experimental animals. The cows were penned by breed cross in a feedlot at the Agriculture Canada Research Station at Brandon, Manitoba commencing October 5, 1983.

One hundred and ninety-two cows were backcross cows, varying in the proportions of their British (Hereford, Angus, or Shorthorn) and exotic (Charolais or Simmental) parentage. The remaining sixty-four cows were halfblood cows. The number of cows of each age and breed cross are shown in Table 1. Breed crosses which were 75% Hereford, Angus, or Shorthorn were termed British and those which were 75% Simmental or Charolais were termed exotic.

Cows were penned outdoors by breed cross and had access to straw bedding. Corn silage was fed daily at a maintenance level, with cow weight used as the criterion to estimate daily feed allowances with feeding increased during extreme cold, and increased if necessary to maintain cow condition (Fredeen 1987).

Table 1. Number of cows of each age group and breed cross.

							Breed Cross†								
Age (years)	ACA	ASA	CCA	CCH	CCN	CNN	HAA	HCH	HSH	NCN	NSN	SNN	SSA	SSH	SSN	total
One	9	7	6	6	10	7	10	9	3	15	4	5	4	5	3	103
Two	10	2	11	7	6	8	5	10	9	4	4	18	6	6	5	111
Three	0	8	0	6	0	0	11	12	0	0	0	0	5	0	0	42
	19	17	17	19	16	15	26	31	12	19	8	23	15	11	8	256

† The first letter of the three letter breed cross code indicates the breed of the sire, while the last two letters indicate the breed of the dam.
(e.g. ACA = 3/4 Angus, 1/4 Charolais)

A=Angus C=Charolais H=Hereford N=Shorthorn S=Simmental

1.7.2 Environmental Temperatures

Mean monthly air temperatures for Brandon provided by Environment Canada were:

October 1983	+5°C
November 1983	-2°C
December 1983	-21°C
January 1984	-14°C
February 1984	-5°C
March 1984	-7°C

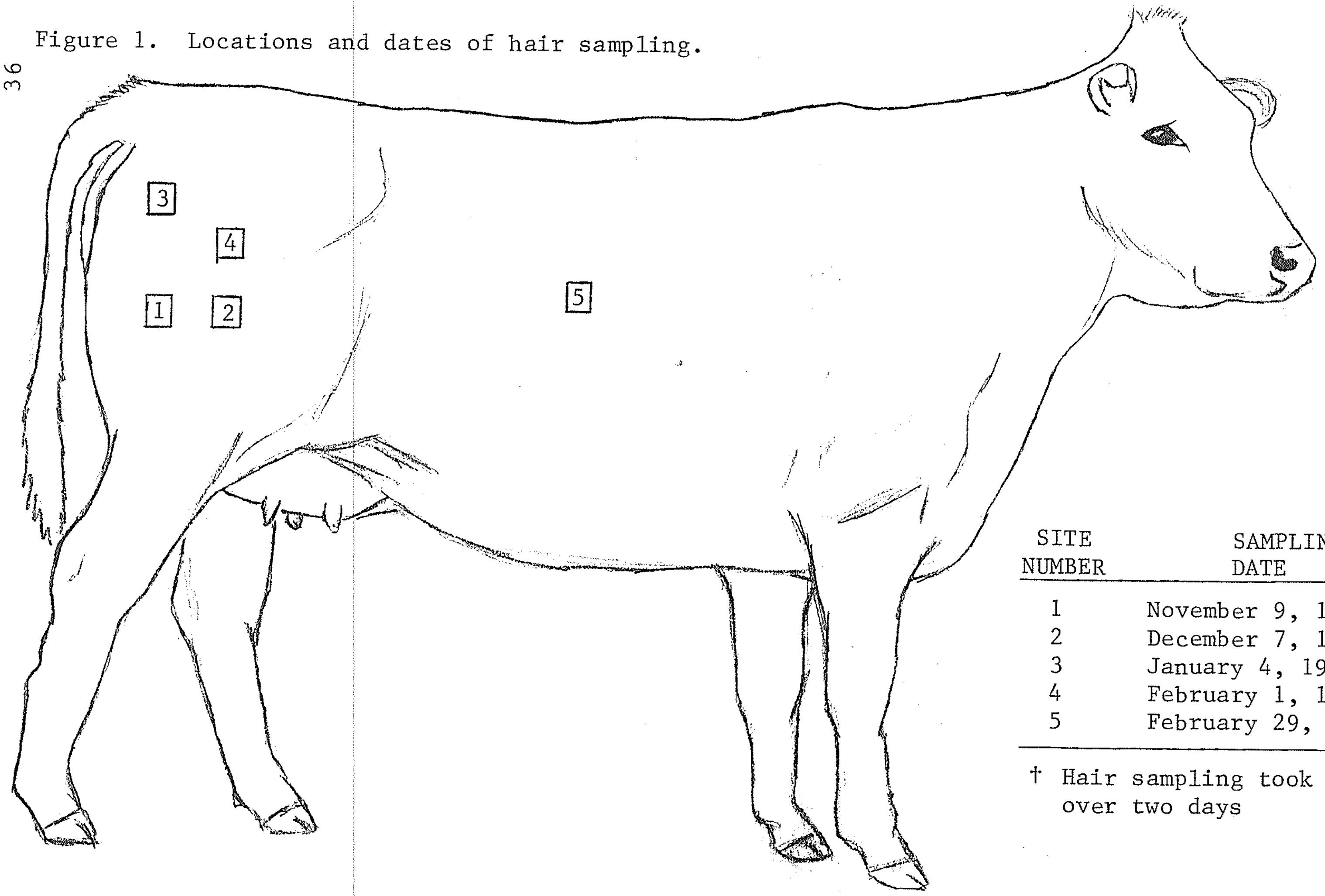
1.7.3 Experimental Design

Each month each animal was shaved at a predetermined site on the body in order to determine hair weight per unit area. The site chosen each month for hair sampling was the same for all cows, but the site varied from month to month. The sites and the dates at which cows were shaved are shown in Figure 1.

1.7.4 Hair Sampling Technique

Hair samples were taken from cows standing in an indoor chute. Hair was shaved with an Oster® small animal clipper (model A5) using a size 40 clipper head. The clippers were used in conjunction with a hard plastic template to which an opened eighteen-ounce Whirl-Pak® bag was fastened (Figure 2), in order to maintain uniformity of hair sample size and to prevent loss of hair samples. The template was pressed

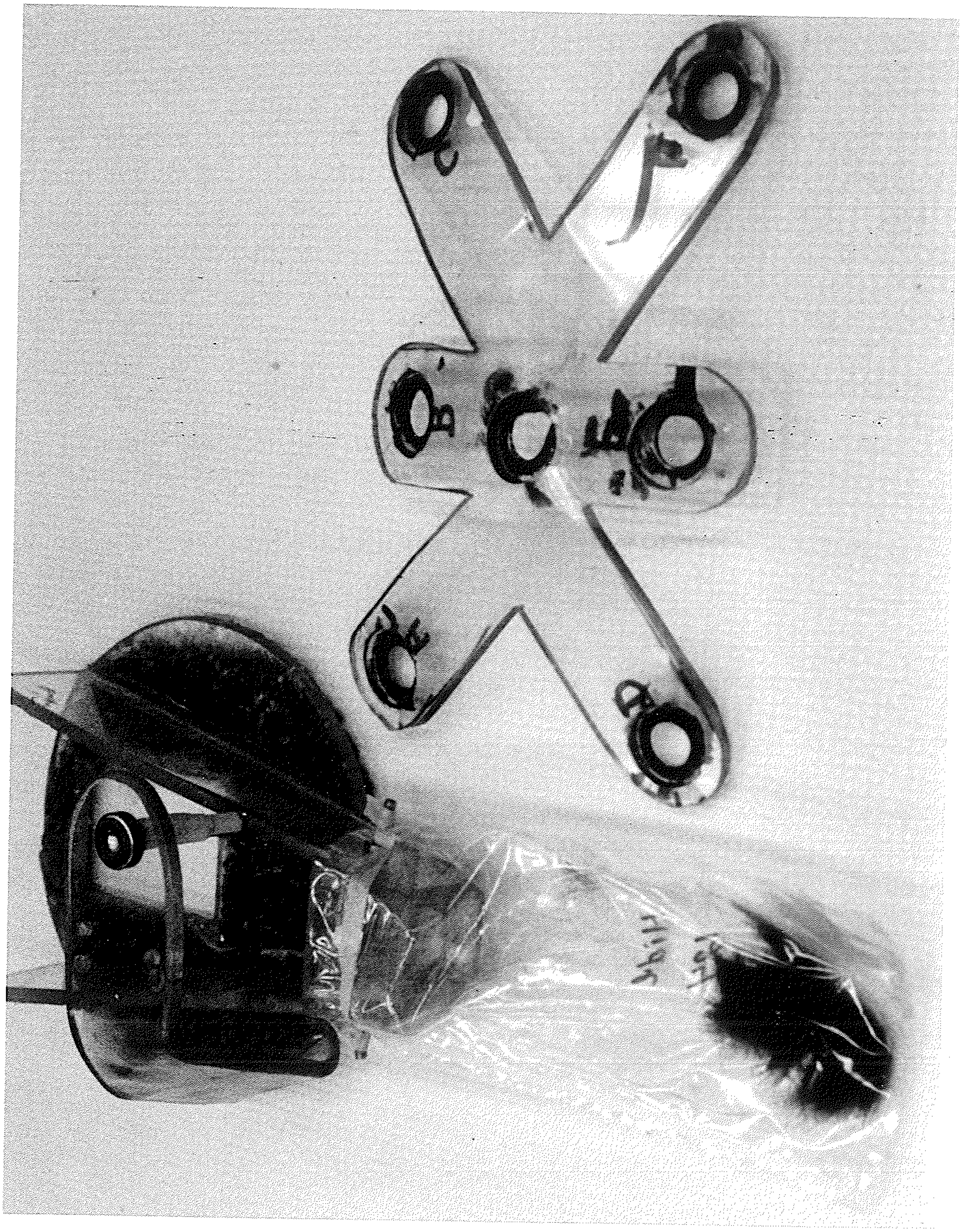
Figure 1. Locations and dates of hair sampling.



SITE NUMBER	SAMPLING DATE
1	November 9, 1983
2	December 7, 1983
3	January 4, 1984
4	February 1, 1984
5	February 29, 1984 †

† Hair sampling took place over two days

Figure 2. Stencil for determining location of sampling site in Experiment Two (top) and template for regulating size of hair sample in Experiment One and Two.



firmly against the body of the cow such that a 33.12 cm^2 swath could be shaved from the pelage.

The previously-weighed Whirl-Pak® bags containing the hair samples were sealed and stored after shaving. At a later date, each hair sample was oven-dried in the bag at 75°C for twenty-four hours and weighed.

1.7.5 Measurement of Ultrasonic Subcutaneous Fat Depth

On the day of hair sampling, ultrasonic subcutaneous fat depth measurements (U.S.) were taken between the eleventh and twelfth rib using a model USK7 Krautkramer-Branson Ultrasonic Flaw Detector®. Only the 153 cows that were two years of age and older were ultrasonically probed.

1.7.6 Statistical Analysis

1.7.6.1 Test of Sampling Sites

During the last sampling period, multiple sampling was conducted to determine whether the site at which hair was shaved affected the weight of the hair sample. Ten cows which were not involved in Experiment One, but which had been penned and maintained in the same fashion, were shaved in each of the five hair sampling sites. The cows used were three years of age and represented various breed crosses.

Differences among hair sampling sites were determined using a one-way analysis of variance (Sas Institute Inc. 1985) and Tukey's studentized range test (Steel and Torrie 1980).

1.7.6.2 Regression Model

Stepwise regression (SAS Institute Inc. 1985) for each age of cow within each of the fifteen breed crosses was used to establish the relationship between hair weight per unit area and time. Three-year-olds were grouped with two-year-olds for the purposes of statistical analysis because of the limited number of three-year-old cows tested, and because three-year-olds were not represented in every breed cross. The pattern of hair and fat parameters over time could either be flat, linear, or curvilinear. Since it was not known which pattern best described the data, all the following models were tested for best fit:

$Y = a + b(\text{month})$

$Y = a + b(\text{month}) + c(\text{month})^2$

$Y = a + b(\text{month}) + c(\text{month})^2 + d(\text{month})^3$

$Y = a + b(\log \text{month})$

$Y = a + b(\log \text{month}) + c(\log \text{month})^2$

$Y = a + b(\log \text{month}) + c(\log \text{month})^2 + d(\log \text{month})^3$

$\log Y = a + b(\text{month})$

$\log Y = a + b(\text{month}) + c(\text{month})^2$

$\log Y = a + b(\text{month}) + c(\text{month})^2 + d(\text{month})^3$

$\log Y = a + b(\log \text{month})$

$\log Y = a + b(\log \text{month}) + c(\log \text{month})^2$

$\log Y = a + b(\log \text{month}) + c(\log \text{month})^2 + d(\log \text{month})^3$

The best fit model was that which yielded the greatest R^2. In determining the best fit model, R^2 values which differed by a factor of less than 10% were not considered to be different from one another. The model chosen for subsequent analyses was that which best described the relationship between dependent variable and time as found in the analysis of the fifteen breed crosses subdivided by age. Least squares means (SAS Institute Inc. 1985) for monthly measurements of hair coat characters and U.S. within breed cross and age of cow are provided in Appendix A.

1.7.6.3 Test for Outliers

Data points that lay extremely far from the regression line were examined for the possibility of being outliers. Large or small data points which lay more than three standard deviations from the mean or data points that were found to be biologically impossible were considered to be outliers and were dropped from the analysis.

1.7.6.4 Test of Effect of Age

Analysis of variance by general linear model (SAS Institute Inc. 1985) was used to compare the slopes and intercepts for regression lines for ages within a breed cross. Ages within a breed cross were considered to differ significantly if: (1) the intercepts were significantly different, but the slopes were the same, (2) the slopes were significantly different, but the intercepts were the same, or (3) both intercepts and slopes were significantly different.

1.7.6.5 Analysis of Variance for Breed Cross and Age

Regression coefficients were determined for individual cows using the best fit model arrived at as described in section 1.6.2. Subsequent comparisons among breed crosses and between ages were made on the basis of the slope and the intercept of these regression lines, rather than the original or log transformed data, in order to compare breed crosses and ages in terms of hair weight per unit area at the beginning of the study period and rate of increase in hair weight over time.

1.7.6.6 Contrasts

Contrasts (Steel and Torrie 1980) were performed upon least squares means for breed crosses and groups of breed crosses when differences among breed crosses for intercept or slope were significant. When the effect of age on hair weight slope or intercept was significant, contrasts of breed crosses or groups of breed crosses were performed separately within each age group. Based upon the major genetic component of the breed crosses, the fifteen breed crosses were grouped to aid in biological interpretation of the data. Table 2 shows the contrasts between groups of means.

Each breed cross was referred to by the name of the breed that contributed to three-quarters of its parentage. Charolais x Shorthorn (CNN) and Simmental x Shorthorn (SNN),

Table 2. Sets of contrasts among groups of means

	Breed Crosses														
	ACA	ASA	CCA	CCH	CCN	CNN	HAA	HCH	HSH	NCN	NSN	SNN	SSA	SSH	SSN
HAA vs others	1	1	1	1	1	1	-14	1	1	1	1	1	1	1	1
HAA vs Exotics	0	0	1	1	1	0	-6	0	0	0	0	0	1	1	1
HAA vs British	1	1	0	0	0	0	-6	1	1	1	1	0	0	0	0
HAA vs Halfbloods	0	0	0	0	0	1	-2	0	0	0	0	1	0	0	0
Exotics vs British	-1	-1	1	1	1	0	0	-1	-1	-1	-1	0	1	1	1
Exotics vs Halfbloods	0	0	1	1	1	-3	0	0	0	0	0	-3	1	1	1
British vs Halfbloods	1	1	0	0	0	-3	0	1	1	1	1	-3	0	0	0
Exotics: Charolais vs Simmental	0	0	1	1	1	0	0	0	0	0	0	0	-1	-1	-1
British: Angus vs others	2	2	0	0	0	0	0	-1	-1	-1	-1	0	0	0	0
British: Hereford vs others	-1	-1	0	0	0	0	0	2	2	-1	-1	0	0	0	0
British: Shorthorn vs others	-1	-1	0	0	0	0	0	-1	-1	2	2	0	0	0	0
British: Angus vs Hereford	1	1	0	0	0	0	0	-1	-1	0	0	0	0	0	0
British: Hereford vs Shorthorn	0	0	0	0	0	0	0	1	1	-1	-1	0	0	0	0
British: Shorthorn vs Angus	-1	-1	0	0	0	0	0	0	0	1	1	0	0	0	0

which were halfblood cross-bred cows were referred to as 'halfbloods'. The standard breed cross, against which all other breed crosses were compared, was Hereford x Angus (HAA). Breed crosses were also referred to as belonging to the 'exotic' (Charolais and Simmental) or 'British' (Hereford, Angus, and Shorthorn) groups.

All breed crosses were compared to HAA. All exotic breed crosses (CCA, CCH, CCN, SSA, SSH, and SSN), all British breed crosses (ACA, ASA, HCH, HSH, NCN, and NSN), and the halfbloods (CNN and SNN) were compared to HAA in three separate contrasts. The exotic breed crosses were compared to the British breed crosses. The exotic breed crosses and the British breed crosses were compared to the halfbloods in two separate contrasts.

The breed crosses within the exotic group (Charolais and Simmental) were compared to each other.

Within the British group (Hereford, Angus, and Shorthorn breed crosses) six separate contrasts were made. Hereford were compared to the Angus plus Shorthorn breed crosses, Angus were compared to the Hereford plus Shorthorn breed crosses, and Shorthorn were compared to the Hereford plus Angus breed crosses. Then Hereford, Angus, and Shorthorn breed crosses were each compared to each other in three separate contrasts.

1.7.6.7 Analysis of Ultrasonic Subcutaneous Fat Depth

Regression Model

Stepwise regression analysis (SAS Institute Inc. 1985) for each of the fifteen breed crosses was used to establish the relationship between U.S. and time. The models tested were those described earlier to test the relationship between hair weight and time.

Analysis of Variance for Breed Cross

Based upon the results of the stepwise regression procedure, in which U.S. remained constant throughout the winter in 80% of the cases, one-way analysis of variance (SAS Institute Inc. 1985) was used to test for differences in U.S. among breed crosses.

Contrasts

Contrasts were performed upon least squares means for breed crosses and groups of breed crosses to determine which breed crosses and groups of breed crosses differed in terms of U.S. Contrasts performed were as shown in Table 2.

1.8 EXPERIMENT TWO (1984/1985)

Experiment One was repeated the following winter. Changes in procedures and animals used are indicated below.

1.8.1 Animals and Management

Two hundred and twenty-eight of the cows described in Experiment One were used in Experiment Two. These cows were two and three years of age. Cows were penned and fed in the manner described in Experiment One commencing on October 4, 1984.

One hundred and sixty-eight cows were backcross cows, varying in the proportions of their British and exotic parentage, while the remaining sixty animals were halfblood cows. The number of cows of each age and breed cross are shown in Table 3.

1.8.2 Environmental Temperatures

Mean monthly air temperatures for Brandon provided by Environment Canada were:

October 1984	+4°C
November 1984	-6°C
December 1984	-19°C
January 1985	-18°C
February 1985	-17°C
March 1985	-4°C

Table 3. Number of cows of each age group and breed cross.

Age								Breed Cross								
(years)	ACA	ASA	CCA	CCH	CCN	CNN	HAA	HCH	HSH	NCN	NSN	SNN	SSA	SSH	SSN	total
Two	12	7	7	5	9	9	13	9	4	15	5	4	3	4	3	109
Three	8	4	10	8	10	10	6	9	9	5	7	18	7	4	4	119
	20	11	17	13	19	19	19	18	13	20	12	22	10	8	7	228

1.8.3 Experimental Design

Based on the results of the test of sampling sites conducted in Experiment One, it was concluded that in Experiment Two all hair weight samples should be taken exclusively from the area of the hip bordered by the hook and pin bones.

Unlike Experiment One, in Experiment Two all cows were not shaved at the same site in a given month. In Experiment Two, each cow was randomly assigned a sampling site sequence. Each cow was to be shaved at six sites on the flank--one site each month from November to April.

Although six sampling sites were randomly assigned to each cow, in actuality, only five sampling sites were used. The last scheduled shaving period (April) was eliminated, as the herd was drawing too close to parturition. One random site per cow was thus left unshaven.

The actual dates of hair sampling were:

November 7-8, 1984
December 5-6, 1984
January 2-3, 1985
February 5-6, 1985
February 26-27, 1985

Breed crosses were hair-sampled at random over the two day period in which hair sampling took place.

The assignment of a sampling site sequence to each cow was semi-random in that all six sites were to be sampled in all six months with equal frequency among all breed crosses. The sites at which cows were shaved are shown in Figure 3.

1.8.4 Hair Sampling Technique

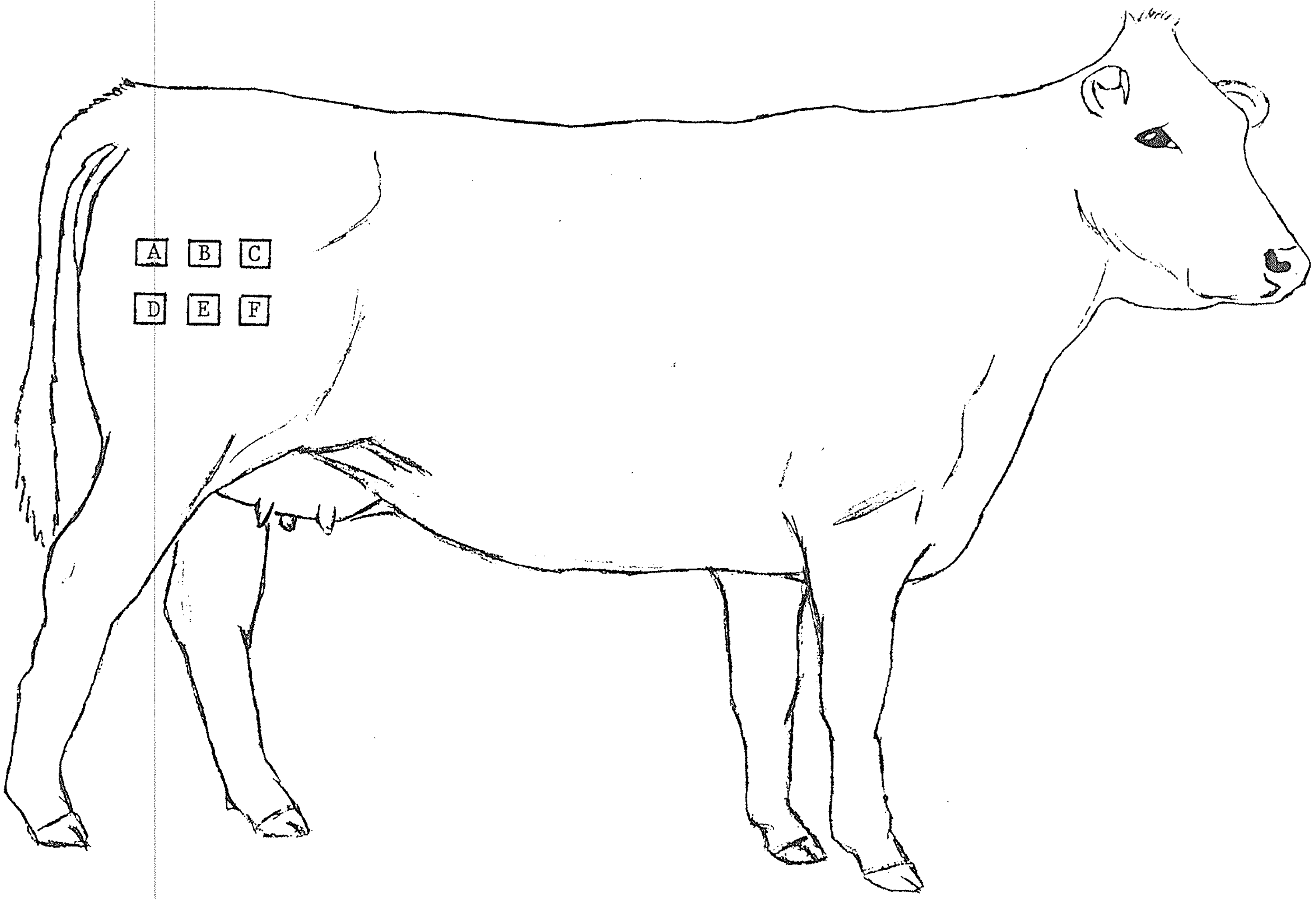
The shaving technique was as described in Experiment One except that a molded plastic stencil (Figure 2) was used to indicate the precise shaving site. The stencil was perforated with six holes corresponding to the centre of each of the six shaving sites on the hip. Prior to shaving, the stencil was placed on the hip of the cow and the appropriate site was marked on the hip with a felt marker.

Drying and weighing of the collected hair samples were as described in Experiment One.

1.8.5 Hair Length

Hair coat length was measured monthly on all experimental animals in conjunction with hair sampling. A single central site, determined with the aid of the stencil used in shaving, was measured each month. In addition to the six holes in the stencil, which were previously described, there was also a central hole in the stencil, midway between shaving sites B and E (Figure 3), through which the site of hair coat length measurement was marked on the flank with a felt

Figure 3. Locations of hair sampling.



marker. On cows with dark coats, Liquid Paper®, rather than a felt marker, was used.

Length measurements were taken with a thin sewing gauge modified such that it could be placed easily beneath a swatch of hair 15 to 20 hairs thick. The gauge was placed beneath the hair shafts, such that the tip of the gauge was placed at the hair roots, and the straightened hair ran along the length of the gauge. Hair length was then read off the gauge.

An alternate method for measuring hair length (Appendix B) was also tested.

1.8.6 Pelage Depth

Pelage depth was measured monthly on all experimental animals in conjunction with hair sampling. Each month one depth measurement was taken at the hair length measurement site.

Depth measurements were taken with the sewing gauge as used for length measurements. The gauge was positioned perpendicular to the surface of the animal. The tip of the gauge was then inserted through the pelage until it reached the skin. Hair depth was then read off the gauge.

1.8.7 Ultrasonic Subcutaneous Fat Depth

U.S. measurements were taken on all experimental animals using the method described in Experiment One.

1.8.8 Test of Sampling Sites

Additional hair weight measurements were taken monthly on cows not involved in Experiment Two, but which were subjected to identical environmental and management conditions. The purpose of this test was to monitor monthly the sites on the hip from which hair was shaved to determine if variation in monthly hair sample weights was in any way due to sampling site on the hip. The test was also done to confirm that randomization of the shaving sites each month was necessary to ensure that any possible site within time effect was blocked.

Each month seven different four-year-old cows from six different breed crosses were shaved at all six shaving sites. The breed crosses chosen for this multiple sampling test (ACA, ASA, CCA, CCH, SSN, and HAA) were those for which the largest number of cows were available.

The effect of sampling site and sampling period upon hair weight were analyzed by two-way analysis of variance (SAS Institute Inc. 1985).

1.8.9 Statistical Analysis

1.8.9.1 Analysis of Hair Characters

Hair weight per unit area, hair length, and pelage depth were statistically analyzed according to the methods described in Experiment One for hair weight analysis.

1.8.9.2 Analysis of Ultrasonic Subcutaneous Fat Depth

Regression Model

Stepwise regression analysis (SAS Institute Inc. 1985) for each age of cow within each breed cross was used to establish the relationship between U.S. and time. The models tested were those described for Experiment One.

Analysis of Variance for Breed Cross and Age

Based upon the results of the stepwise regression procedure, in which U.S. remained constant throughout the winter in 50% of the cases and showed a very weak relationship with month in the remainder, one-way analysis of variance (SAS Institute Inc. 1985) was used to test for differences in U.S. among breed crosses.

Contrasts

Contrasts of least squares means of breed crosses and groups of breed crosses were performed separately within each age group. Contrasts performed were as shown in Table 2.

RESULTS

1.9 EXPERIMENT ONE (1983/1984)

1.9.1 Hair Weight

1.9.1.1 Test of Sampling Sites

Multiple sampling during the last sampling period determined that there were no significant differences ($p>0.05$) in hair weight per unit area among the sampling sites on the hip. Samples taken from the February 29 sampling site further from the hip were incongruous with other sampling sites located exclusively on the hip. Table 4 shows differences in least squares means for hair weight among sampling sites as determined by Tukey's studentized range test. Samples that were taken February 29 of Experiment One were consequently dropped from the analysis because sampling site and month were confounded.

1.9.1.2 Regression Model

The model hair weight = a + b(month) yielded the best fit in 87% of the cases. Thus, in 26 out of 30 cases, this model gave an R^2 as good as or better than all other models. In two of these cases, the model was not significant ($p>0.05$). However, transformation of the data did not in-

Table 4. Least squares means ± standard errors for hair weight of sampling sites.

Sampling Site	Hair Weight (g/cm^2)
3	1.06 ± 0.08 a†
1	1.09 ± 0.08 a,b
2	1.11 ± 0.08 a,b
4	1.17 ± 0.08 a,b
5	1.39 ± 0.08 b

†ab Means with different subscripts were significantly different (p=0.04).

crease the R^2. Table 5 gives the R^2 values for all stepwise regression models tested.

The remaining 13%, 4 out of 30 cases, were not linear. In two cases, the best fit model was log hair weight = a + b(log month). In one case each the best fit model was:

$$\text{hair weight} = a + b(\text{month}) + c(\text{month})^2$$

$$\log \text{hair weight} = a + b(\text{month})$$

As the linear regression gave the best overall fit, it was the model used in all subsequent analyses of hair weight per unit area in Experiment One.

1.9.1.3 Test for Outliers

All extreme data points were found to lie within three standard deviations of the predicted value. The data points were therefore confirmed to be valid data points and remained in the data set. However, seven data points which were obviously biologically impossible were removed from the data set.

1.9.1.4 Age Effect

In 5 out of 15 cases, there was a significant difference ($p<0.05$) between ages within a breed cross. Since the effect of age upon hair weight was significant in 33% of the cases, age was considered relevant in its effect upon hair weight and was retained in the model in subsequent analyses.

Table 5. R^2 values for stepwise regressions of hair weight on month within breed cross and age of cow.†

		BREED CROSS AND AGE (YRS)															
		ACA		ASA		CCA		CCH		CCN		CNN		HAA		HCH	
POLYNOMIAL MODELS		1	2+3	1	2+3	1	2+3	1	2+3	1	2+3	1	2+3	1	2+3	1	2+3
y=hair weight x=month	Linear	0.48	0.41	0.46	0.37	0.30	0.25	0.14	0.64	0.79	0.58	0.53	0.48	0.29	0.46	0.30	0.52
	Quadratic	‡															
	Cubic																
y=hair weight x=log(month)	Linear	0.44	0.39	0.47	0.37	0.28	0.27	0.13	0.65	0.74	0.57	0.51	0.44	0.30	0.46	0.29	0.51
	Quadratic	0.49								0.80							
	Cubic												0.49				
y=log(hair weight) x=month	Linear	0.42	0.39	0.44	0.37	0.33	0.26	0.21	0.60	0.82	0.57	0.48	0.38	0.24	0.44	0.30	0.52
	Quadratic																
	Cubic																
y=log(hair weight) x=log(month)	Linear	0.40	0.39	0.47	0.38	0.31	0.29	0.20	0.63	0.79	0.58	0.48	0.36	0.25	0.46	0.31	0.53
	Quadratic									0.82							
	Cubic																

† The four polynomial models used various combinations of hair weight, month and the logarithms of hair weight and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Empty cells indicate that the variable added was not significant ($p > 0.15$)

Continued.........

Table 5 (continued). R^2 values for stepwise regressions of hair weight on month within breed cross and age of cow.†

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS)													
		HSH		NCN		NSN		SNN		SSA		SSH		SSN	
		1	2+3	1	2+3	1	2+3	1	2+3	1	2+3	1	2+3	1	2+3
y=hair weight x=month	Linear	0.35	0.27‡	0.58	0.43	0.81	0.50	0.56	0.50	0.44	0.37	0.47	0.14‡	0.54	0.16‡
	Quadratic	0.48	§												
	Cubic	0.41													
y=hair weight x=log(month)	Linear	0.30	0.24‡	0.58	0.44	0.76	0.48	0.55	0.47	0.40	0.37	0.44	0.16‡	0.46	0.16‡
	Quadratic	0.48												0.60	
	Cubic	0.38				0.81				0.44					
y=log(hair weight) x=month	Linear	0.33	0.22‡	0.57	0.41	0.84	0.53	0.58	0.49	0.44	0.35	0.49	0.18‡	0.48	0.16‡
	Quadratic							0.60							
	Cubic														
y=log(hair weight) x=log(month)	Linear	0.30	0.21‡	0.59	0.44	0.86	0.52	0.60	0.48	0.42	0.35	0.48	0.21	0.41	0.17‡
	Quadratic													0.53	
	Cubic														

† The four polynomial models used various combinations of hair weight, month and the logarithms of hair weight and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($P>0.05$)

§ Empty cells indicate that the variable added was not significant ($p>0.15$)

1.9.1.5 Intercept of Linear Regression Line

Analysis of Variance

Two-way analysis of variance of the intercept of the regression lines of individual animals indicated a significant difference (p=0.004) among breed crosses. The effect of cow age upon the intercept of the hair weight growth curve was highly significant (p=0.0001), and there was a significant interaction (p=0.02) between breed cross and age. Figure 4 shows the least squares means and standard errors of each breed cross and age for the intercepts of the hair weight regression lines.

Visual inspection of the data suggested that there was no effect of age upon the intercepts in ACA, CCH, CNN, HAA, HCH, HSH, and NCN breed crosses. In ASA, CCA, CCN, NSN, SNN, SSA, SSH, and SSN, the one-year-old cows appeared to have higher intercept hair weights than did the two- and three-year-old cows.

Contrasts

Differences in hair weight intercepts among breed crosses are summarized in Table 6.

(1) One-Year-Old Cows

HAA did not differ (p>0.05) from all other breeds combined. Neither the exotic breed crosses, the British breed crosses, nor the halfbloods differed (p>0.05) from HAA. The intercept for exotic breed crosses was significantly higher

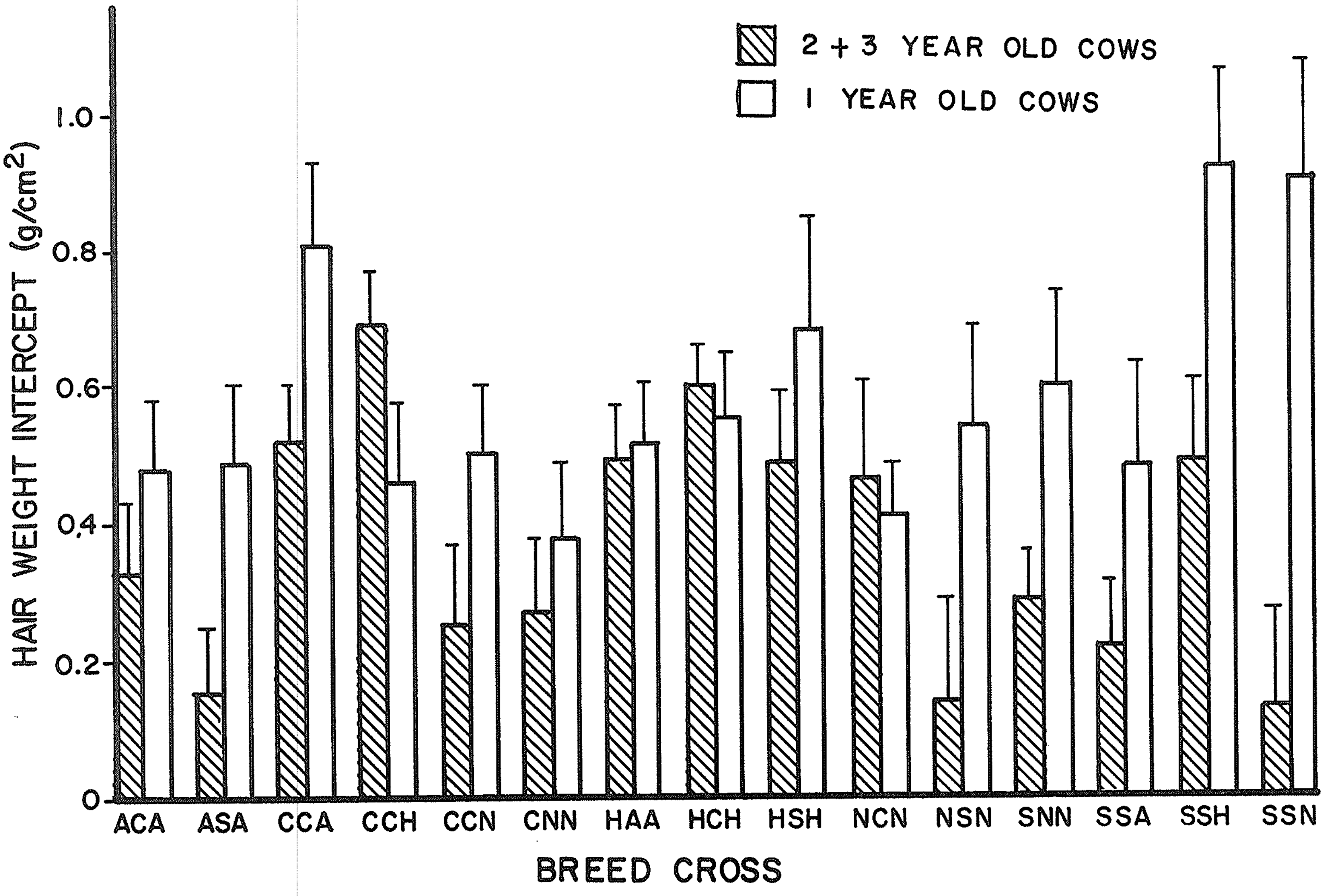


Figure 4. Least squares means ± standard errors for regression line intercepts of hair weight by breed cross and age of cow.

Table 6. Summary of contrasts among groups of means for hair weight, length and depth.

HAIR WEIGHT (g/cm^2)			HAIR LENGTH (cm)	HAIR DEPTH (cm)
1983/84		1984/85	1984/85	1984/85
Intercept†		Intercept	Intercept	Intercept
1 Year Olds	2 + 3 Year Olds		2 > 3 year olds(p=0.008)	
HAA = Others HAA = Exotics = British = ½N ‡ Exotics > British > ½N British = ½N Simmental > Charolais Hereford = Shorthorn = Angus	HAA = Others HAA = Exotics = British > ½N Exotics = British = ½N British = ½N Charolais > Simmental Hereford > Angus Shorthorn = Hereford = Angus	HAA = Others HAA = Exotics = British = ½N Exotics > British ½N = Exotics = British Charolais = Simmental Shorthorn > Angus Hereford = Shorthorn = Angus	Others > HAA Exotics > HAA ½N > HAA HAA = British Exotics > British ½N > British Exotics = ½N Charolais = Simmental Shorthorn > Hereford Hereford > Angus	HAA = Others Exotics > HAA ½N > HAA HAA = British ½N > British Exotics > British = ½N Charolais > Simmental Hereford = Shorthorn = Angus
Slope		Slope	Slope	Slope
2 + 3 year olds > 1 year olds (p=0.002) HAA = Others HAA = Exotics = British ½N > HAA Exotics = British ½N > Exotics > British Charolais = Simmental Hereford = Shorthorn = Angus		3 > 2 year olds(p=0.05) breed cross (p>0.05)	HAA = Others HAA > Exotics = British = ½N British > Exotics ½N = Exotics = British Charolais = Simmental Angus > Shorthorn Hereford > Shorthorn = Angus	HAA > Others HAA > Exotics > ½N = British British > Exotics > ½N Exotics = ½N Simmental > Charolais Hereford = Shorthorn = Angus

† Interaction of breed cross and age significant for intercept (p=0.02)

‡ ½N = Halfbloods (CNN and SNN)

than for both the British breed crosses (p=0.01) and the halfbloods (p=0.03). The British breed crosses did not differ (p>0.05) from the halfbloods.

Within the exotic group, the hair weight intercept of Simmental was significantly greater (p=0.05) than that of Charolais.

Breed crosses did not differ (p>0.05) within the British group.

(2) Two- and Three-Year-Old Cows

HAA did not differ (p>0.05) from all other breed crosses combined. Neither the exotic breed crosses nor the British breed crosses differed (p>0.05) significantly from HAA. The hair weight intercept of the halfbloods (CNN and SNN) was significantly lower (p=0.05) than that of HAA. The halfbloods did not differ from the exotic (p>0.05) or the British breed crosses (p>0.05). The British breed crosses did not differ (p>0.05) from the exotic breed crosses.

Within the exotic group, the hair weight intercept of the Charolais breed crosses was significantly greater (p=0.04) than that of the Simmental breed crosses.

Within the British group, the Hereford hair weight intercept was significantly higher (p=0.005) than that of the Angus plus Shorthorn breed crosses, as well as higher (p=0.003) than the Angus breed crosses alone. The Shorthorn breed crosses did not differ from the Hereford breed crosses (p>0.05) or from the Angus breed crosses (p>0.05).

1.9.1.6 Slope of Linear Regression Line

Analysis of Variance

Two-way analysis of variance of the slope of the regression lines, or rate of increase in hair weight, of individual animals indicated a significant difference (p=0.03) among breed crosses. The effect of age upon slope of regression lines was also significant (p=0.002). The slope of the regression line for cows that were two and three years old was 0.20±0.01 g/month and for cows that were one year old was 0.16±0.01 g/month. There was no interaction (p>0.05) between breed cross and age for regression line slope. Figure 5 shows the least squares means and standard errors of each breed cross and both ages for the slopes of the hair weight regression lines.

Contrasts

Differences in hair weight slopes among breed crosses are summarized in Table 6.

HAA did not differ (p>0.05) from all other breed crosses. Neither the exotic nor the British breed crosses differed (p>0.05) from HAA. The halfbloods (CNN and SNN) had significantly higher (p=0.01) hair weight slopes than HAA. The exotic breed crosses did not differ (p>0.05) from the British breed crosses. The halfbloods had a significantly high-

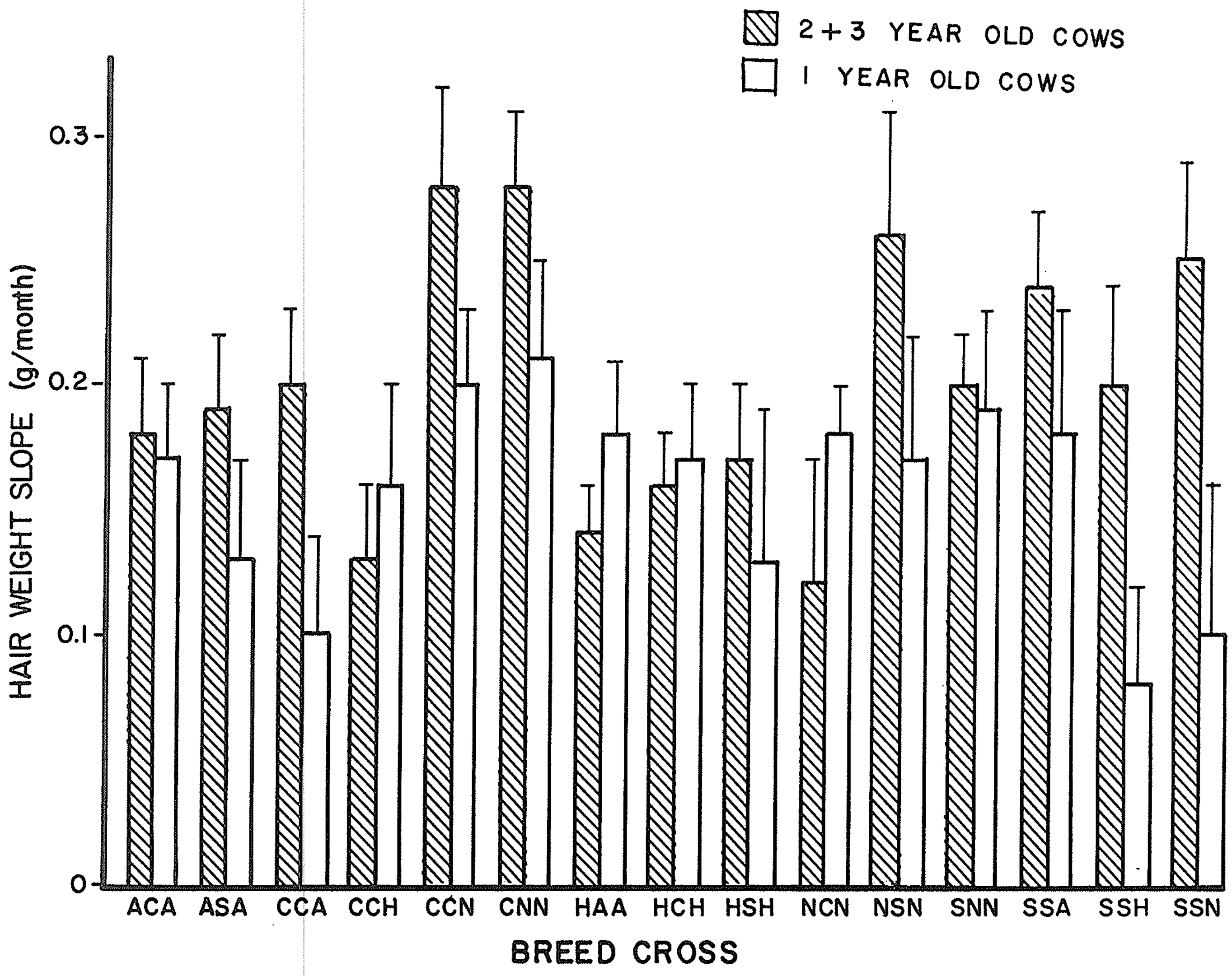


Figure 5. Least squares means ± standard errors for regression line slopes of hair weight by breed cross and age of cow.

er hair weight slope than both the exotic ($p=0.05$) and the British ($p=0.02$) breed crosses.

Breed crosses within the exotic group (Charolais and Simmental) did not differ ($p>0.05$) from each other.

Breed crosses within the British group (Hereford, Angus, and Shorthorn) did not differ ($p>0.05$) from one another.

1.9.2 Ultrasonic Subcutaneous Fat Depth

1.9.2.1 Regression Model

Regression models tested were non-significant ($p>0.05$) in 80% of the cases. Thus, in 12 out of 15 breed crosses, U.S. remained constant throughout the winter. Three out of fifteen breed crosses showed a significant ($p<0.05$) relationship of U.S. with time. Table 7 gives the R^2 values for all stepwise regression models tested. In the breed cross HSH, the R^2 was highest and equal for the three models:

$$\text{U.S.} = a + b(\text{month}) + c(\text{month})^2 + d(\text{month})^3$$

$$\log \text{U.S.} = a + b(\text{month}) + c(\text{month})^2 + d(\text{month})^3$$

$$\log \text{U.S.} = a + b(\text{l month}) + c(\text{l month})^2 + d(\text{l month})^3$$

In the breed cross SSH, the R^2 was highest and equal for the two models:

$$\text{U.S.} = a + b(\log \text{month}) + d(\text{month})^3$$

$$\log \text{U.S.} = a + b(\log \text{month}) + c(\log \text{month})^2$$

In the breed cross SNN, the models $\log \text{U.S.} = a + b(\text{month})$ and $\log \text{U.S.} = a + b(\log \text{month})$ yielded the highest R^2. However, although the R^2 was significant ($p=0.01$), it was extremely low ($R^2=0.07$).

Although U.S. did not remain constant throughout the winter in all cases, this was the predominant pattern in 80% of the cases. Consequently, a mean U.S. for the winter was used to describe each breed cross in all subsequent analyses.

Table 7. R^2 values for stepwise regressions of ultrasonic subcutaneous fat depth (U.S.) on month within breed cross.†

POLYNOMIAL MODELS		BREED CROSS														
		ACA	ASA	CCA	CCH	CCN	CNN	HAA	HCH	HSH	NCN	NSN	SNN	SSA	SSH	SSN
y=U.S. x=month	Linear	0.04 ‡	0.02 ‡	0.02 ‡	0.07 ‡	0.02 ‡	0.00 ‡	0.00 ‡	0.01 ‡	0.29	0.06 ‡	0.04 ‡	0.06	0.01 ‡	0.23	0.07 ‡
	Quadratic	§								0.36						
	Cubic									0.44						
y=U.S. x=log(month)	Linear	0.04 ‡	0.01 ‡	0.02 ‡	0.06 ‡	0.02 ‡	0.00 ‡	0.00 ‡	0.01 ‡	0.21	0.06 ‡	0.04 ‡	0.05	0.01 ‡	0.18	0.06 ‡
	Quadratic									0.41						
	Cubic														0.28	
y=log(U.S.) x=month	Linear	0.05 ‡	0.01 ‡	0.03 ‡	0.06 ‡	0.02 ‡	0.00 ‡	0.00 ‡	0.02 ‡	0.26	0.09 ‡	0.03 ‡	0.07 ‡	0.01 ‡	0.24	0.12 ‡
	Quadratic									0.33						
	Cubic									0.44						
y=log(U.S.) x=log(month)	Linear	0.05 ‡	0.00 ‡	0.02 ‡	0.06 ‡	0.02 ‡	0.00 ‡	0.00 ‡	0.02 ‡	0.18	0.08 ‡	0.03 ‡	0.07 ‡	0.01 ‡	0.19	0.10 ‡
	Quadratic									0.39					0.28	
	Cubic									0.44						

† The four polynomial models used various combinations of U.S., month and the logarithms of U.S. and month in models of of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

1.9.2.2 Analysis of Variance for Breed Cross

One-way analysis of variance indicated a highly significant difference (p=0.0001) in U.S. among breed crosses. Figure 6 shows the least squares means and standard errors for winter U.S. for each breed cross.

1.9.2.3 Contrasts

Differences in U.S. among breed crosses are summarized in Table 8.

HAA was significantly higher (p=0.0001) in U.S. than all other breed crosses combined. HAA was significantly higher (p=0.0001) than the exotic breed crosses, the British breed crosses, and the halfbloods. The British breed crosses had significantly higher U.S. than both the exotic breed crosses (p=0.0001) and the halfbloods (p=0.01). The exotic breed crosses did not differ (p>0.05) from the halfbloods.

Within the exotic group, Charolais breed crosses did not differ (p>0.05) from Simmental breed crosses.

Within the British group, the Hereford breed crosses were significantly higher (p=0.009) than the Angus plus Shorthorn breed crosses. Individually, the Hereford breed crosses were higher than the Shorthorn breed crosses (p=0.0003), but did not differ (p>0.05) from the Angus breed crosses. The Shorthorn breed crosses were significantly lower than the Angus plus Hereford breed crosses (p=0.0009), as well as

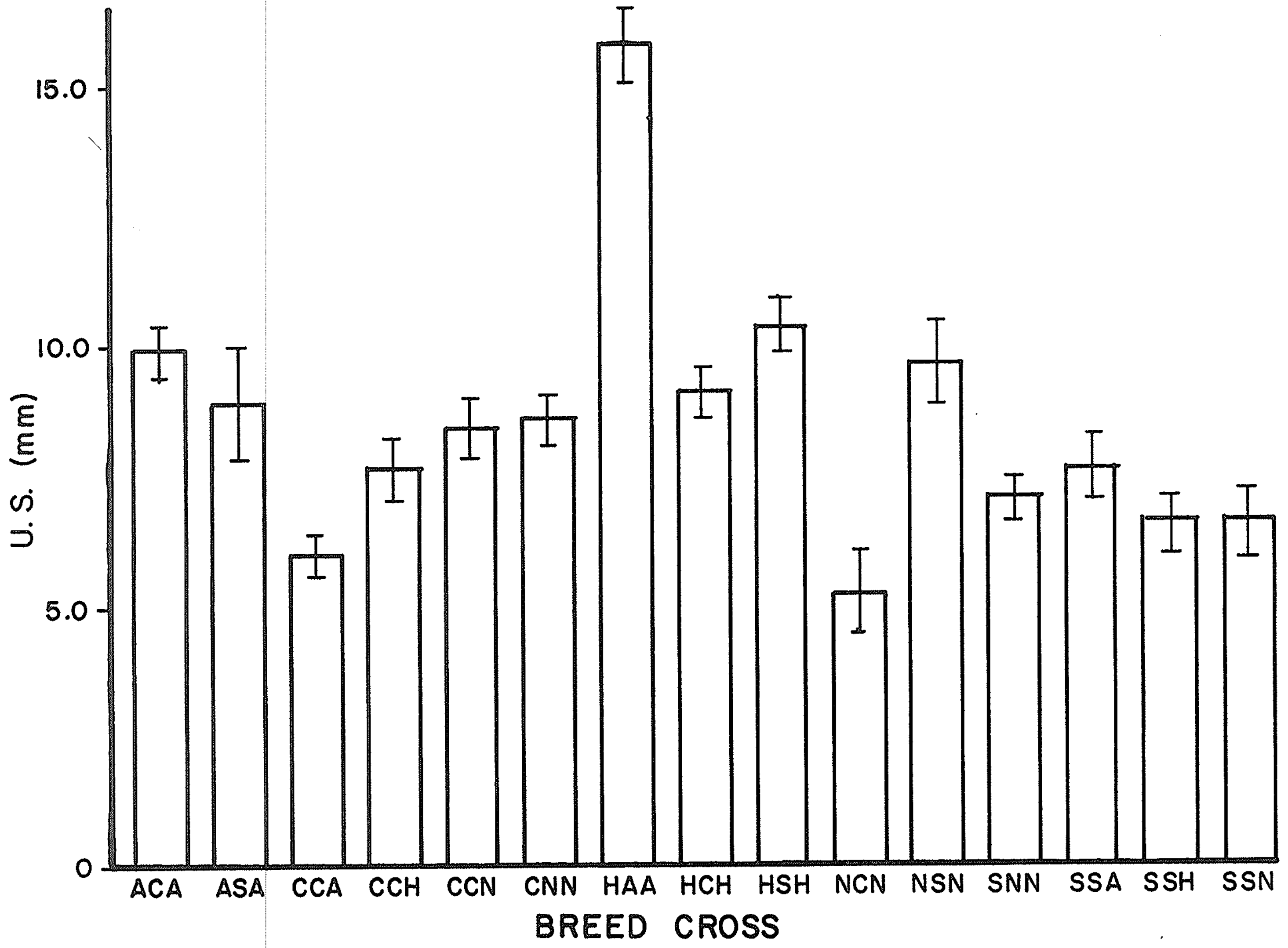


Figure 6. Least squares means ± standard errors of ultrasonic subcutaneous fat depth (U.S.) by breed cross.

Table 8. Summary of contrasts among groups of means for ultrasonic subcutaneous fat depth (U.S.)

1983/84†	1984/85‡	
	2 Year Olds	3 Year Olds
HAA > Others	HAA > Others	HAA > Others
HAA > Exotics > British > ½N §	HAA > Exotics > British > ½N	HAA > Exotics > British > ½N
British > Exotics > ½N Exotics = ½N	British > Exotics ½N > Exotics British = ½N	British > Exotics > ½N Exotics = ½N
Charolais = Simmental	Charolais = Simmental	Charolais > Simmental
Hereford > Shorthorn Angus > Shorthorn Hereford = Angus	Hereford > Angus Angus > Shorthorn	Shorthorn > Angus > Hereford Angus = Hereford

† One year olds not measured

‡ Interaction of breed cross and age significant (p=0.0001)

§ ½N = Halfbloods (CNN and SNN)

than the Angus breed crosses (p=0.02) and the Hereford breed crosses (p=0.0003) separately.

1.10 EXPERIMENT TWO (1984/1985)

1.10.1 Hair Weight

1.10.1.1 Test of Sampling Sites

Two-way analysis of variance indicated no difference ($p>0.05$) among sampling sites. Differences in hair weight among months were highly significant ($p=0.0001$). The interaction of site and month was not significant ($p>0.05$).

1.10.1.2 Regression Model

The model log hair weight = a + b(log month) provided the best fit in 77% of the cases. Thus, in 23 out of 30 cases, this model gave an R^2 as good as or better than all other models. In two of the 23 cases, the model was not significant ($p>0.05$). However, in these two cases, other transformations of the data did not improve the R^2. Table 9 gives the R^2 values for all stepwise regression models tested.

In two cases each, the best fit model was:

hair weight = a + b(month)

hair weight = a + b(month) + c$(\text{month})^2$ + d$(\text{month})^3$

In one case each, the best fit model was:

log hair weight = a + b(month) + c$(\text{month})^3$

log hair weight = a + b(month)

hair weight = a + b(log month)

Table 9. R^2 values for stepwise regressions of hair weight on month within breed cross and age of cow.†

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS)															
		ACA		ASA		CCA		CCH		CCN		CNN		HAA		HCH	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair weight x=month	Linear	0.19	0.34	0.11‡	0.27	0.22	0.36	0.10‡	0.42	0.42	0.13	0.42	0.06‡	0.36	0.26	0.34	0.44
	Quadratic	§								0.46		0.45					
	Cubic									0.54		0.48					
y=hair weight x=log(month)	Linear	0.22	0.35	0.09‡	0.27	0.22	0.37	0.08‡	0.43	0.47	0.15	0.46	0.07‡	0.38	0.27	0.34	0.41
	Quadratic																
	Cubic																
y=log(hair weight) x=month	Linear	0.22	0.36	0.12‡	0.29	0.24	0.38	0.17	0.46	0.37	0.16	0.50	0.08‡	0.36	0.27	0.35	0.42
	Quadratic									0.44		0.56					
	Cubic						0.42			0.51		0.59					
y=log(hair weight) x=log(month)	Linear	0.24	0.38	0.11‡	0.29	0.25	0.41	0.17	0.48	0.44	0.18	0.57	0.08‡	0.39	0.29	0.37	0.41
	Quadratic									0.47							
	Cubic																

† The four polynomial models used various combinations of hair weight, month and the logarithms of hair weight and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

Continued.........

Table 9 (continued). R^2 values for stepwise regressions of hair weight on month within breed cross and age of cow.†

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS)													
		HSH		NCN		NSN		SNN		SSA		SSH		SSN	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair weight x=month	Linear	0.23	0.40	0.14‡	0.06	0.30	0.04‡	0.21	0.21	0.36	0.33	0.20‡	0.18‡	0.22	0.07‡
	Quadratic	§								0.44				0.33	
	Cubic	0.31													
y=hair weight x=log(month)	Linear	0.17	0.37	0.13‡	0.07	0.31	0.03‡	0.23	0.18	0.43	0.34	0.24	0.18‡	0.28	0.10‡
	Quadratic														
	Cubic	0.28													
y=log(hair weight) x=month	Linear	0.21	0.30	0.19	0.08	0.28	0.07‡	0.22	0.20	0.40	0.29	0.19‡	0.19‡	0.28	0.01‡
	Quadratic							0.25		0.48				0.38	
	Cubic	0.28													
y=log(hair weight) x=log(month)	Linear	0.16	0.26	0.17	0.09	0.29	0.05‡	0.25	0.17‡	0.47	0.32	0.23	0.21	0.34	0.02‡
	Quadratic														
	Cubic	0.26													

† The four polynomial models used various combinations of hair weight, month and the logarithms of hair weight and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

The last two models were not significant ($p>0.05$).

As the model log hair weight = a + b(log month) yielded the best overall fit, it was used in all subsequent analyses of hair weight per unit area in Experiment Two.

1.10.1.3 Test for Outliers

All extreme data points were found to lie within three standard deviations of the predicted value. However, four data points which were obviously biologically impossible were removed from the data set.

1.10.1.4 Age Effect

In 4 out of 15 cases, there was a significant difference ($p<0.05$) between ages within a breed cross. Age was thus considered relevant to hair weight and was retained in the model in subsequent analyses.

1.10.1.5 Intercept of Regression Line

Analysis of Variance

Two-way analysis of variance of the intercepts of the regression lines of individual animals indicated a significant difference ($p=0.05$) among breed crosses. Age of animal had no effect ($p>0.05$) upon intercept of the hair weight growth curve. There was no interaction ($p>0.05$) between breed cross and age. Figure 7 shows the least squares means and

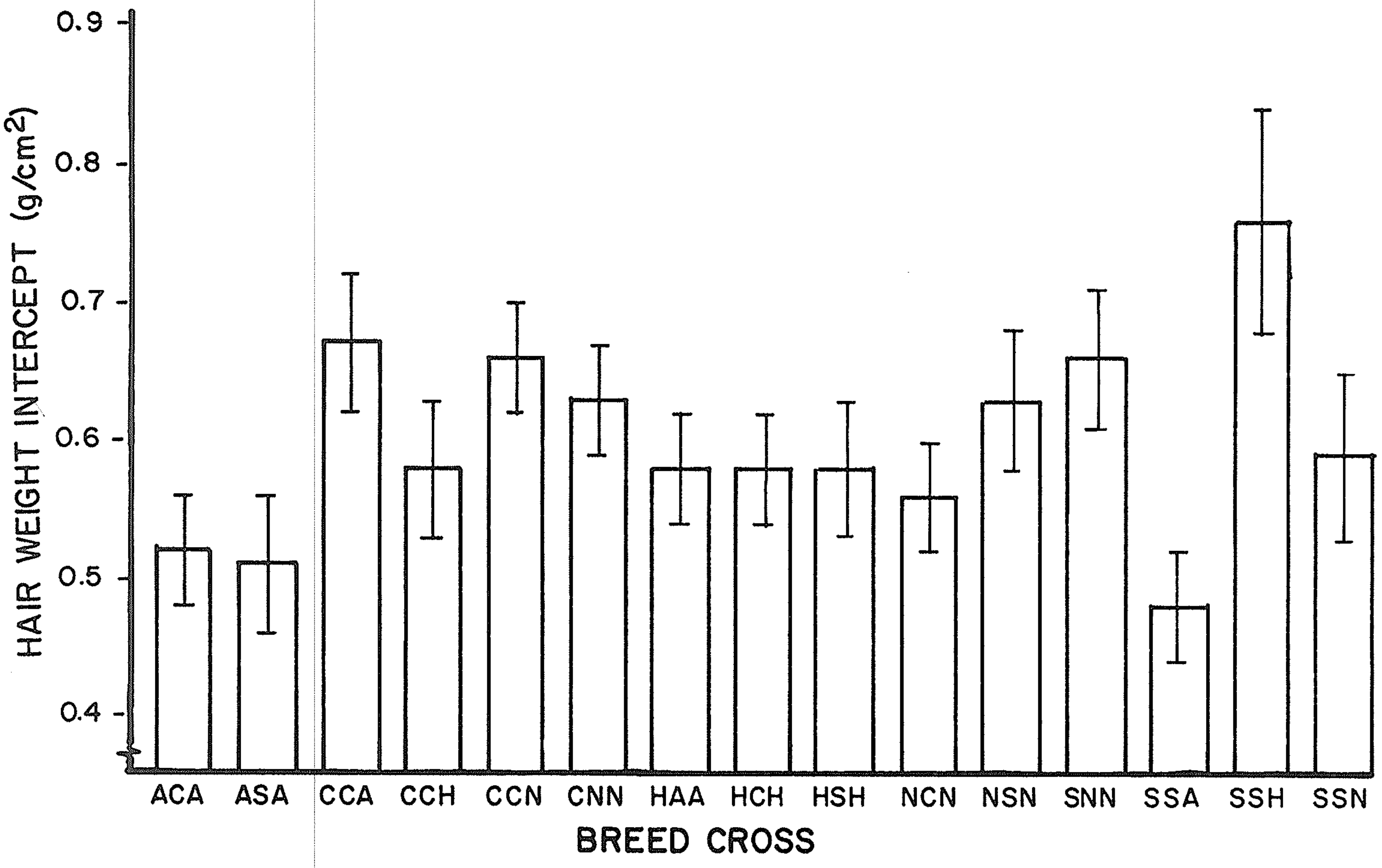


Figure 7. Least squares means ± standard errors for regression line intercepts of hair weight by breed cross.

standard errors for intercepts of regression lines for hair weight of each breed cross. In this figure, intercepts of the hair weight growth curves are shown in the antilog form.

Contrasts

Differences in hair weight intercepts among breed crosses are summarized in Table 6.

HAA did not differ ($p>0.05$) from all other breed crosses combined. Neither the exotic breed crosses, the British breed crosses, nor the halfbloods differed ($p>0.05$) from HAA. The exotic breed crosses had a significantly higher ($p=0.05$) intercept for hair weight than the British breed crosses. The halfbloods did not differ ($p>0.05$) from the exotic or the British breed crosses.

Breed crosses within the exotic group (Charolais and Simmental) did not differ ($p>0.05$) from each other.

Within the British group, the hair weight intercept of the Angus breed crosses was significantly lower than that of the Hereford plus Shorthorn breed crosses ($p=0.03$), as well as lower than the Shorthorn breed crosses alone ($p=0.02$). The Hereford breed crosses did not differ ($p>0.05$) from the Shorthorn or from the Angus breed crosses.

1.10.1.6 Slope of Regression Lines

Two-way analysis of variance of the slopes of the regression lines of individual animals indicated no significant difference ($p>0.05$) among breed crosses. The effect of age upon rate of increase in hair weight was significant ($p=0.05$). Two-year-old cows had a lower slope for hair weight (0.26 ± 0.02 log g/log month) than did three-year-old cows (0.32 ± 0.02 log g/log month). There was no interaction ($p>0.05$) between breed cross and age.

1.10.2 Length

1.10.2.1 Regression Model

The model log hair length = a + b(log month) yielded the best fit in 73% of the cases. Thus, in 22 out of 30 cases, this model gave an R^2 as good as or better than all other models. The remaining 27%, 8 out of 30 cases, did not fit this pattern best. Of the remaining cases, in seven, the model log hair length = a + b(log month) + c(log month)^2 provided the best fit, while in one case, the model log hair length = a + b(log month) + c(log month)^2 + d(log month)^3 gave the best fit. All models were significant ($p<0.05$). Table 10 gives the R^2 values for all stepwise regression models tested.

Although the model log hair length = a + b(log month) did not yield the highest R^2 in every case, it did give the best fit in 73% of the cases. This model was used in all subsequent analyses of hair length data.

1.10.2.2 Test for Outliers

Four data points that lay extremely far from the regression line and, upon examination were found to be biologically impossible, were removed from the data set.

Table 10. R^2 values for stepwise regressions of hair length on month within breed cross and age of cow.†

BREED CROSS AND AGE (YRS)

POLYNOMIAL MODELS		ACA		ASA		CCA		CCH		CCN		CNN		HAA		HCH	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair length x=month	Linear	0.55	0.61	0.65	0.54	0.68	0.72	0.67	0.75	0.61	0.56	0.67	0.42	0.61	0.68	0.74	0.77
	Quadratic	0.66	0.75	0.78	0.65	0.74	0.83	0.82	0.83	0.75	0.66	0.77	0.51	0.69	0.80		0.87
	Cubic	‡									0.68					0.82	
y=hair length x=log(month)	Linear	0.64	0.72	0.76	0.63	0.75	0.81	0.78	0.82	0.72	0.65	0.76	0.48	0.68	0.78	0.80	0.86
	Quadratic	0.67						0.82			0.68	0.78					
	Cubic		0.75	0.79			0.82			0.75					0.80		0.87
y=log(hair length) x=month	Linear	0.54	0.58	0.61	0.54	0.62	0.71	0.63	0.71	0.60	0.58	0.62	0.45	0.62	0.64	0.72	0.71
	Quadratic	0.72	0.78	0.81	0.70	0.74	0.90	0.83	0.84	0.79	0.74	0.78	0.59	0.76	0.83	0.84	0.88
	Cubic	0.75	0.80	0.85		0.76		0.85		0.81	0.78	0.81			0.85		0.89
y=log(hair length) x=log(month)	Linear	0.67	0.72	0.76	0.66	0.73	0.85	0.77	0.82	0.74	0.71	0.75	0.55	0.74	0.78	0.82	0.84
	Quadratic	0.75	0.80	0.84		0.76		0.85	0.85	0.81	0.77	0.81	0.60	0.78	0.85		0.90
	Cubic				0.71		0.90									0.84	

† The four polynomial models used various combinations of hair length, month and the logarithms of hair length and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Empty cells indicate that the variable added was not significant ($p > 0.15$)

Continued..........

Table 10 (continued). R^2 values for stepwise regressions of hair length on month within breed cross and age of cow.†

BREED CROSS AND AGE (YRS)

POLYNOMIAL MODEL		HSH		NCN		NSN		SNN		SSA		SSH		SSN	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair length x=month	Linear	0.64	0.66	0.61	0.60	0.55	0.51	0.64	0.51	0.50	0.51	0.73	0.77	0.60	0.62
	Quadratic	‡			0.66		0.68	0.78		0.58		0.87		0.90	
	Cubic					0.78			0.68				0.87		0.73
y=hair length x=log(month)	Linear	0.65	0.70	0.62	0.66	0.68	0.62	0.75	0.62	0.57	0.56	0.84	0.86	0.78	0.69
	Quadratic														
	Cubic					0.76	0.68	0.79	0.67			0.87		0.91	
y=log(hair length) x=month	Linear	0.56	0.57	0.53	0.58	0.56	0.51	0.59	0.54	0.51	0.54	0.66	0.73	0.58	0.60
	Quadratic	0.61	0.65		0.68	0.83	0.71	0.79	0.74	0.66	0.63	0.85	0.88	0.90	
	Cubic	0.66			0.70			0.81						0.93	0.74
y=log(hair length) x=log(month)	Linear	0.62	0.65	0.58	0.67	0.72	0.65	0.73	0.67	0.62	0.62	0.80	0.86	0.78	0.69
	Quadratic				0.69		0.73	0.81	0.75	0.67				0.94	
	Cubic					0.84						0.86	0.89		

† The four polynomial models used various combinations of hair length, month and the logarithms of hair length and and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Empty cells indicate that the variable added was not significant ($p > 0.15$)

1.10.2.3 Age Effect

In two out of fifteen cases, there was a significant difference ($p<0.05$) between ages within a breed cross. Since the effect of age upon hair length was significant in 13% of the cases, age was considered relevant to hair length and was retained in the model in subsequent analyses.

1.10.2.4 Intercept of Regression Line

Analysis of Variance

Two-way analysis of variance of the intercepts of the regression lines of individual animals indicated a highly significant difference ($p=0.0001$) among breed crosses. The effect of age upon intercept of hair length growth curves was also significant ($p=0.008$). There was no interaction ($p>0.05$) between breed cross and age.

Figure 8 gives the least squares means and standard errors for the intercept of the regression lines for hair length for each breed cross. In this figure, intercepts of hair length growth curves are shown in the antilog form.

Two-year-old cows had a higher intercept hair length (1.89±0.05 cm) than did three-year-old cows (1.70±0.05 cm).

Contrasts

Differences in hair length intercepts among breed crosses are summarized in Table 6.

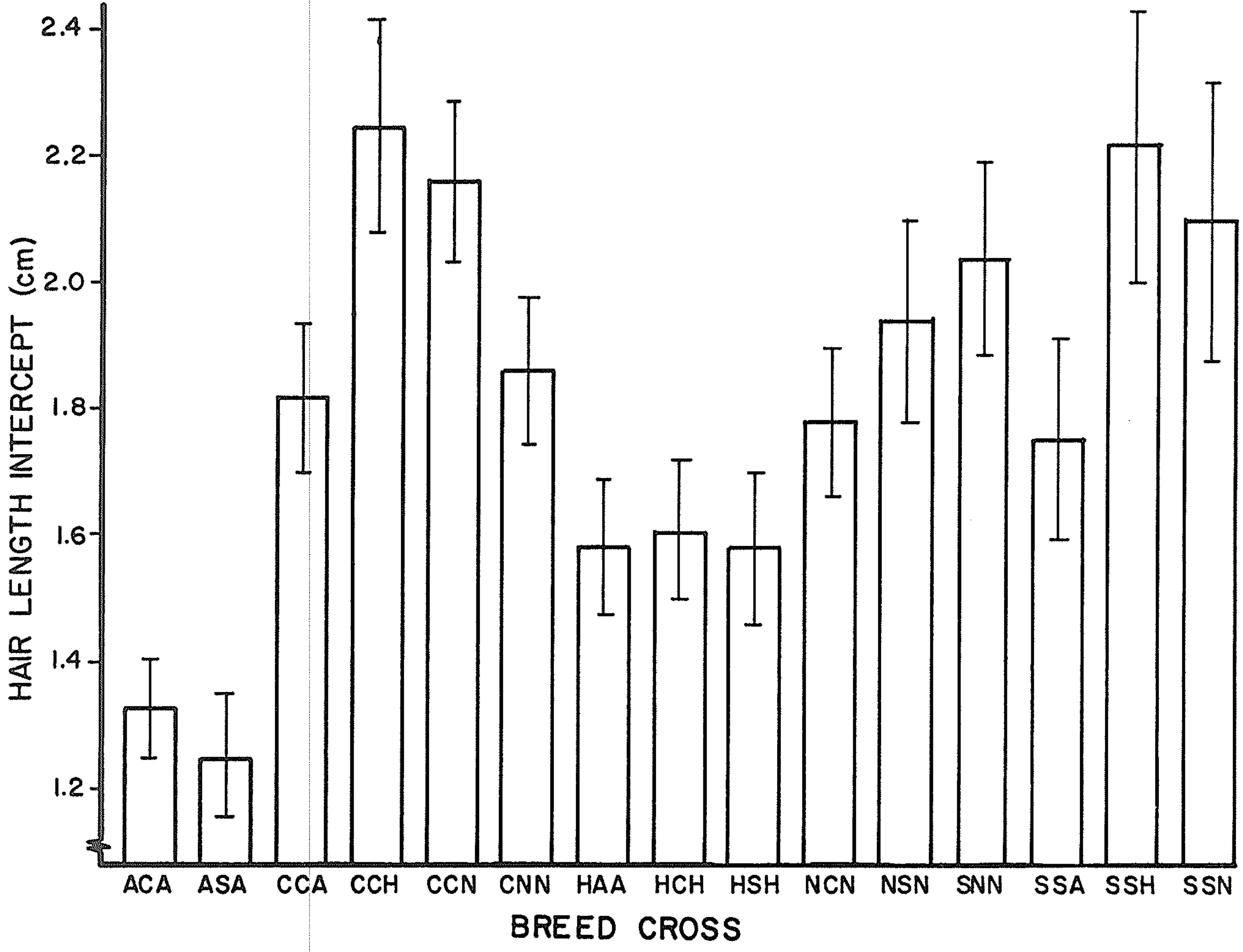


Figure 8. Least squares means ± standard errors for regression line intercepts of hair length by breed cross.

Hair length intercept for HAA was significantly lower (p=0.04) than the other breed crosses combined. Intercept hair length for HAA was significantly lower than intercept hair length of the exotic breed crosses (p=0.0005) and of the halfbloods (p=0.02), but did not differ (p>0.05) from the British breed crosses. The British breed crosses were significantly lower than the exotic breed crosses (p=0.0001) and the halfbloods (p=0.0008). The exotic breed crosses and the halfbloods did not differ (p>0.05) in intercept hair length.

The breed crosses within the exotic group (Charolais and Simmental) did not differ (p>0.05) from each other.

Within the British group, the hair length intercept of the Angus breed crosses was significantly lower than the intercept of the Hereford plus Shorthorn breed crosses (p=0.0001), as well as from the Hereford breed crosses (p=0.005) and the Shorthorn breed crosses (p=0.0001) separately. The Shorthorn breed crosses had a significantly higher hair length intercept than the Angus plus Hereford breed crosses (p=0.0001), as well as the Hereford breed crosses (p=0.04) and the Angus breed crosses (p=0.0001) separately.

1.10.2.5 Slope of Regression Line

Analysis of Variance

Two-way analysis of variance of the slopes of the regression lines of individual animals indicated a significant difference (p=0.003) among breed crosses. There was no significant difference (p>0.05) in rate of increase in hair length between ages.

Figure 9 gives the least squares means and standard errors for the slopes of the regression lines for hair length for each breed cross.

Contrasts

Differences in hair length slopes among breed crosses are summarized in Table 6.

HAA did not differ (p>0.05) from all other breed crosses combined. The hair length slope of HAA was significantly higher than that of the exotic breed crosses (p=0.01), but did not differ (p>0.05) from the British breed crosses or the halfbloods. The exotic breed crosses had a significantly lower (p=0.0009) hair length slope than the British breed crosses. The halfbloods did not differ from either the exotic breed crosses (p>0.05) or the British breed crosses (p>0.05).

The breed crosses within the exotic group (Charolais and Simmental) did not differ (p>0.05) from each other.

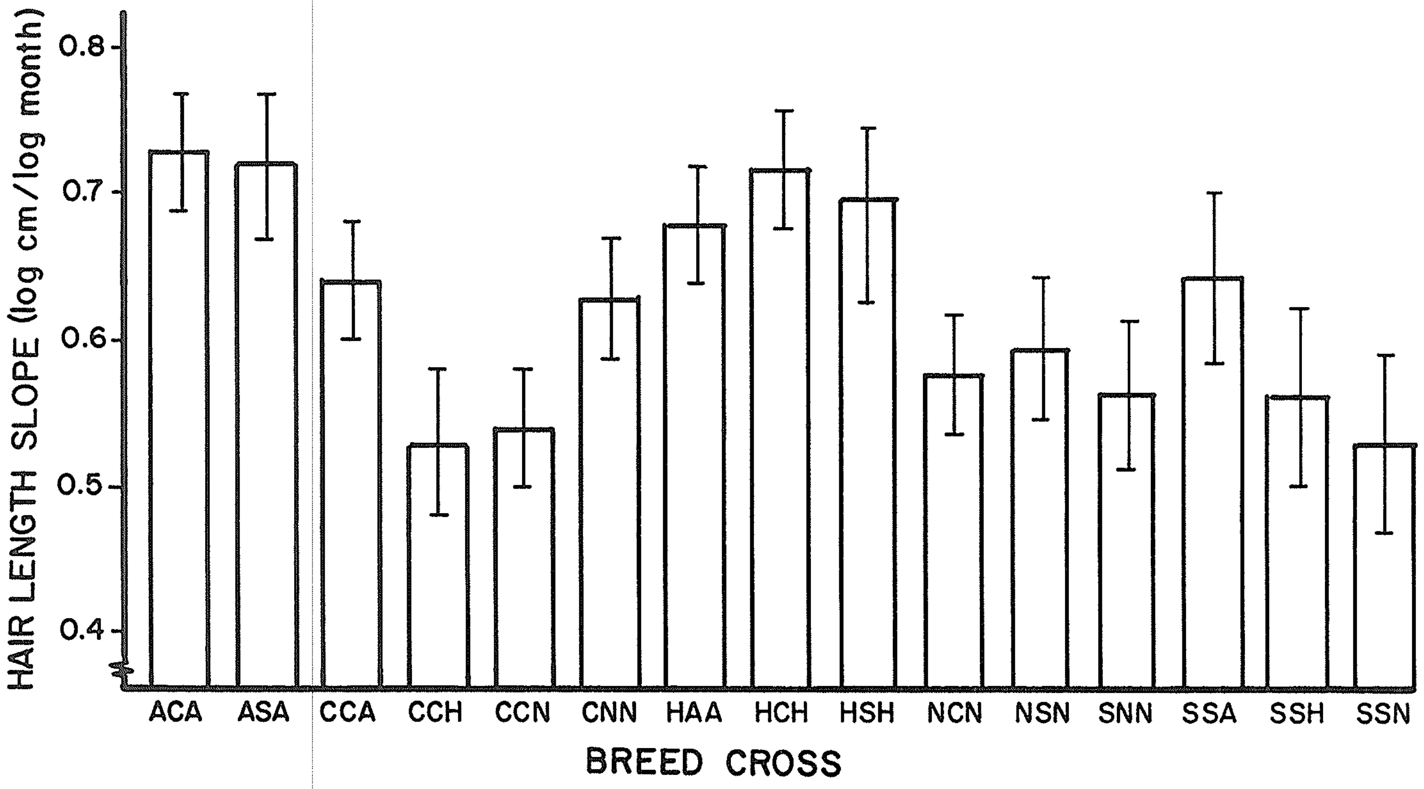


Figure 9. Least squares means ± standard errors for regression line slopes of hair length by breed cross.

Within the British group, the hair length slope of the Shorthorn breed crosses was significantly lower ($p=0.002$) than that of the Angus plus Hereford breed crosses, as well as that of the Angus breed crosses ($p=0.004$) and that of the Hereford breed crosses ($p=0.01$) separately. The Angus breed crosses did not differ ($p>0.05$) from the Hereford plus Shorthorn breed crosses, nor did the Hereford breed crosses differ ($p>0.05$) from the Angus plus Shorthorn breed crosses.

1.10.3 Depth

1.10.3.1 Regression Model

The model log hair depth = a + b(log month) yielded the best fit in 14 out of 30 cases. In one of these cases, the model was not significant ($p>0.05$). Table 11 gives the R^2 values for all stepwise regression models tested.

Although the model log hair depth = a + b(log month) did not yield the highest R^2 in every case, it did provide the best fit in 47% of the cases. Of the remaining 16 cases, 5 fit the model log hair depth = a + b(log month) + c(log month)^2 best and 9 fit the model log hair depth = a + b(log month) + c(log month)^2 + d(log month)^3 best. In one case each, the best fit model was:

log hair depth = a + b(month)

log hair depth = a + b(month) + c(month)^2 + d(month)^3

Since the model log hair depth = a + b(log month) gave the best fit in 47% of the cases, it was used in all subsequent analyses of the hair depth data.

1.10.3.2 Test for Outliers

Three data points were found to be biologically impossible and were removed from the data set.

Table 11. R^2 values for stepwise regressions of hair depth on month within breed cross and age of cow.†

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS)															
		ACA		ASA		CCA		CCH		CCN		CNN		HAA		HCH	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair depth x=month	Linear	0.56	0.35	0.64	0.32	0.35	0.37	0.22	0.11‡	0.22	0.11	0.49	0.44	0.54	0.55	0.62	0.51
	Quadratic	§	0.40	0.75	0.38	0.48	0.46				0.15	0.61		0.59	0.62	0.68	0.57
	Cubic		0.47		0.54	0.58	0.61				0.30	0.65	0.50	0.66	0.64	0.74	0.71
y=hair depth x=log(month)	Linear	0.59	0.41	0.75	0.40	0.45	0.46	0.18	0.10‡	0.25	0.15	0.60	0.49	0.61	0.62	0.70	0.59
	Quadratic		0.44	0.78	0.45	0.54	0.53	0.23			0.22	0.65			0.64	0.71	0.63
	Cubic		0.48		0.54	0.57	0.60				0.30						0.74
y=log(hair depth) x=month	Linear	0.51	0.46	0.58	0.30	0.38	0.40	0.25	0.14‡	0.24	0.13	0.52	0.46	0.55	0.51	0.57	0.52
	Quadratic	0.57	0.57	0.79	0.41	0.55	0.54			0.28	0.20	0.68	0.54	0.67	0.64	0.68	0.63
	Cubic	0.62	0.64	0.85	0.55	0.65	0.69			0.36	0.36	0.74		0.75	0.68	0.74	0.78
y=log(hair depth) x=log(month)	Linear	0.58	0.63	0.74	0.39	0.50	0.52	0.22	0.13‡	0.26	0.19	0.65	0.53	0.66	0.62	0.67	0.64
	Quadratic		0.68	0.85	0.47	0.62	0.63				0.27	0.73		0.73	0.68	0.72	0.72
	Cubic				0.57	0.65	0.69				0.36	0.75		0.77	0.69		0.81

† The four polynomial models used various combination of hair depth, month and the logarithms of hair depth and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

Continued..........

Table 11 (continued). R^2 values for stepwise regressions of hair depth on month within breed cross and age of cow.†

		BREED CROSS AND AGE (YRS)													
		HSH		NCN		NSN		SNN		SSA		SSH		SSN	
POLYNOMIAL MODELS		2	3	2	3	2	3	2	3	2	3	2	3	2	3
y=hair depth x=month	Linear	0.72	0.53	0.32	0.44	0.41	0.23	0.45	0.34	0.26	0.35	0.48	0.30	0.48	0.23‡
	Quadratic	§			0.51	0.64		0.57		0.38					
	Cubic				0.61					0.48					
y=hair depth x=log(month)	Linear	0.71	0.51	0.34	0.52	0.54	0.28	0.54	0.40	0.35	0.42	0.50	0.35	0.52	0.31
	Quadratic				0.55	0.66		0.58		0.43					
	Cubic				0.59										
y=log(hair depth) x=month	Linear	0.65	0.49	0.36	0.42	0.42	0.27	0.44	0.35	0.30	0.33	0.43	0.33	0.47	0.39
	Quadratic	0.68		0.44	0.55	0.68	0.36	0.60		0.45					0.54
	Cubic				0.65	0.73		0.62		0.53					
y=log(hair depth) x=log(month)	Linear	0.69	0.51	0.43	0.54	0.58	0.34	0.56	0.43	0.40	0.41	0.50	0.40	0.53	0.51
	Quadratic				0.62	0.74		0.63		0.50					0.61
	Cubic				0.65										

† The four polynomial models used various combinations of hair depth, month and the logarithms of hair depth and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

1.10.3.3 Age Effect

In 3 out of 15 cases, there was a significant difference ($p<0.05$) between ages within a breed cross. Since the effect of age upon hair depth was significant in 20% of the cases, age was considered relevant in its effect upon hair depth and was retained in the model in subsequent analyses.

1.10.3.4 Intercept of Regression Line

Analysis of Variance

Two-way analysis of variance of the intercepts of regression lines of individual animals indicated a highly significant difference ($p=0.0001$) among breed crosses. There was no difference ($p>0.05$) in intercepts of hair depth growth curves between ages and the interaction of breed cross and age was not significant ($p>0.05$).

Figure 10 gives the least squares means and standard errors for the intercepts of the regression lines for hair depth for each breed cross. In this figure, intercepts of hair depth growth curves are shown in the antilog form.

Contrasts

Differences in hair depth intercepts among breed crosses are summarized in Table 6.

HAA did not differ ($p>0.05$) from all other breed crosses combined. HAA had a significantly lower intercept hair depth than that of the exotic breed crosses ($p=0.0007$) and

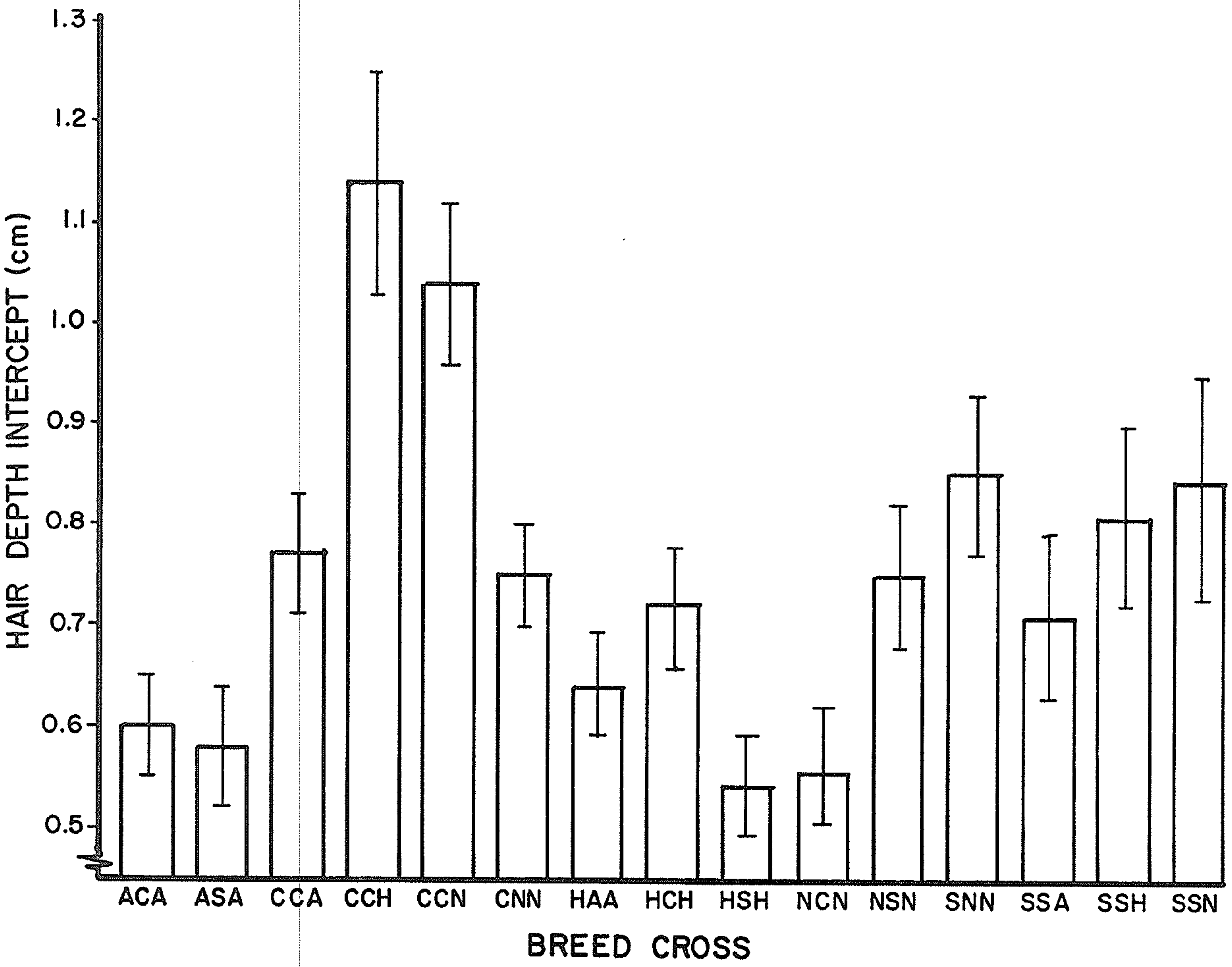


Figure 10. Least squares means ± standard errors for regression line intercepts of hair depth by breed cross.

that of the halfbloods (p=0.04), but did not differ (p>0.05) from the British breed crosses. The hair depth intercept of the British breed crosses was significantly lower than that of the exotic breed crosses (p=0.0001) and that of the halfbloods (p=0.002). The exotic breed crosses and the halfbloods did not differ (p>0.05).

Within the exotic group, the Charolais breed crosses were significantly higher (p=0.01) than the Simmental breed crosses.

The breed crosses within the British group (Hereford, Angus, and Shorthorn) did not differ (p>0.05) from one another.

1.10.3.5 Slope of Regression Line

Analysis of Variance

Two-way analysis of variance of the slopes of the regression lines of individual animals indicated a highly significant difference (p=0.0001) among breed crosses. There was no difference (p>0.05) in rate of increase in hair depth between ages and no interaction (p>0.05) of breed cross and age.

Figure 11 gives the least squares means and standard errors for the slopes of the regression lines for hair depth for each breed cross.

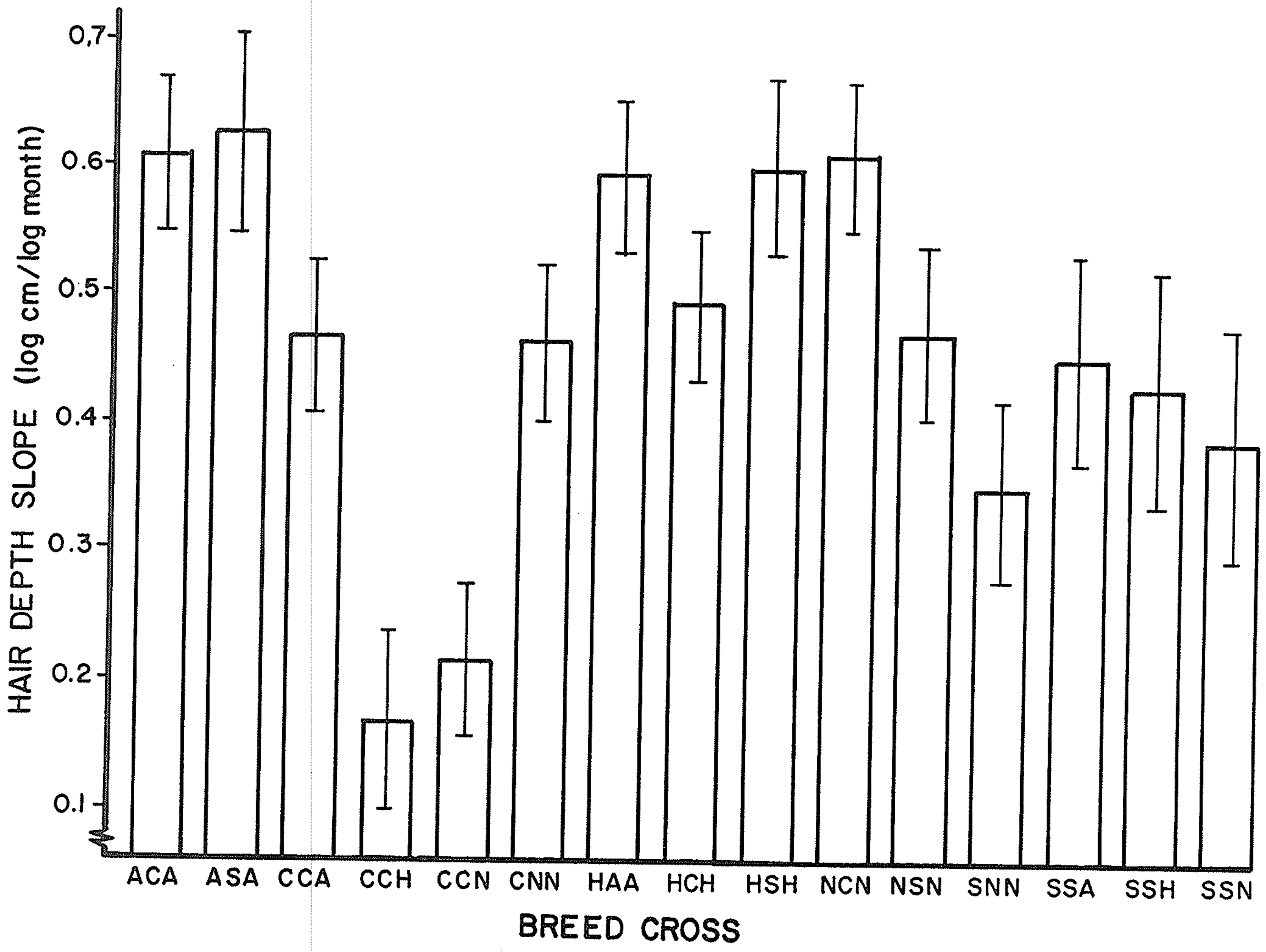


Figure 11. Least squares means ± standard errors for regression line slopes of hair depth by breed cross.

Contrasts

Differences in hair depth slopes among breed crosses are summarized in Table 6.

HAA had a significantly higher slope of hair depth ($p=0.006$) than all other breed crosses combined. The hair depth slope of HAA was significantly higher than that of the exotic breed crosses ($p=0.0001$), as well as that of the halfbloods ($p=0.01$), but did not differ ($p>0.05$) from the British breed crosses. The British breed crosses were significantly higher ($p=0.01$) than the halfbloods and very significantly higher ($p=0.0001$) than the exotic breed crosses. The exotic breed crosses did not differ ($p>0.05$) from the halfbloods.

Within the exotic group, the slope for hair depth of the Simmental breed crosses was significantly higher ($p=0.03$) than that of the Charolais breed crosses.

Hereford, Angus, and Shorthorn, the breed crosses within the British group, did not differ ($p>0.05$) from one another.

1.10.4 Ultrasonic Subcutaneous Fat Depth

1.10.4.1 Regression Model

The regression models tested were non-significant ($p>0.05$) in 50% of the cases. Thus, in 15 out of 30 cases, U.S. remained constant throughout the winter. The remaining 50% showed a significant ($p<0.05$) relationship of U.S. with time. In 14 out of 30 cases, the best fit model was log U.S. = a + b(log month), while in one case, the best fit model was log U.S. = a + b(month).

Although U.S. did not remain constant throughout the winter in all cases, this was the predominant pattern in 50% of the cases. In the cases in which U.S. did show a relationship with time, the R^2 remained very low. Table 12 gives the R^2 values for all stepwise regression models tested. A mean U.S. for the winter was used to describe each breed cross in all subsequent analyses.

1.10.4.2 Analysis of Variance for Breed Cross and Age

Two-way analysis of variance indicated a significant difference ($p=0.0001$) among breed crosses and between ages. There was also a significant interaction ($p=0.0001$) between breed cross and age. Figure 12 shows the least squares means and standard errors for U.S. of each breed cross and age.

Table 12. R^2 values for stepwise regressions of ultrasonic subcutaneous fat depth (U.S.) on month within breed cross and age of cow.†

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS) ACA		ASA		CCA		CCH		CCN		CNN		HAA		HCH	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3	2	3
y= U.S. x=month	Linear	0.20	0.00 ‡	0.00 ‡	0.05 ‡	0.31	0.17	0.07 ‡	0.14 ‡	0.03 ‡	0.06 ‡	0.09	0.09	0.00 ‡	0.00 ‡	0.20	0.16
	Quadratic	§															
	Cubic														0.04 ‡		
y= U.S. x=log(month)	Linear	0.18	0.00 ‡	0.00 ‡	0.06 ‡	0.29	0.17	0.08 ‡	0.14 ‡	0.03 ‡	0.06 ‡	0.11	0.10	0.00 ‡	0.01 ‡	0.21	0.18
	Quadratic																
	Cubic																
y=log(U.S.) x=month	Linear	0.19	0.00 ‡	0.00 ‡	0.04 ‡	0.35	0.16	0.13	0.16	0.04 ‡	0.08 ‡	0.12	0.12	0.00 ‡	0.02 ‡	0.25	0.17
	Quadratic																
	Cubic														0.07 ‡		
y=log(U.S.) x=log(month)	Linear	0.18	0.00 ‡	0.00 ‡	0.05 ‡	0.36	0.16	0.14	0.18	0.04 ‡	0.08	0.14	0.12	0.00 ‡	0.03 ‡	0.27	0.19
	Quadratic																
	Cubic																

† The four polynomial models used various combinations of U.S., month and logarithms of U.S. and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant $(P > 0.05)$

§ Empty cells indicate that the variable added was not significant $(p > 0.15)$

Continued..........

Table 12 (continued). R^2 values for stepwise regressions of ultrasonic subcutaneous fat depth (U.S.) on month within within breed cross and age of cow. †

POLYNOMIAL MODELS		BREED CROSS AND AGE (YRS)													
		HSH		NCN		NSN		SNN		SSA		SSH		SSN	
		2	3	2	3	2	3	2	3	2	3	2	3	2	3
y= U.S. x=month	Linear	0.12	0.28	0.00 ‡	0.06	0.01 ‡	0.06 ‡	0.04	0.05 ‡	0.08 ‡	0.05 ‡	0.33	0.07 ‡	0.14 ‡	0.00 ‡
	Quadratic	§													
	Cubic												0.21 ‡		
y= U.S. x=log(month)	Linear	0.10	0.24	0.00 ‡	0.06	0.01 ‡	0.06 ‡	0.04 ‡	0.06 ‡	0.08 ‡	0.05 ‡	0.34	0.11 ‡	0.13 ‡	0.00 ‡
	Quadratic														
	Cubic														
y=log(U.S.) x=month	Linear	0.09	0.27	0.01 ‡	0.08	0.01 ‡	0.12 ‡	0.04	0.08 ‡	0.12	0.06 ‡	0.31	0.09 ‡	0.09 ‡	0.00 ‡
	Quadratic												0.24 ‡		
	Cubic														
y=log(U.S.) x=log(month)	Linear	0.08 ‡	0.23	0.01 ‡	0.08	0.01 ‡	0.12 ‡	0.04	0.09 ‡	0.12	0.05 ‡	0.33	0.15 ‡	0.09 ‡	0.01 ‡
	Quadratic														
	Cubic														

† The four polynomial models used various combinations of U.S., month and logarithms of U.S. and month in models of the form $y = a + bx + cx^2 + dx^3$

‡ Non-significant ($p > 0.05$)

§ Empty cells indicate that the variable added was not significant ($p > 0.15$)

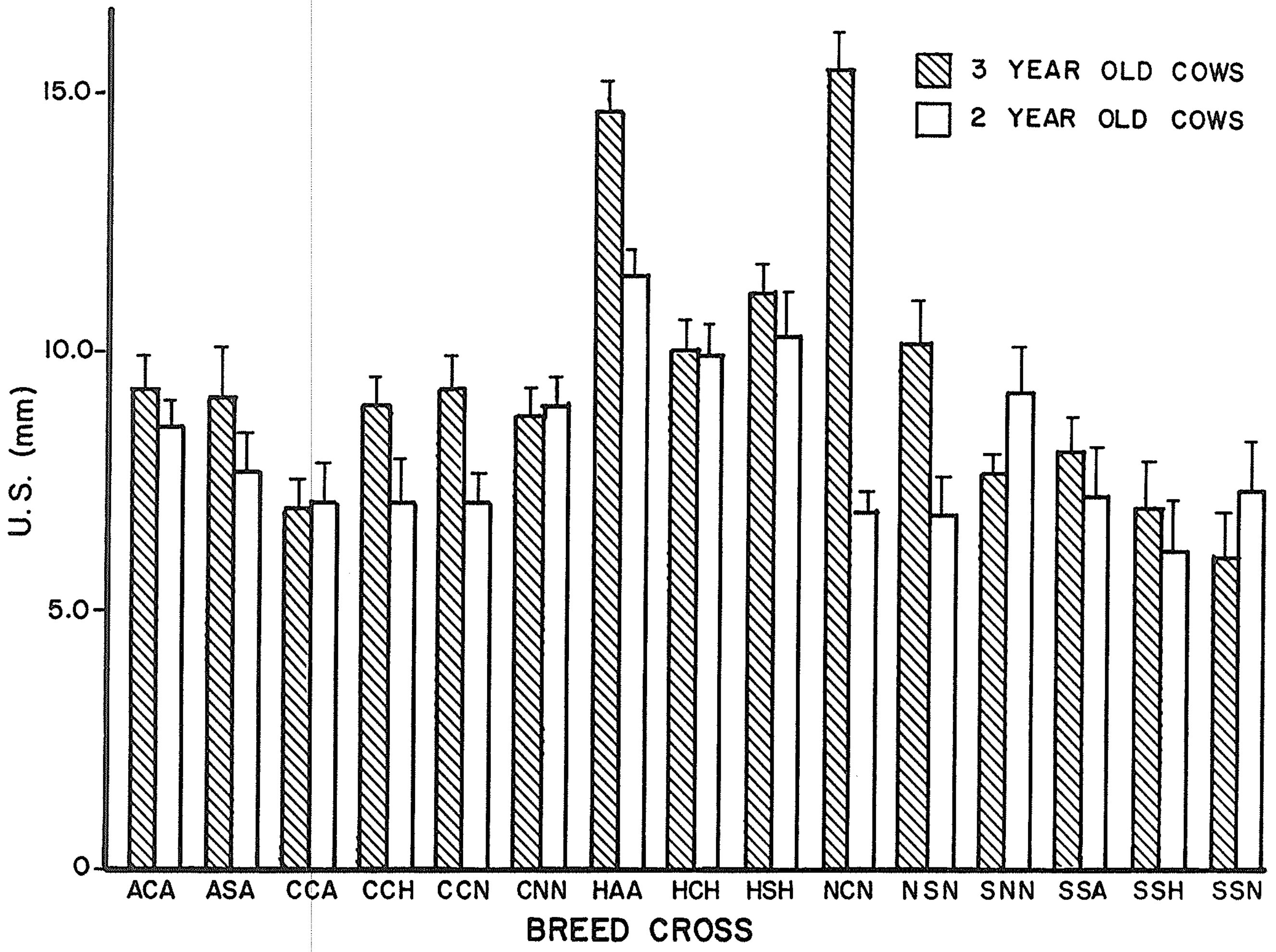


Figure 12. Least squares means ± standard errors of ultrasonic subcutaneous fat depth (U.S.) by breed cross and age of cow.

1.10.4.3 Contrasts

Differences in U.S. among breed crosses are summarized in Table 8.

(1) Two-Year-Old Cows

HAA was significantly higher (p=0.0001) in U.S. than all other breed crosses combined. HAA was significantly higher (p=0.0001) than the exotic breed crosses, the British breed crosses, and the halfbloods. The exotic breed crosses had significantly lower U.S. than both the British breed crosses (p=0.0002) and the halfbloods (p=0.0001). The British breed crosses did not differ (p>0.05) from the halfbloods.

Within the exotic group, the Charolais breed crosses did not differ (p>0.05) from the Simmental breed crosses.

Within the British group, the Hereford breed crosses were significantly higher than the Angus plus Shorthorn breed crosses (p=0.0001), as well as than the Angus breed crosses (p=0.0004) and the Shorthorn breed crosses (p=0.0001) alone. The Shorthorn breed crosses were significantly lower than the Angus plus Hereford breed crosses (p=0.0001), as well as than the Hereford breed crosses (p=0.0001) and the Angus breed crosses (p=0.006) separately.

(2) Three-Year-Old Cows

HAA was significantly higher (p=0.0001) in U.S. than all other breed crosses combined. HAA was significantly higher (p=0.0001) than the exotic breed crosses, the British breed crosses, and the halfbloods. The British breed crosses had significantly higher (p=0.0001) U.S. than both the exotic breed crosses and the halfbloods. The exotic breed crosses did not differ (p>0.05) from the halfbloods.

Within the exotic group, the Charolais breed crosses had significantly higher (p=0.04) U.S. than the Simmental breed crosses.

Within the British group, the Angus breed crosses were significantly lower (p=0.001) than the Hereford plus Shorthorn breed crosses. Individually, the Angus breed crosses were significantly lower (p=0.0001) than the Shorthorn breed crosses, but did not differ (p>0.05) from the Hereford breed crosses. The Shorthorn breed crosses were significantly higher than the Angus plus Hereford breed crosses (p=0.0001), as well as than the Hereford breed crosses (p=0.005) and the Angus breed crosses (p=0.0001) separately. However, an examination of the raw data for U.S. measurements of individual cows revealed that the extraordinarily high value of the three year old Shorthorn breed cross cows, in terms of U.S., was due solely to the very high ultrasonic subcutaneous fat measurements of one cow within the NCN breed cross.

DISCUSSION

1.11 INTRODUCTION

An increase in the length of the hair fibres comprising the pelage is a direct manifestation of the hair growth processes. A change in hair weight per unit area, on the other hand, encompasses both the processes of hair growth and shedding (Webster *et al*. 1970), while an increase in pelage depth may be a result either of increased hair length, temporary piloerection, or both. Because increases in hair length throughout the winter and differences in hair length among breed crosses are direct indicators of the growth of the winter pelage in these breed crosses, length results will be discussed first. A discussion of pelage depth, which is a function of hair length, curvature, and angle of attachment (Schleger and Turner 1960), will follow. Finally, hair weight per unit area, which depends on both growth and shedding of the pelage, and which is a function of hair length, diameter, and number (Schleger and Turner 1960) will be discussed.

1.12 LENGTH

In the present study, measurements of hair length were taken from the hip of fifteen breed crosses of beef cows to estimate breed cross differences in the insulative value of the pelage. Pan (1964) found the hip area of Jersey cattle to be the most representative of mean hair length of the twenty-one areas of the body tested.

Neurand *et al*. (1980) reported that, in cattle, autumn shedding began in mid-August and ended in October. The present study period began November 5. Presumably, all cows in the experiment had fully completed their autumn shed and had commenced growth of the winter pelage.

The higher hair length intercept of two-year-old cows compared to three-year-old cows in Experiment Two suggests that the younger cows began growth of the winter pelage sooner than the older cows. Hayman (1965) found that the restriction of energy intake in cattle induced early commencement of winter hair growth. Thus, body condition appears to influence winter hair growth. In the present study, it was found that younger cows had significantly less subcutaneous fat that did older cows. Possibly, two-year-old cows commenced winter hair growth earlier than three-year-old cows to compensate for the reduced subcutaneous fat insulation.

In Experiment Two, when all breed crosses were separated into British, exotic, or halfblood groups and compared to the Hereford x Angus standard breed cross, it was found that Hereford x Angus began the winter study period with shorter hair length than the exotics and the halfbloods, but not the British breed crosses. This appears to be primarily because of the Angus breed crosses, contained within the British group, which also began the winter with a short hair length.

Although Hereford x Angus began the winter study period with shorter hair length, the rate of increase of hair length throughout the winter study period for Hereford x Angus was the same as for the British and halfblood breed crosses, but more rapid than for the exotic breed crosses (See Figure C1 in Appendix C).

The exotic breed crosses began the winter study period with longer hair length than the British breed crosses and Hereford x Angus. The results suggest that exotic breed crosses have greater hair length early in the winter and that the increase in length of pelage during the winter is less for exotics than for British and Hereford x Angus. The exotic breed crosses were also found to have less ultrasonic subcutaneous fat in Experiment Two than the other breed crosses. This is in agreement with Rahnefeld et al. (1984), who found that Hereford x Angus carcasses had a higher average rib fat than various F1 crosses of Charolais, Simmental, Limousin, Chianina, Hereford, Angus, and Shorthorn to which Hereford x Angus were compared. It is possible that the growth of the winter pelage began sooner in exotic breed crosses and that the comparisons made during the winter study period represented the most rapid phase of growth in the British breed crosses and Hereford x Angus and the latter phase of growth in the exotic breed crosses. This seems likely, in that exotic breed crosses had less subcutaneous fat than other breed cross groups and, therefore, as suggested for the two-year-old cows compared to three-year-old cows, may have been more cold stressed than the British breed crosses and Hereford x Angus. It therefore seems possible that exotic breed crosses would begin rapid hair growth earlier than Hereford x Angus cows which were in better condition.

Whether exotic breed crosses have longer hair length than British breed crosses and Hereford x Angus throughout the entire year was not determined by this study. Bianca *et al.* (1974) found that Simmental pelages consisted of longer fibres than Holstein or Brown Swiss pelages at all times of the year.

There were differences in hair length among breed crosses within the British group. The Shorthorn breed crosses began the winter study period with the longest hair length and subsequently had the lowest rate of increase in hair length throughout the winter, while Angus breed crosses began the winter study period with the shortest hair length, but increased length of hair throughout the winter at a higher rate than Shorthorn and at the same rate as the Hereford breed crosses (Figure C2). Evaluation of the ultrasonic subcutaneous fat depth of these breed crosses does not indicate that differences in hair length were related to amount of subcutaneous fat of each breed cross.

There appear to be no studies reported in the literature which compare the hair coat lengths of the particular breed crosses of cattle of British and exotic origin which were studied in this experiment.

Log hair length increased linearly with log time during the winter study period of Experiment Two, which suggests a curvilinear pattern in hair length increase over time in the untransformed data. Thus as winter progressed, the increase in hair length per month got progressively smaller. The data in Table A4 shows that in some breed crosses x age groups hair length actually decreased between periods 4 and 5. This suggests that the cessation of winter hair growth and the onset of spring shedding may have commenced by February 26. This is in agreement with the findings of Hayman and Nay (1961) and Neurand *et al*. (1980) who reported the onset of spring shedding in cattle in a temperate climate to begin five to ten weeks and six to nine weeks following the winter solstice, respectively.

1.13 DEPTH

The depth of the pelage has a major influence upon insulation (Hart 1956; Schleger and Turner 1960; Berry and Shanklin 1961; Bennett 1964; Mount 1979; Jacobsen 1980), because a deep coat stabilizes more still air than a shallow one. Hart (1956) determined that a change in pelage depth from summer to winter was the primary factor in seasonal changes in the insulative quality of the pelage.

In Experiment Two, pelage depth was measured on the hip. Berry and Shanklin (1961) reported that measurements of pelage depth taken from the hip of dairy cows varied linearly with total insulation as determined by a heat flow meter. The choice of the hip area as sampling site for estimating pelage depth is also supported by the results presented in Appendix D, where a cattle hide that had been preserved in brine was used to examine pelage characteristics across an entire hide. Depth measurements from the hip area of the hide studied did not differ from depth measurements from the other nineteen areas of the hide.

There were some similarities between hair depth and hair length, in terms of breed cross differences. In the study of hair depth in Experiment Two, as was true for the measurement of hair length in the same experiment, the exotic breed crosses and the halfbloods had a higher intercept hair depth than the Hereford x Angus and the British breed crosses. This is in agreement with Ames and Insley (1975) who found that hides from Charolais cattle had deeper coats than hides from Hereford and Angus cattle.

The rate of increase in pelage depth for Hereford x Angus throughout Experiment Two was the same as for the British breed crosses, but more rapid than for the exotic breed crosses and the halfbloods. The results suggest that exotic breed crosses and halfbloods have greater pelage depth early in the winter and that the increase in depth of pelage during the winter is less for exotic breed crosses and halfbloods than for British breed crosses and Hereford x Angus (Figure C3).

Within the group of exotic breed crosses, Charolais breed crosses began the winter study period of Experiment Two with a thicker pelage depth than Simmental breed crosses, but subsequently had a lower rate of increase in pelage depth throughout the winter (Figure C4). The difference in pelage depth between Charolais and Simmental breed crosses was not the result of a difference in hair length, as these breed crosses showed no difference in hair length intercept or rate of increase throughout the winter. It is possible that Charolais breed crosses had more curvature to their hair fibres than did Simmental breed crosses, resulting in a pelage of greater depth, but of equivalent hair fibre length, to that of Simmental. Another explanation may be that, at the time of measuring, Charolais breed crosses were piloerected and Simmental breed crosses were not. This seems unlikely, however, as hair coat measurements were made in a heated building.

As was true for the analysis of hair length data, log hair depth increased linearly with log time during the winter study period of Experiment Two, which suggests a curvilinear pattern of hair depth increase over time in the untransformed data. Thus as the winter progressed, the increase in hair depth per month got progressively smaller. The data in Table A5 shows that in some breed cross x age groups hair depth actually decreased between periods 4 and 5. Cessation of winter hair growth may have commenced by February 26.

1.14 WEIGHT

In Experiment One and Two of the present study, measurements of hair weight per unit area were taken from the hip. Berry and Shanklin (1961) reported that measurements of hair weight per unit area taken from the hip of dairy calves varied linearly with total insulation as determined by a heat flow meter. The choice of the hip area as sampling site for estimating hair weight is also supported by the results presented in Appendix D, where hair weight measurements from the hip were shown to be representative of hair weight measurements from across the entire hide, and Appendix E, where hair weight measurements from the hip were correlated with hair weight measurements from the side of the body and the neck.

Hair weight per unit area is a function of hair length, diameter, and number (Schleger and Turner 1960) and would thus be influenced by both hair growth and shedding.

In Experiment One of the present study, eight of the fifteen breed crosses demonstrated an effect of age upon intercept hair weight, while seven of the fifteen breed crosses did not. In the breed crosses that showed an age effect (ASA, CCA, CCN, NSN, SNN, SSA, SSH, and SSN), one-year-old cows began the winter study period with a greater hair weight per unit area than did two- and three-year-old cows. In these breed crosses, younger cows must have either began the winter study period with longer hair length than older cows or with a greater number of hairs per unit area than older cows. Neither hair length nor number of hairs per unit area were measured in Experiment One. Measurement of hair length in Experiment Two showed that two-year-old cows did begin the winter study period with longer hair than three-year-old cows. However, a comparison of hair length between two- and three-year-old cows (Experiment Two) may not be relevant to a comparison between one- and two- to three-year-old cows (Experiment One).

Carter and Dowling (1954) found that hair density in the adult cow was much less than at birth and that the density of hair follicles per unit area dropped dramatically from birth to three years of age. This presumably reflects an increasing body size coupled with a stable hair follicle population. That two- and three-year-old cows began the winter with lighter hair weight per unit area than one-year-old cows may thus be strictly a consequence of an increase in body size coupled with a stable hair follicle population.

The breed crosses which showed an effect of age upon intercept hair weight in Experiment One were primarily of exotic origin, while those that did not show an effect of age were primarily of British origin. Exotic breed crosses grow faster than British breed crosses (Rahnefeld _et_ _al_. submitted for publication), and it is therefore not surprising that the negative effect of age upon hair follicle density would be more prevalent in the faster growing exotic breed crosses.

As Experiment Two was conducted in the winter following Experiment One, all experimental cows were a year older than in Experiment One. In Experiment Two there was no effect of age upon hair weight intercept. Thus, hair weight of two-year-old cows was not different from that of three-year-old cows. The dramatic drop in hair follicle density from birth to three years of age (Carter and Dowling 1954) thus likely occurs before two years of age.

In Experiment One of the present study, one-year-old cows had a lower rate of increase in hair weight per unit area over the winter study period than did two- and three-year-old cows, but there was no interaction of age and breed cross, as was found for hair weight intercept. Thus, the one-year-old cows of the breed crosses ASA, CCA, CCN, NSN, SNN, SSA, SSH, and SSN had a greater hair weight intercept than older cows, but the hair weight slope, or rate of increase in hair weight, of these one-year-old cows equalled that of the other one-year-old breed crosses, and that of all one-year-old cows was less than that of two- and three-year-old cows. The pelage insulation disadvantage of the two- and three-year-old cows observed early in the winter (intercept) would thus tend to have disappeared by the end of the study in the ASA, CCA, CCN, NSN, SNN, SSA, SSH, and SSN breed crosses. In contrast, in the ACA, CCH, CNN, HAA, HCH, HSH, and NCN breed crosses, differences in pelage weight would have been increasingly apparent over time as the slope of two- and three-year-old cows was greater than that of one-year-old cows, but intercepts did not differ. If younger cows had begun winter hair growth earlier than older cows, then the lower rate of growth in younger cows could reflect the fact that the younger cows had approached the latter part of the growth phase during the study period (Figure C5).

The possible early commencement of growth of the winter pelage in younger cows could have been a result of greater winter nutritional stress in younger cows. Cows were fed on a pen basis to achieve maintenance of the pen. Perhaps competition for feed was a factor which resulted in younger cows being leaner than older cows. However, this possibility cannot be verified from ultrasonic subcutaneous fat data, as one-year-old cows were not ultrasonically probed for subcutaneous fat thickness in Experiment One. In Experiment Two, however, it was shown that younger cows had lower subcutaneous fat thickness than older cows throughout the winter. Further studies are required to clarify the interaction of breed cross and age on pelage growth. A sampling schedule commencing in September and extending to April would be necessary to clarify this interaction.

In Experiment Two of the present study, the two- and the three-year-old cows did not differ in hair weight intercept, but the older cows had a greater rate of increase in hair weight over the winter. Also, hair length was longer at the beginning of the winter study period in the two-year-old cows, but there was no difference in the rates of increase in hair length over the winter between two- and three-year-old cows. Thus three-year-old cows had a lower hair length intercept but a hair weight intercept similar to two-year-old cows.

Since it is unlikely that three-year-old cows would have a greater hair follicle concentration than two-year-old cows (Carter and Dowling 1954), the discrepancy between hair weight and hair length for these two age groups could perhaps be explained by a difference in hair fibre diameter between two- and three-year-old cows. Turner and Schleger (1970) found that, in unmedullated hair, an increase in diameter was associated with an increase in hair weight per unit area. If three-year-old cows had pelages comprised of hair fibres of greater diameter than those in pelages of two-year-old cows, this could explain why younger cows began the winter study period with the same hair weight per unit area, but longer hair length than, older cows. This would also explain why older cows had a higher rate of increase in hair weight, but not length, than younger cows. There has been no research comparing fibre diameter in cows of different ages.

In Experiment One of the present study, the exotic breed crosses had a heavier intercept hair weight than did the British breed crosses and the halfbloods in the one-year-old cows, but did not differ in intercept in the two- and three-year -old cows. As hair length was not measured in Experiment One, it is not known whether the difference in hair weight among breed crosses within the one-year-old cows was due to a difference in hair length or other hair characteristics. It is likely that one-year-old exotic cows of Experiment One had longer hair, as this was the case in Experiment Two for two-year-old cows. For the cows that were two and three years old in Experiment One, there was no difference in intercept hair weight among breed cross groups. Although it is likely that the exotic breed crosses had longer intercept hair length than British breed crosses (based upon the results of hair length comparisons in Experiment Two), perhaps in the older cows, the exotic breed crosses had grown to a greater body size than the British breed crosses and the halfbloods, such that a greater increase in hair length was not reflected in hair weight because of a decrease in hair follicle density.

In Experiment One, within groups of exotic breed crosses, Simmental breed crosses had heavier intercept hair weight than Charolais breed crosses within the younger cows, but had lighter intercept hair weight within the older cows. Evaluation of the hair length data in Experiment Two suggests that there may be no difference in hair length between these breed crosses in Experiment One. It is possible that, at a very young age, Charolais breed crosses were larger than Simmental breed crosses, resulting in a denser concentration of hair follicles in Simmental, compared to Charolais, breed crosses and, consequently, a heavier hair weight. However, Lawson _et_ _al_. (1980) found that at eighteen months of age, Charolais-cross heifers did not differ in body weight from Simmental-cross heifers. Perhaps Simmental breed crosses grew more rapidly in their second and third year of life than did Charolais breed crosses, which would then result in a denser concentration of hair follicles and a heavier hair weight in Charolais, rather than Simmental, breed crosses. However, Lawson _et_ _al_. (1980) found that by thirty months of age, Charolais-cross cows had heavier body weights than Simmental-cross cows.

Within the group of British breed crosses in Experiment One, there was no difference in intercept hair weight within the one-year-old cows, but for two- and three-year-old cows, Hereford breed crosses had a heavier intercept hair weight than Angus breed crosses. It seems unlikely that two- and three-year-old Hereford breed cross cows would have a smaller body size and, consequently, a greater hair follicle population than Angus breed cross cows. Although Angus calves generally have a lower birth weight than Hereford calves, weaning weights are generally comparable to those of Hereford calves (Diggins and Bundy 1962). It is possible that, within the older cows, the Hereford breed crosses had either longer hair length or a greater hair fibre diameter than the Angus breed crosses.

The halfblood cows had a faster rate of increase in hair weight per unit area over the winter study period in Experiment One than did Hereford x Angus, the exotic breed crosses, or the British breed crosses (Figure C6). The halfbloods were found to have lower subcutaneous fat thickness than the Hereford x Angus and the British breed crosses, but not lower than the exotic breed crosses. It is possible that the lower subcutaneous fat of the halfbloods necessitated a large increase in hair cover over the winter to provide an alternate source of insulation. As hair length was not measured in Experiment One, it is possible only to speculate that perhaps the faster rate of increase in hair weight in the halfbloods was due to a faster rate of increase in hair length.

In Experiment Two of the present study, although there was no difference in the slope of the hair weight growth curve among breed crosses, the exotic breed crosses had a heavier hair weight intercept than the British breed crosses. This was associated with a longer hair length in the exotic, as compared to the British, breed crosses. Exotic breed crosses were found to have less subcutaneous fat than British breed crosses. It is possible that the exotic breed crosses began growth of the winter pelage earlier in the fall than did the British breed crosses to compensate for a thinner layer of subcutaneous fat.

Within the British group of breed crosses in Experiment Two, the Shorthorn breed crosses had a heavier hair weight intercept than the Angus breed crosses. This corresponded with the longer hair length reported in the Shorthorn, as compared to the Angus, breed crosses at the beginning of the winter study period. Ultrasonic evaluation of the thickness of the subcutaneous fat of these breed crosses did not indicate that differences in hair weight per unit area and hair length between these breed crosses were related to amount of subcutaneous fat.

Hayman and Nay (1961) reported that the onset of spring shedding in cattle in a temperate environment could begin as early as five weeks after the winter solstice. Neurand *et al*. (1980) and Yeates (1955) found evidence of spring shedding six to nine weeks and ten to twelve weeks following the winter solstice, respectively. Hair weight per unit area in

Experiment One increased linearly during the winter study period, which extended from November 9 to February 1. Thus, in Experiment One there was no indication of the cessation of winter hair growth, let alone the onset of spring shedding, in any breed cross during the study period, which ended six weeks after the winter solstice. Extension of the winter study period further into the spring would have allowed for the detection of a decline in hair weight, indicative of the onset of spring shedding.

In Experiment Two, the winter study period was extended a month further into the spring, to February 27. Log hair weight increased linearly with log time during the winter study period, which suggests a curvilinear pattern in hair weight per unit area over time in the untransformed data. This would indicate that, as the winter progressed, the increase in hair weight per unit area each month got progressively smaller. However, Table A3 shows that in some breed cross x age groups hair weight per unit area in Experiment Two actually decreased between periods 4 and 5. This suggests that cessation of winter hair growth and the onset of spring shedding may have commenced by February 26.

SUMMARY AND CONCLUSIONS

The breed cross used as a standard in this study, Hereford x Angus, had a thicker layer of subcutaneous fat, coupled with shorter hair length, than all other breed crosses.

Exotic breed crosses may have begun growth of the winter pelage earlier than British breed crosses and Hereford x Angus because they had less condition than the other breed crosses. At the beginning of the study period, the exotic breed crosses tended to have longer hair length, deeper pelage depth, and heavier hair weight per unit area, combined with less ultrasonically determined subcutaneous fat, than other breed crosses.

Younger cows, likely because of their smaller body size coupled with a stable hair follicle population, had a greater hair weight per unit area than older cows. The difference was more prevalent in one-year-old versus two- and three-year-old cows than in two-year-old versus three-year-old cows. The age difference was also more prevalent in exotic breed crosses than in British breed crosses, presumably because exotic breed crosses grew at a faster rate.

An alternate explanation is that younger cows may have begun growth of the winter pelage earlier than older cows because of poor condition. At the beginning of the study period, younger cows had longer hair length and a thinner layer of subcutaneous fat than did older cows.

Hair weight per unit area in Experiment One increased linearly throughout the winter study period, indicating that the winter pelage was still growing at the beginning of February.

Logarithmic transformation of hair data in Experiment Two showed a linear relationship of log hair weight, log hair length, and log hair depth over log time which extended to February 27. Thus, these hair characteristics followed a curvilinear pattern over the winter in the untransformed data, indicating that the rate of hair growth became progressively smaller as the winter progressed.

There was no clear indication of breed cross differences in cessation of winter hair growth.

Further studies, with an extension of the winter study period further into the spring, are necessary to examine the effect of breed cross on the time of cessation of winter hair growth and the onset of spring shedding.

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APPENDIX A. Least squares means ± standard errors for monthly measurements of hair coat characters and ultrasonic subcutaneous fat depth within breed cross and age of cow.

Table A1. Least squares means ± standard errors for monthly hair weight measurements (g/cm^2) within breed cross and age of cow.

BREED CROSS	AGE (YRS)	MONTH (1983/84)			
		NOVEMBER	DECEMBER	JANUARY	FEBRUARY
ACA	1	0.56 ± 0.08	0.67 ± 0.08	0.86 ± 0.08	1.06 ± 0.08
"	2+3	0.65 ± 0.08	0.89 ± 0.08	0.93 ± 0.08	1.21 ± 0.08
ASA	1	0.30 ± 0.08	0.68 ± 0.08	0.60 ± 0.08	0.93 ± 0.08
"	2+3	0.59 ± 0.09	0.76 ± 0.09	0.90 ± 0.09	0.98 ± 0.10
CCA	1	0.72 ± 0.08	0.86 ± 0.08	1.18 ± 0.08	1.27 ± 0.08
"	2+3	0.88 ± 0.10	1.03 ± 0.10	1.15 ± 0.10	1.17 ± 0.10
CCH	1	0.82 ± 0.08	1.07 ± 0.07	0.92 ± 0.07	1.29 ± 0.07
"	2+3	0.58 ± 0.10	0.81 ± 0.12	0.93 ± 0.10	1.07 ± 0.10
CCN	1	0.56 ± 0.10	0.74 ± 0.11	1.11 ± 0.10	1.38 ± 0.10
"	2+3	0.69 ± 0.08	0.92 ± 0.08	1.09 ± 0.08	1.29 ± 0.08
CNN	1	0.54 ± 0.09	0.91 ± 0.09	1.02 ± 0.09	1.44 ± 0.09
"	2+3	0.60 ± 0.09	0.82 ± 0.09	0.88 ± 0.10	1.27 ± 0.09
HAA	1	0.60 ± 0.06	0.88 ± 0.06	0.84 ± 0.06	1.10 ± 0.06
"	2+3	0.64 ± 0.08	0.99 ± 0.08	0.94 ± 0.08	1.26 ± 0.08
HCH	1	0.72 ± 0.05	0.98 ± 0.06	1.00 ± 0.05	1.27 ± 0.05
"	2+3	0.70 ± 0.08	1.01 ± 0.09	0.96 ± 0.08	1.30 ± 0.08
HSH	1	0.69 ± 0.08	0.88 ± 0.08	0.81 ± 0.08	1.28 ± 0.08
"	2+3	0.83 ± 0.14	0.93 ± 0.14	0.99 ± 0.14	1.23 ± 0.14
NCN	1	0.55 ± 0.12	0.72 ± 0.12	0.79 ± 0.12	0.91 ± 0.12
"	2+3	0.55 ± 0.06	0.89 ± 0.06	0.87 ± 0.06	1.17 ± 0.06
NSN	1	0.41 ± 0.12	0.69 ± 0.12	0.84 ± 0.12	1.22 ± 0.12
"	2+3	0.69 ± 0.12	0.75 ± 0.18	1.07 ± 0.12	1.20 ± 0.12
SNN	1	0.47 ± 0.06	0.70 ± 0.06	0.89 ± 0.06	1.06 ± 0.06
"	2+3	0.80 ± 0.11	1.02 ± 0.11	1.11 ± 0.11	1.41 ± 0.11
SSA	1	0.49 ± 0.08	0.66 ± 0.08	0.91 ± 0.08	1.21 ± 0.08
"	2+3	0.62 ± 0.08	0.95 ± 0.12	0.90 ± 0.12	1.23 ± 0.12
SSH	1	0.68 ± 0.10	0.99 ± 0.10	0.91 ± 0.10	1.37 ± 0.10
"	2+3	0.96 ± 0.11	1.14 ± 0.12	1.14 ± 0.11	1.17 ± 0.12
SSN	1	0.48 ± 0.11	0.40 ± 0.12	0.94 ± 0.11	1.17 ± 0.11
"	2+3	0.95 ± 0.14	1.23 ± 0.14	1.08 ± 0.14	1.34 ± 0.14

Table A2. Least squares means ± standard errors for monthly ultrasonic subcutaneous fat measurements (mm) within breed cross.

BREED CROSS	MONTH (1983/84)				
	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
ACA	8.90 ± 1.08	9.79 ± 1.08	10.60 ± 1.08	8.69 ± 1.08	11.46 ± 1.08
ASA	8.50 ± 2.41	10.80 ± 2.41	7.70 ± 2.41	9.50 ± 2.41	8.20 ± 2.41
CCA	5.53 ± 1.03	6.06 ± 1.03	5.09 ± 1.03	6.39 ± 1.03	6.95 ± 1.03
CCH	6.98 ± 1.29	6.57 ± 1.29	8.51 ± 1.29	7.24 ± 1.29	9.28 ± 1.29
CCN	7.62 ± 1.39	7.55 ± 1.39	8.72 ± 1.39	9.60 ± 1.39	8.78 ± 1.39
CNN	8.80 ± 1.20	8.29 ± 1.20	8.68 ± 1.20	8.25 ± 1.20	8.82 ± 1.20
HAA	14.60 ± 1.52	16.60 ± 1.52	16.20 ± 1.52	16.86 ± 1.52	14.86 ± 1.52
HCH	8.21 ± 1.08	10.11 ± 1.08	9.36 ± 1.08	8.13 ± 1.08	10.44 ± 1.08
HSH	9.58 ± 1.14	7.59 ± 1.14	9.42 ± 1.14	12.43 ± 1.14	13.08 ± 1.14
NCN	4.40 ± 1.70	4.18 ± 1.70	4.90 ± 1.70	7.35 ± 1.70	5.58 ± 1.70
NSN	8.82 ± 1.70	8.60 ± 1.70	10.25 ± 1.70	10.40 ± 1.70	10.60 ± 1.70
SNN	6.18 ± 0.80	6.59 ± 0.80	7.23 ± 0.80	7.29 ± 0.80	8.32 ± 0.80
SSA	7.45 ± 1.39	7.17 ± 1.39	7.17 ± 1.39	8.45 ± 1.39	8.37 ± 1.39
SSH	5.55 ± 1.39	5.33 ± 1.39	5.50 ± 1.39	7.85 ± 1.39	8.72 ± 1.39
SSN	5.92 ± 1.52	5.74 ± 1.52	6.34 ± 1.52	7.06 ± 1.52	7.92 ± 1.52

Table A3. Least squares means ± standard errors for monthly hair weight measurements (g/cm^2) within breed cross and age of cow.

BREED CROSS	AGE (YRS)	MONTH (1984/85)				
		NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
ACA	2	0.82 ±0.08	0.79 ±0.08	0.94 ±0.08	0.92 ±0.08	0.64 ±0.08
"	3	0.67 ±0.07	0.75 ±0.07	0.78 ±0.07	0.92 ±0.07	0.48 ±0.07
ASA	2	0.70 ±0.12	0.66 ±0.13	0.82 ±0.12	0.61 ±0.13	0.56 ±0.12
"	3	0.72 ±0.09	0.77 ±0.09	0.76 ±0.09	0.89 ±0.09	0.59 ±0.09
CCA	2	0.69 ±0.07	0.90 ±0.07	0.93 ±0.07	0.98 ±0.07	0.75 ±0.07
"	3	0.82 ±0.09	0.89 ±0.09	1.06 ±0.09	1.00 ±0.09	0.71 ±0.09
CCH	2	0.89 ±0.08	1.01 ±0.08	1.06 ±0.08	1.20 ±0.08	0.66 ±0.09
"	3	0.68 ±0.10	0.70 ±0.10	0.87 ±0.10	0.85 ±0.10	0.54 ±0.10
CCN	2	0.85 ±0.08	1.00 ±0.07	0.98 ±0.07	1.03 ±0.07	0.84 ±0.07
"	3	0.82 ±0.08	0.95 ±0.08	0.80 ±0.08	0.98 ±0.08	0.68 ±0.08
CNN	2	0.99 ±0.07	0.97 ±0.07	1.16 ±0.07	0.51 ±0.08	0.83 ±0.07
"	3	0.96 ±0.08	0.75 ±0.08	0.95 ±0.08	0.71 ±0.08	0.78 ±0.08
HAA	2	1.00 ±0.10	0.91 ±0.10	1.07 ±0.10	0.56 ±0.10	0.70 ±0.10
"	3	0.79 ±0.06	1.00 ±0.06	0.95 ±0.06	1.09 ±0.06	0.66 ±0.06
HCH	2	0.76 ±0.08	0.90 ±0.08	0.85 ±0.08	0.98 ±0.08	0.66 ±0.08
"	3	0.77 ±0.08	0.86 ±0.08	1.06 ±0.08	1.14 ±0.08	0.63 ±0.08
HSH	2	0.66 ±0.08	0.61 ±0.08	0.80 ±0.08	0.94 ±0.08	0.68 ±0.08
"	3	0.85 ±0.13	0.83 ±0.12	0.84 ±0.12	1.04 ±0.12	0.62 ±0.12
NCN	2	0.56 ±0.10	0.60 ±0.10	0.68 ±0.12	0.83 ±0.10	0.74 ±0.12
"	3	0.79 ±0.06	0.81 ±0.06	0.78 ±0.06	0.86 ±0.06	0.69 ±0.06
NSN	2	0.78 ±0.12	0.82 ±0.09	1.02 ±0.09	0.80 ±0.09	0.70 ±0.09
"	3	0.75 ±0.12	0.81 ±0.10	0.80 ±0.10	0.89 ±0.10	0.79 ±0.10
SNN	2	0.85 ±0.06	0.89 ±0.06	0.93 ±0.06	0.55 ±0.06	0.79 ±0.06
"	3	0.96 ±0.12	1.07 ±0.12	1.10 ±0.12	0.87 ±0.12	0.84 ±0.12
SSA	2	0.79 ±0.09	0.91 ±0.09	0.88 ±0.09	0.54 ±0.09	0.62 ±0.09
"	3	0.93 ±0.13	0.64 ±0.13	0.73 ±0.13	1.11 ±0.13	0.42 ±0.13
SSH	2	0.99 ±0.12	0.87 ±0.12	1.08 ±0.12	1.10 ±0.13	0.77 ±0.12
"	3	0.85 ±0.12	0.96 ±0.12	1.06 ±0.12	1.02 ±0.12	0.79 ±0.12
SSN	2	0.71 ±0.12	0.75 ±0.12	0.92 ±0.12	0.91 ±0.12	0.62 ±0.12
"	3	1.07 ±0.13	1.04 ±0.13	1.02 ±0.16	1.14 ±0.13	0.55 ±0.13

Table A4. Least squares means ± standard errors for monthly hair length measurements (cm) within breed cross and age of cow.

BREED CROSS	AGE (YRS)	MONTH (1984/85)				
		NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
ACA	2	2.30 ±0.27	3.36 ±0.27	3.58 ±0.27	4.12 ±0.27	1.99 ±0.27
"	3	2.65 ±0.22	3.23 ±0.22	3.63 ±0.22	3.53 ±0.22	1.22 ±0.22
ASA	2	2.82 ±0.38	2.75 ±0.38	3.10 ±0.38	1.60 ±0.38	1.72 ±0.38
"	3	2.76 ±0.29	3.71 ±0.29	3.90 ±0.29	3.97 ±0.29	1.40 ±0.29
CCA	2	2.89 ±0.24	3.70 ±0.24	4.17 ±0.24	4.49 ±0.24	2.49 ±0.24
"	3	3.28 ±0.29	4.04 ±0.29	4.94 ±0.29	4.67 ±0.29	1.68 ±0.29
CCH	2	3.88 ±0.27	4.32 ±0.27	4.98 ±0.27	4.82 ±0.27	2.08 ±0.27
"	3	3.64 ±0.34	3.78 ±0.34	5.02 ±0.34	4.68 ±0.34	2.12 ±0.34
CCN	2	3.00 ±0.24	4.03 ±0.24	4.54 ±0.24	4.43 ±0.24	3.07 ±0.24
"	3	3.64 ±0.26	4.37 ±0.26	4.46 ±0.26	4.79 ±0.26	1.97 ±0.26
CNN	2	3.94 ±0.24	4.58 ±0.24	4.68 ±0.24	1.59 ±0.24	3.40 ±0.24
"	3	4.21 ±0.26	4.52 ±0.26	4.51 ±0.26	2.02 ±0.26	3.43 ±0.26
HAA	2	3.63 ±0.31	3.80 ±0.31	4.10 ±0.31	1.43 ±0.31	2.72 ±0.31
"	3	3.12 ±0.21	3.98 ±0.21	4.38 ±0.21	4.46 ±0.21	1.48 ±0.21
HCH	2	2.72 ±0.26	3.66 ±0.26	4.37 ±0.26	4.18 ±0.26	1.98 ±0.26
"	3	3.19 ±0.26	4.03 ±0.26	4.63 ±0.26	4.79 ±0.26	1.48 ±0.26
HSH	2	2.48 ±0.26	3.33 ±0.26	3.86 ±0.27	4.21 ±0.26	2.40 ±0.26
"	3	3.18 ±0.38	3.80 ±0.38	4.20 ±0.38	4.92 ±0.38	1.62 ±0.38
NCN	2	2.14 ±0.34	2.64 ±0.34	3.84 ±0.34	4.36 ±0.34	3.90 ±0.44
"	3	2.98 ±0.20	3.88 ±0.20	4.22 ±0.20	4.46 ±0.20	1.81 ±0.20
NSN	2	3.54 ±0.29	4.17 ±0.29	4.61 ±0.29	3.08 ±0.29	2.95 ±0.31
"	3	3.54 ±0.34	4.14 ±0.34	4.68 ±0.34	4.32 ±0.34	1.86 ±0.34
SNN	2	3.82 ±0.18	4.46 ±0.18	4.31 ±0.18	1.57 ±0.19	3.28 ±0.18
"	3	4.05 ±0.38	5.48 ±0.38	4.58 ±0.38	2.20 ±0.38	4.10 ±0.38
SSA	2	3.80 ±0.29	3.91 ±0.29	4.16 ±0.29	2.61 ±0.29	2.17 ±0.29
"	3	3.57 ±0.44	4.00 ±0.44	4.80 ±0.44	4.80 ±0.44	2.07 ±0.44
SSH	2	3.52 ±0.38	4.32 ±0.38	4.82 ±0.38	4.70 ±0.44	2.05 ±0.38
"	3	3.80 ±0.38	4.42 ±0.38	5.45 ±0.38	5.25 ±0.38	2.15 ±0.38
SSN	2	3.08 ±0.38	3.72 ±0.38	4.00 ±0.38	4.10 ±0.38	2.20 ±0.38
"	3	3.30 ±0.44	4.50 ±0.44	5.27 ±0.44	4.80 ±0.44	2.37 ±0.44

Table A5. Least squares means ± standard errors for monthly hair depth measurements (cm) within breed cross and age of cow.

BREED	AGE	MONTH (1984/85)				
CROSS	(YRS)	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
ACA	2	1.02 ± 0.10	1.21 ± 0.10	1.32 ± 0.10	1.54 ± 0.10	1.05 ± 0.10
"	3	1.06 ± 0.09	1.18 ± 0.09	1.26 ± 0.09	1.48 ± 0.09	0.50 ± 0.09
ASA	2	1.12 ± 0.15	1.30 ± 0.15	1.48 ± 0.15	0.62 ± 0.15	0.85 ± 0.15
"	3	1.38 ± 0.11	1.30 ± 0.11	1.26 ± 0.11	1.54 ± 0.11	0.77 ± 0.12
CCA	2	1.23 ± 0.09	1.44 ± 0.09	1.44 ± 0.09	1.46 ± 0.09	0.89 ± 0.09
"	3	1.41 ± 0.11	1.43 ± 0.11	1.31 ± 0.11	1.60 ± 0.11	0.71 ± 0.11
CCH	2	1.22 ± 0.10	1.31 ± 0.10	1.58 ± 0.10	1.55 ± 0.10	1.24 ± 0.10
"	3	1.36 ± 0.13	1.18 ± 0.13	1.56 ± 0.13	1.48 ± 0.13	1.20 ± 0.13
CCN	2	1.24 ± 0.10	1.35 ± 0.09	1.32 ± 0.09	1.41 ± 0.09	1.21 ± 0.09
"	3	1.49 ± 0.10	1.38 ± 0.10	1.29 ± 0.10	1.48 ± 0.10	1.01 ± 0.10
CNN	2	1.40 ± 0.09	1.50 ± 0.09	1.58 ± 0.09	0.68 ± 0.09	1.34 ± 0.09
"	3	1.28 ± 0.10	1.47 ± 0.10	1.41 ± 0.10	0.76 ± 0.10	1.08 ± 0.10
HAA	2	1.23 ± 0.12	1.38 ± 0.12	1.57 ± 0.12	0.58 ± 0.12	1.25 ± 0.12
"	3	1.27 ± 0.08	1.33 ± 0.08	1.56 ± 0.08	1.65 ± 0.08	0.60 ± 0.08
HCH	2	1.10 ± 0.10	1.33 ± 0.10	1.36 ± 0.10	1.40 ± 0.10	0.79 ± 0.10
"	3	1.40 ± 0.10	1.26 ± 0.10	1.38 ± 0.10	1.61 ± 0.10	0.67 ± 0.10
HSH	2	0.88 ± 0.10	1.10 ± 0.10	1.20 ± 0.10	1.38 ± 0.10	0.76 ± 0.10
"	3	0.85 ± 0.15	1.00 ± 0.15	1.45 ± 0.15	1.40 ± 0.15	0.62 ± 0.15
NCN	2	0.90 ± 0.13	1.06 ± 0.13	1.28 ± 0.13	1.16 ± 0.13	1.02 ± 0.15
"	3	1.22 ± 0.08	1.31 ± 0.08	1.24 ± 0.08	1.55 ± 0.08	0.55 ± 0.08
NSN	2	1.28 ± 0.11	1.46 ± 0.11	1.41 ± 0.11	1.18 ± 0.11	1.07 ± 0.11
"	3	1.30 ± 0.13	1.34 ± 0.13	1.30 ± 0.13	1.48 ± 0.13	0.84 ± 0.13
SNN	2	1.27 ± 0.07	1.57 ± 0.07	1.45 ± 0.07	0.72 ± 0.07	1.29 ± 0.07
"	3	1.15 ± 0.15	1.45 ± 0.15	1.40 ± 0.15	0.90 ± 0.15	1.35 ± 0.15
SSA	2	1.17 ± 0.11	1.26 ± 0.11	1.17 ± 0.11	0.97 ± 0.11	1.03 ± 0.11
"	3	1.37 ± 0.17	1.23 ± 0.17	1.27 ± 0.17	1.53 ± 0.17	0.73 ± 0.17
SSH	2	1.30 ± 0.15	1.28 ± 0.15	1.32 ± 0.15	1.73 ± 0.17	0.80 ± 0.15
"	3	1.45 ± 0.15	1.35 ± 0.15	1.42 ± 0.15	1.65 ± 0.15	0.82 ± 0.15
SSN	2	1.08 ± 0.15	1.15 ± 0.15	1.18 ± 0.15	1.38 ± 0.15	1.00 ± 0.15
"	3	1.73 ± 0.17	1.47 ± 0.17	1.63 ± 0.17	1.70 ± 0.17	0.73 ± 0.17

Table A6. Least squares means ± standard errors for monthly ultrasonic subcutaneous fat depth measurements (mm) within breed cross and age of cow.

BREED	AGE	MONTH (1984/85)				
CROSS	(YRS)	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH
ACA	2	8.32±1.17	9.12±1.17	7.51±1.17	9.19±1.17	8.63±1.17
"	3	8.24±1.43	8.49±1.43	9.19±1.43	11.59±1.43	8.88±1.43
ASA	2	6.38±1.53	7.30±1.53	7.04±1.53	9.57±1.53	8.37±1.53
"	3	9.52±2.03	9.68±2.03	10.50±2.03	8.00±2.03	8.42±2.03
CCA	2	5.67±1.53	6.28±1.53	7.23±1.53	8.00±1.53	8.53±1.53
"	3	4.43±1.28	5.54±1.28	7.15±1.28	7.61±1.28	9.83±1.28
CCH	2	5.74±1.81	6.54±1.81	7.54±1.81	7.14±1.81	8.52±1.81
"	3	7.34±1.43	7.85±1.43	9.91±1.43	9.92±1.43	9.61±1.43
CCN	2	6.23±1.35	6.52±1.35	6.71±1.35	8.46±1.35	7.51±1.35
"	3	8.59±1.28	7.80±1.28	10.60±1.28	10.02±1.28	9.53±1.28
CNN	2	6.79±1.35	8.22±1.35	9.89±1.35	9.47±1.35	10.22±1.35
"	3	7.21±1.28	9.28±1.28	9.24±1.28	8.47±1.28	9.30±1.28
HAA	2	10.55±1.12	10.71±1.12	12.34±1.12	12.72±1.12	10.71±1.12
"	3	15.33±1.66	14.77±1.66	15.65±1.66	14.83±1.66	12.68±1.66
HCH	2	8.67±1.35	9.71±1.35	10.67±1.35	11.38±1.35	9.07±1.35
"	3	6.07±1.35	7.49±1.35	9.69±1.35	11.26±1.35	15.63±1.35
HSH	2	9.50±2.03	8.55±2.03	11.60±2.03	11.35±2.03	10.42±2.03
"	3	10.16±1.35	10.21±1.35	11.40±1.35	11.38±1.35	12.48±1.35
NCN	2	5.56±1.05	6.57±1.05	7.20±1.05	7.26±1.05	7.49±1.05
"	3	15.68±1.81	14.80±1.81	16.94±1.81	18.10±1.81	10.82±2.03
NSN	2	5.32±1.81	6.00±1.81	6.00±1.81	6.94±1.81	9.40±1.81
"	3	9.54±1.53	9.94±1.53	10.47±1.53	11.24±1.53	9.80±1.53
SNN	2	7.32±2.03	7.60±2.03	9.50±2.03	10.40±2.03	11.32±2.03
"	3	6.73±0.96	6.69±0.96	7.77±0.96	8.06±0.96	8.71±0.96
SSA	2	6.23±2.34	6.33±2.34	6.77±2.34	7.43±2.34	9.10±2.34
"	3	5.76±1.53	6.24±1.53	7.86±1.53	8.33±1.53	12.10±1.53
SSH	2	4.58±2.03	6.68±2.03	6.28±2.03	7.60±2.03	5.92±2.03
"	3	5.08±2.03	6.18±2.03	7.00±2.03	7.57±2.34	8.75±2.03
SSN	2	7.10±2.34	6.77±2.34	7.77±2.34	7.57±2.34	7.43±2.34
"	3	3.92±2.03	4.02±2.03	5.15±2.03	5.00±2.03	11.22±2.03

APPENDIX B: AN EXAMINATION OF AN ALTERNATE MEANS OF HAIR LENGTH DETERMINATION

Previously shaved and bagged hairs were analyzed for length to determine whether an alternative method to measuring length of hair on the live animal was feasible. Twenty bagged hair samples, all collected in the same sampling period and each representing a sample from a different cow, were selected randomly. Each selected sample was subdivided into five subsamples and forty hairs were selected randomly from each subsample for length measurement, using a ruler lying flat on a paper backdrop. Wavy hairs were held straight for measurement. Table B1 gives least squares means for hair length of each subsample.

Two-way analysis of variance indicated that there was a significant difference (p=0.0001) in hair length among samples from different cows. There was also a significant difference (p=0.0001) in hair length among subsamples from an animal. Because hair lengths did differ among subsamples in a sample, the measurement of hair length on forty hairs of a subsample would be an inadequate method for estimating mean hair length in a sample.

Qualitative consideration of this method of measuring hair length following removal from the animal is suggestive of the reason for subsample variation. The method of hair removal itself altered the nature of the individual hair.

Table B1. *In situ* hair length and least squares means ± standard errors of subsample hair length

COW NO.	IN SITU HAIR LENGTH (cm)	SUBSAMPLE HAIR LENGTH (cm)				
		1	2	3	4	5
1	1.7	3.19±0.11	3.29±0.11	3.56±0.11	3.26±0.11	3.04±0.11
2	1.8	2.65±0.11	2.58±0.11	2.48±0.11	2.34±0.11	2.30±0.11
3	1.8	2.63±0.11	3.03±0.11	3.42±0.11	2.77±0.11	3.14±0.11
4	2.4	2.70±0.11	3.05±0.11	2.78±0.11	2.87±0.11	3.12±0.11
5	1.8	2.54±0.11	2.40±0.11	2.38±0.11	2.72±0.11	2.68±0.11
6	2.0	3.24±0.11	3.08±0.11	2.86±0.11	3.22±0.11	2.69±0.11
7	1.7	2.29±0.11	2.41±0.11	2.65±0.11	2.83±0.11	2.90±0.11
8	1.9	2.31±0.11	2.04±0.11	2.30±0.11	2.63±0.11	2.27±0.11
9	2.5	2.55±0.11	2.70±0.11	2.08±0.11	3.36±0.11	3.02±0.11
10	1.5	2.93±0.11	2.92±0.11	3.28±0.11	2.89±0.11	3.20±0.11
11	1.6	3.03±0.11	2.88±0.11	3.10±0.11	2.74±0.11	2.46±0.11
12	1.4	2.78±0.11	2.93±0.11	2.09±0.11	1.46±0.11	2.54±0.11
13	0.7	2.72±0.11	2.68±0.11	2.57±0.11	2.30±0.11	2.47±0.11
14	1.3	1.93±0.11	1.96±0.11	2.01±0.11	1.92±0.11	2.03±0.11
15	1.9	3.39±0.11	3.07±0.11	3.02±0.11	3.22±0.11	3.28±0.11
16	1.8	3.81±0.11	3.50±0.11	3.48±0.11	3.33±0.11	3.18±0.11
17	0.9	2.53±0.11	2.73±0.11	2.96±0.11	2.79±0.11	3.07±0.11
18	2.8	2.87±0.11	2.87±0.11	3.00±0.11	3.67±0.11	3.43±0.11
19	1.6	2.65±0.11	2.86±0.11	2.57±0.11	2.73±0.11	2.74±0.11
20	1.7	2.64±0.11	2.28±0.11	2.04±0.11	2.57±0.11	2.81±0.11

Two or sometimes three passes of the clipper blades over the sampling site were often required to completely remove hair. This resulted in bisection of some of the individual hairs and caused the length of hair in the collected sample to be less than representative of the length of hair on the animal. When selecting random hairs from subsamples for length determination, those hairs that had obviously been bisected with the clipper blades were avoided. It is probable that the *in situ* hair length measurements were lower than those from bagged hair samples because hair fibres were more fully straightened when measured from bagged hair samples than when measured on the animal.

A correlation coefficient for the mean of all five subsample hair lengths and actual hair length measured on the animal was calculated to determine how well mean subsample hair length correlated with on-animal hair length. A correlation coefficient of 29% (p=0.004) indicated that bagged hair estimates of hair length correlated poorly with actual on-animal hair lengths.

The measurement of hair lengths following shaving was found to be extremely time consuming. Considering the problems with the subsampling method, the poor correlation between bagged and on-animal hair length, and the prohibitive time factor involved in length determination, this method of hair length measurement is not recommended as an alternative to the measurement of length of hair on the live animal.

APPENDIX C: Regression lines for hair parameters of selected breed cross groups and age of cow groups.

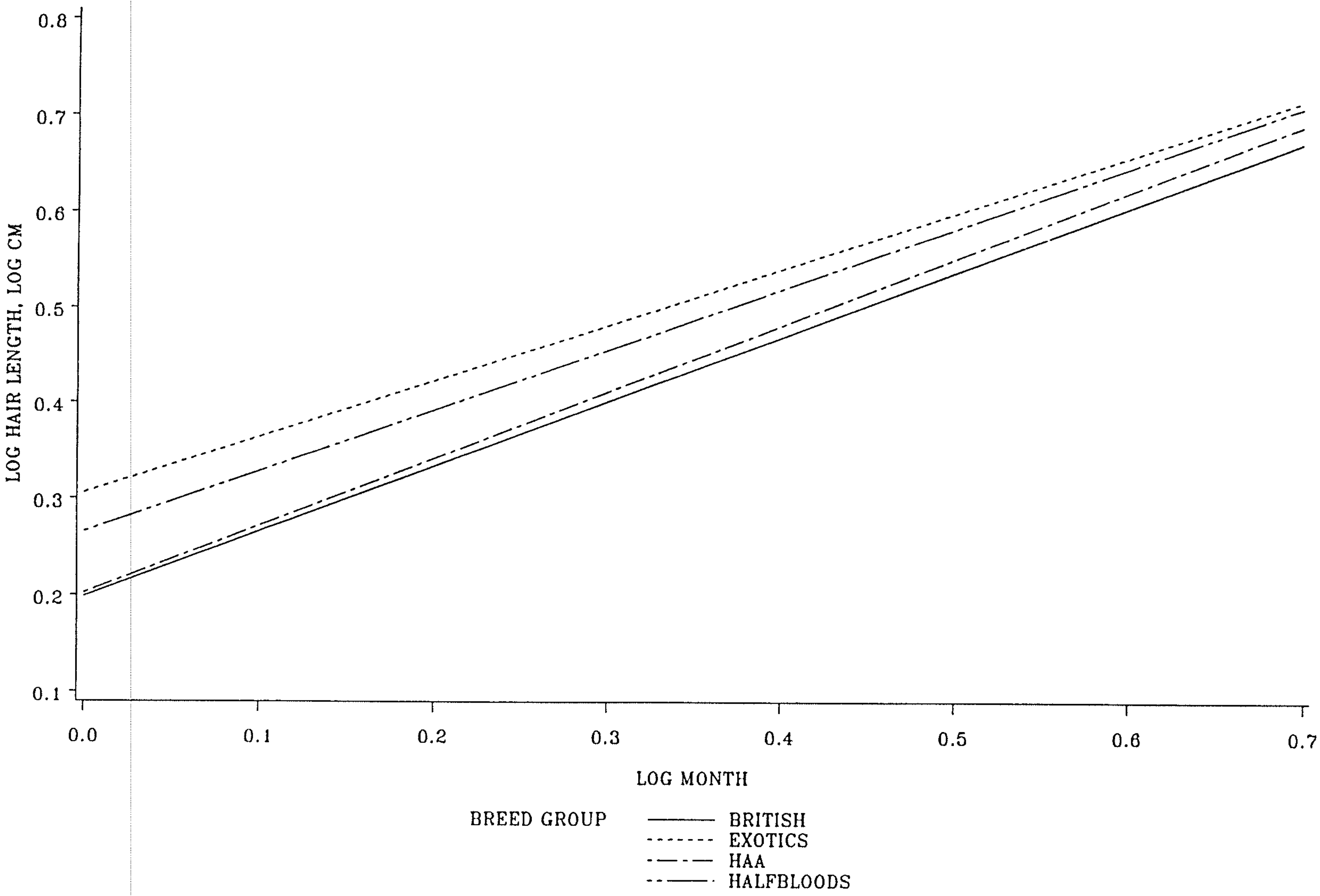


FIGURE C1 (EXPERIMENT TWO): LOG REGRESSIONS OF BREED GROUPS OVER WINTER

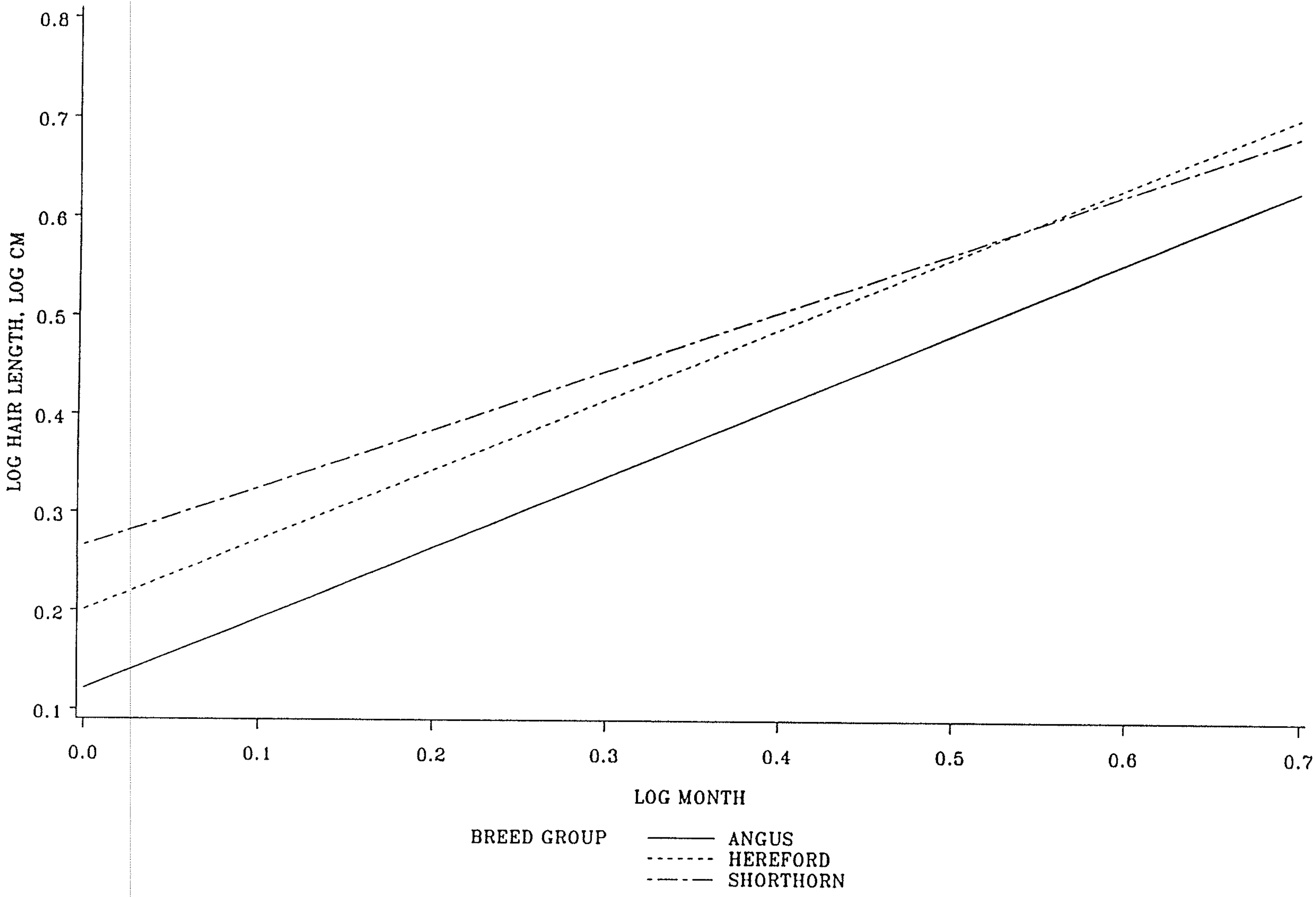


FIGURE C2 (EXPERIMENT TWO): LOG REGRESSIONS OF BREED GROUPS OVER WINTER

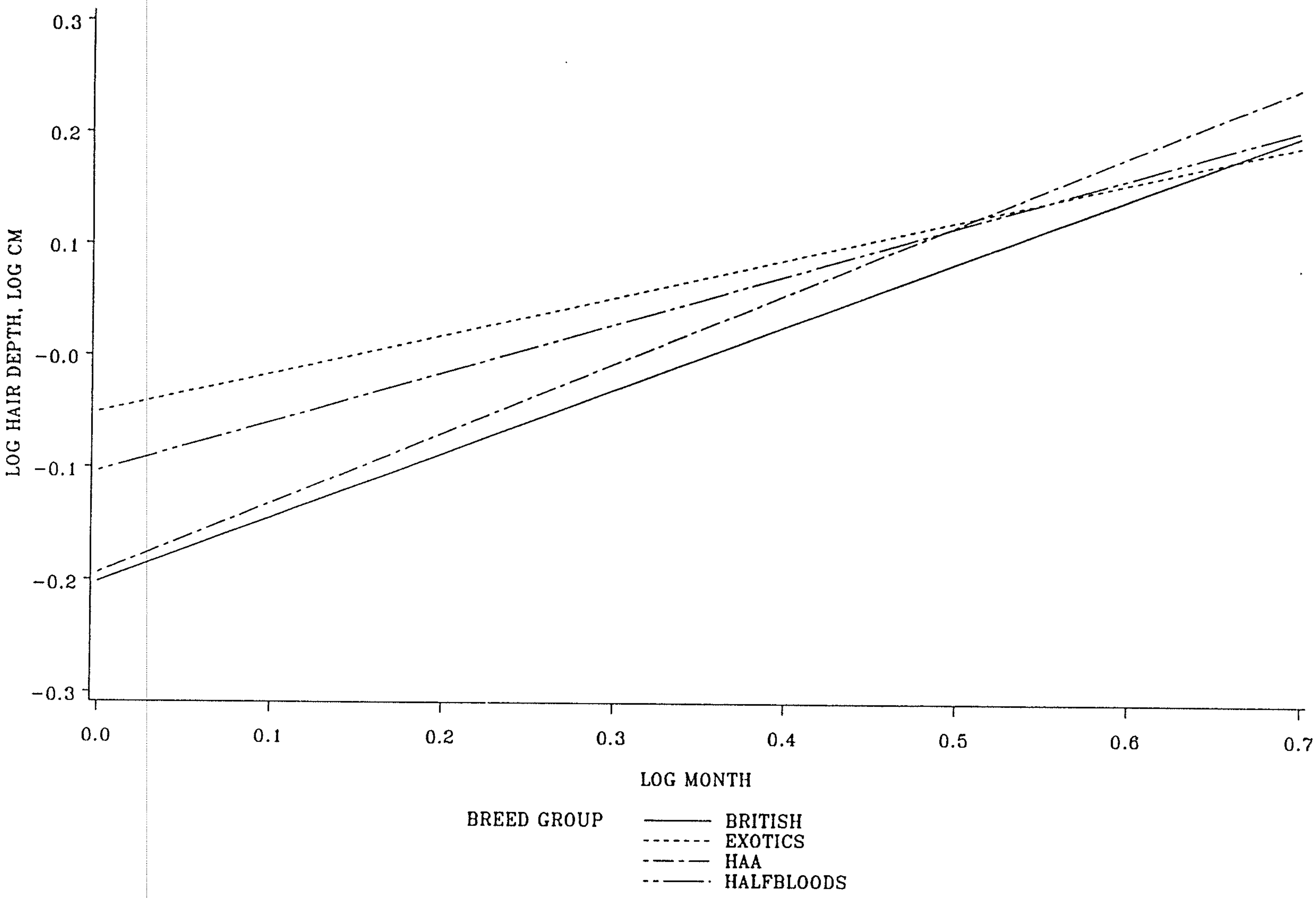


FIGURE C3 (EXPERIMENT TWO): LOG REGRESSIONS OF BREED GROUPS OVER WINTER

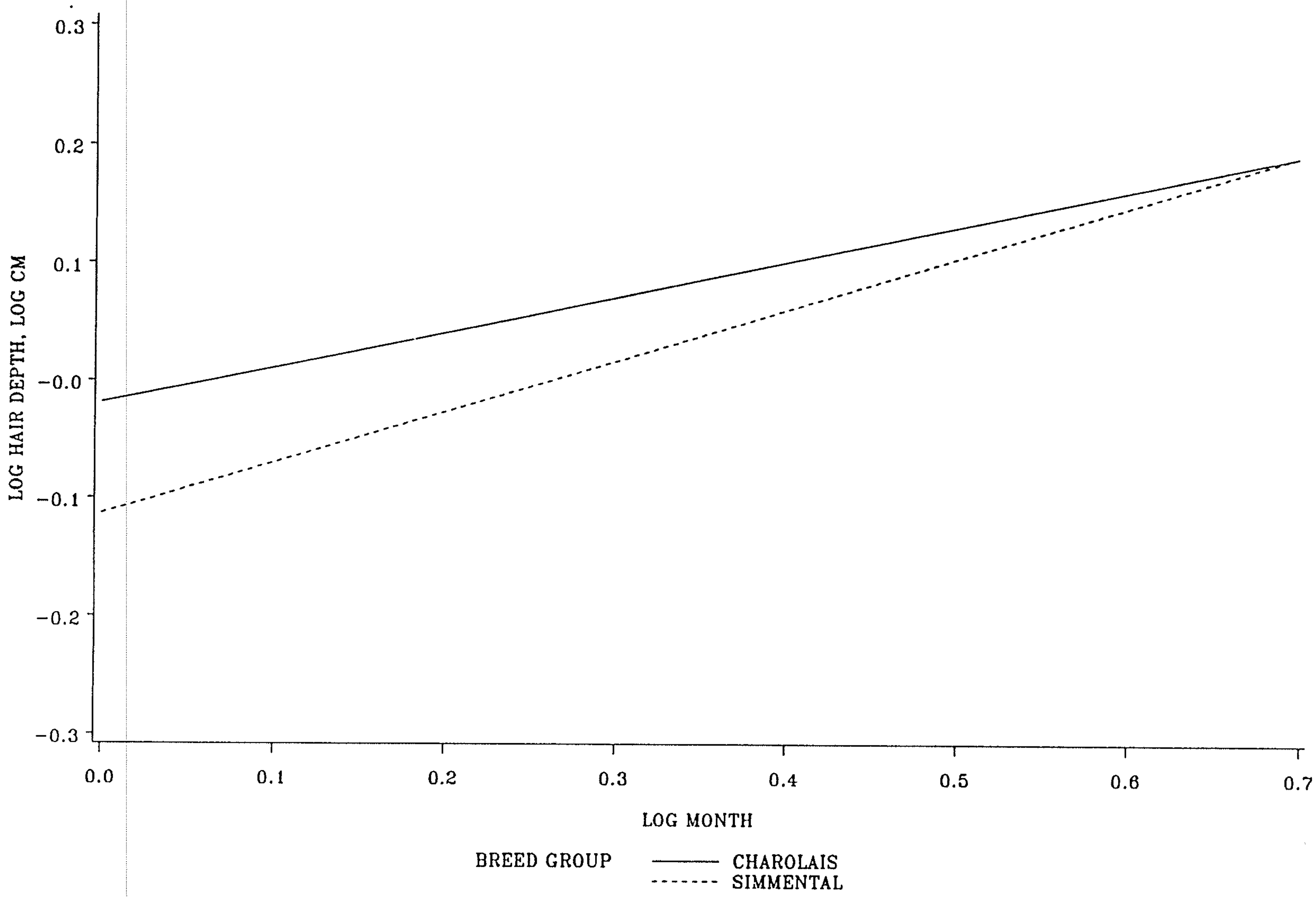


FIGURE C4 (EXPERIMENT TWO): LOG REGRESSIONS OF BREED GROUPS OVER WINTER

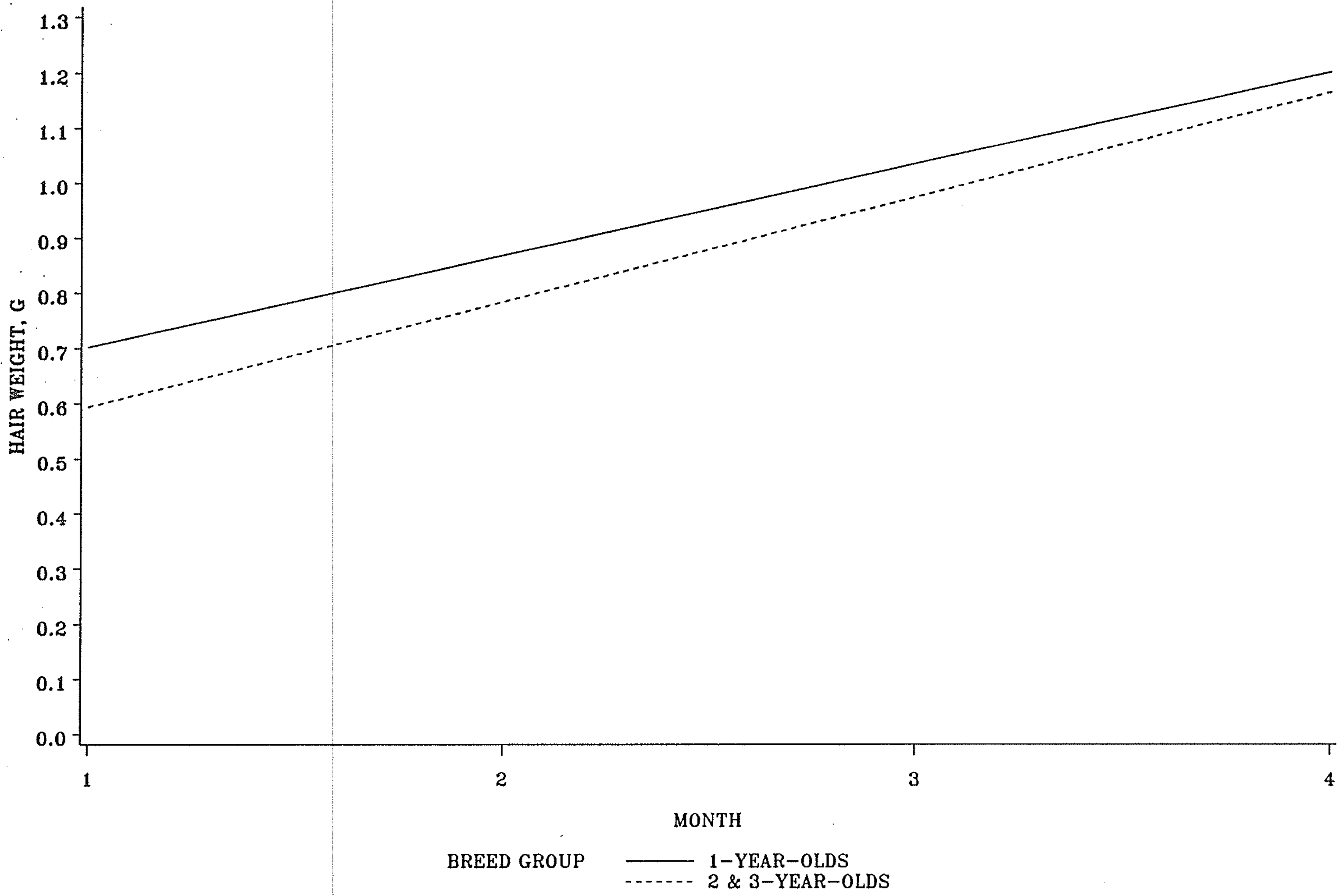


FIGURE C5: REGRESSIONS OF AGE GROUPS OVER WINTER

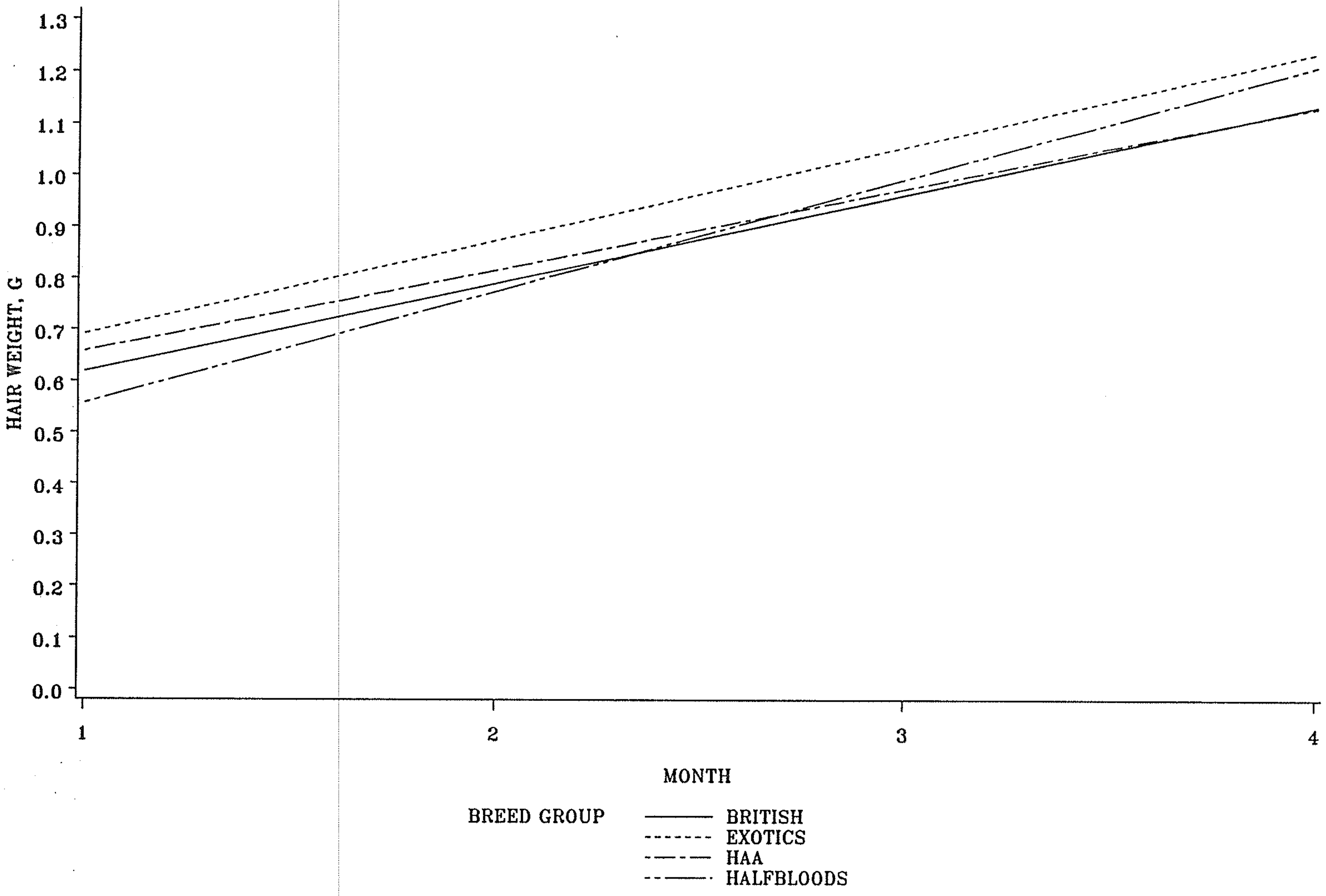


FIGURE C6: **REGRESSIONS OF BREED GROUPS OVER WINTER**

APPENDIX D: HAIR WEIGHT, LENGTH, AND DEPTH MEASUREMENTS ON A CURED CATTLE HIDE

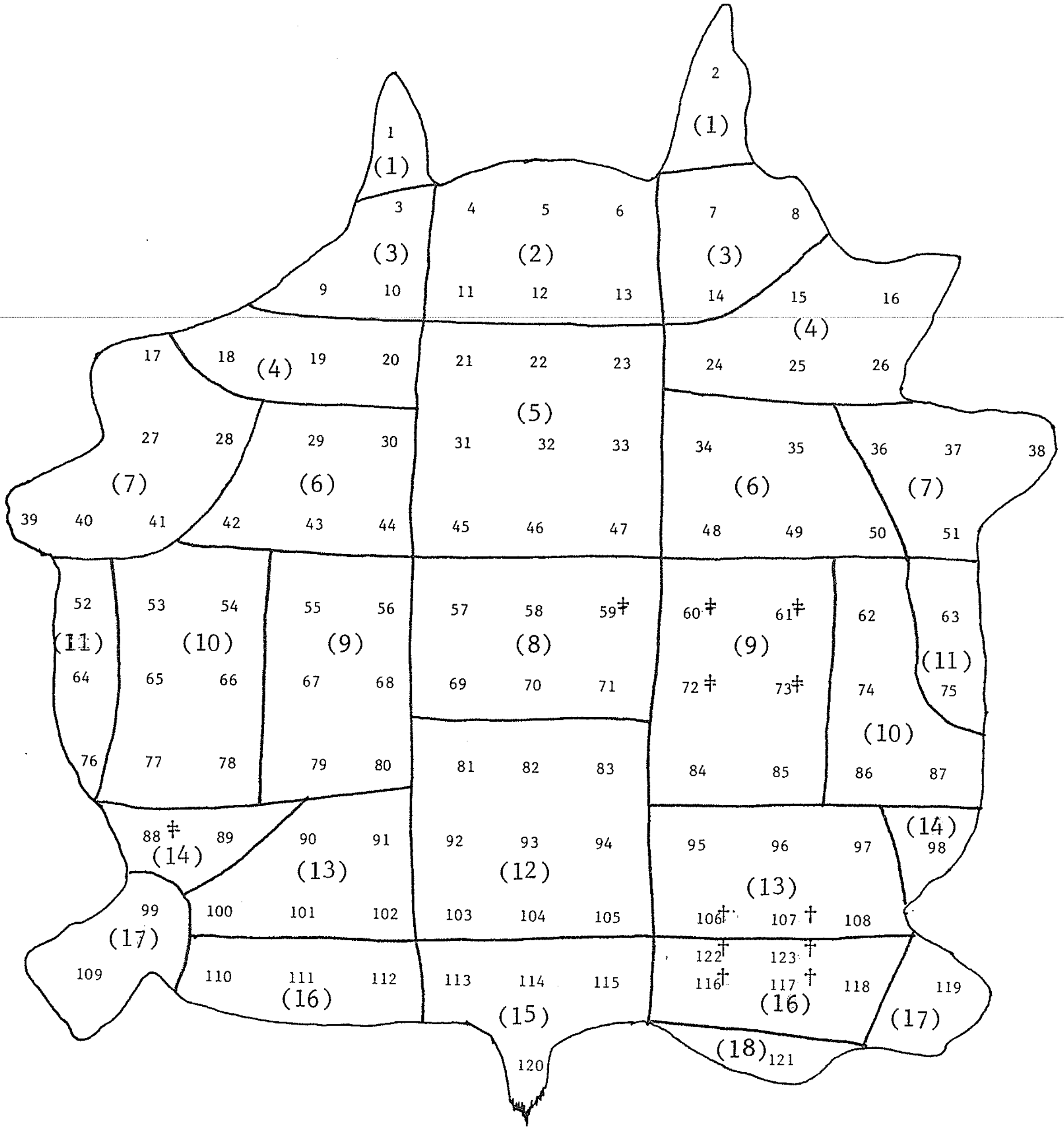
1.15 INTRODUCTION

The quantitative evaluation of hair weight, depth, and length across the entire hide of a slaughtered Hereford-Angus heifer was used as an aid to characterizing the hair coat, and to confirm the validity of the hip as the sampling area in Experiments One and Two. Hair weight, length, and depth were measured at one hundred and twenty-three sites, spaced every fifteen centimeters, on a hide of a Hereford-Angus heifer (Figure D1) to determine the relationship between hair measurements taken across the hide. The cured hide was acquired from a commercial abattoir. The hide was washed free of salt and dried prior to sampling.

Of particular interest was the relationship of hip measurements to measurements from other areas of the hide. Measurements were taken as was indicated for <u>in situ</u> hair sampling (Experiment One and Two). Each hair weight determination site was 33.12 cm^2, and hair length and depth were measured at the centre of each hair weight determination site prior to shaving. Five measurements from the brand area and one from a hairless patch were omitted from the data.

Figure D1. Hair sampling sites and regions on Hereford-Angus hide.

REGION	SITE
1 - face	1,2
2 - upper neck	4,5,6,11,12,13
3 - mid neck	3,7,8,9,10,14
4 - lower neck	15,16,18,19,20,24,25,26
5 - front back	21,22,23,31,32,33,45,46,47
6 - front flank	29,30,34,35,42,43,44,48,49,50
7 - shoulder	17,27,28,36,37,38,39,40,41,51
8 - mid back	57,58,59,69,70,71
9 - mid flank	55,56,60,61,67,68,72,73,80,84,85
10 - abdomen	53,54,62,65,66,74,77,78,86,87
11 - forebelly	52,63,64,75,76
12 - hind back	81,82,83,92,93,94,103,104,105
13 - hind flank	90,91,95,96,97,100,101,102,106,107,108
14 - groin	88,89,98
15 - rump	113,114,115,120
16 - gluteus	110,111,112,116,117,118,122,123
17 - upper hind leg	99,109,119
18 - breech	121



† Hip sampling sites of Experiment Two
‡ Brand and hairless sampling sites

The hide was arbitrarily divided into eighteen regions (Figure D1) based on the regions described by Pan (1963). The large number of anatomical regions gave rise to a limited number of measurements per region. Consequently, the regions were organized into nine larger areas (Figure D2).

1.16 RESULTS AND DISCUSSION

1.16.1 Hair Weight

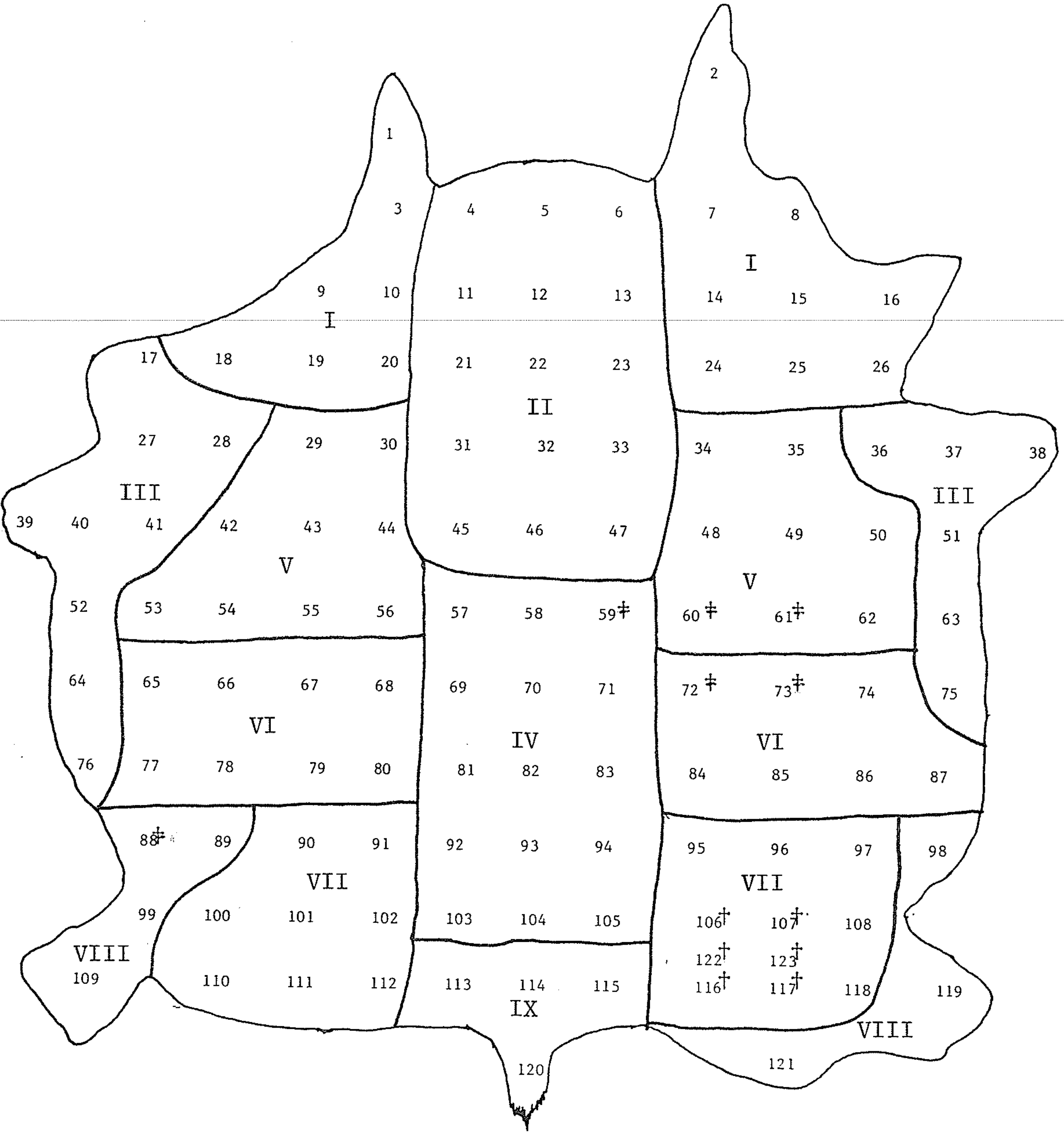
One-way analysis of variance indicated a significant difference ($p=0.002$) in hair weight among areas. Table D1 shows the least squares means and standard errors for hair weight and differences in least squares means for hair weight among areas, as was determined by Student-Newman-Keul's multiple range test. Generally, hair weight increased from anterior to posterior. Lower spine hair weight was significantly greater ($p<0.05$) than the upper spine and side front hair weights. Hair weight measurements from the hip area did not differ from other areas of the hide. This indicates that the hip was a valid choice for a hair sampling area in Experiments One and Two.

1.16.2 Hair Length

One-way analysis of variance indicated a significant difference ($p=0.0001$) in hair length among areas. Table D1 shows the least squares means and standard errors for hair length and differences in least squares means for hair

Figure D2. Hair sampling sites and areas on Hereford-Angus hide.

AREA	SITE
I - neck	1,2,3,7,8,9,10,14,15,16,18,19,20,24,25,26
II - upper spine	4,5,6,11,12,13,21,22,23,31,32,33,45,46,47
III - foreshoulder	17,27,28,36,37,38,39,40,41,51,52,63,64,75,76
IV - lower spine	57,58,59,69,70,71,81,82,83,92,93,94,103,104,105
V - side front	29,30,34,35,42,43,44,48,49,50,53,54,55,56,60,61,62
VI - side rib	65,66,67,68,72,73,74,77,78,79,80,84,85,86,87
VII - hip	90,91,95,96,97,100,101,102,106,107,108,110,111,112,116,117,118,122,123
VIII - hind	88,89,98,99,109,119,121
IX - rump	113,114,115,120



† Hip sampling sites of Experiment Two

‡ Brand and hairless sampling sites

Table D1. Least squares means ± standard errors for hair weight, hair length, and hair depth of anatomical areas of Hereford-Angus hide

AREA	HAIR WEIGHT (g/cm^2)	HAIR LENGTH (cm)	HAIR DEPTH (cm)
IV - lower spine	1.30 ± 0.09 a†	6.53 ± 0.45 a,b	1.04 ± 0.11 a
IX - rump	1.12 ± 0.15 a,b	6.46 ± 0.75 a,b	1.20 ± 0.19 a
VI - side rib	1.01 ± 0.10 a,b	7.33 + 0.46 a,b	0.93 ± 0.12 a
VII - hip	0.98 ± 0.08 a,b	5.75 ± 0.39 b	0.82 ± 0.10 a
III - foreshoulder	0.97 ± 0.09 a,b	5.98 ± 0.43 b	0.93 ± 0.11 a
VIII - hind	0.93 ± 0.14 a,b	5.33 ± 0.68 b	0.77 ± 0.17 a
I - neck	0.87 ± 0.09 a.b	5.21 ± 0.42 b	0.96 ± 0.11 a
II - upper spine	0.80 ± 0.09 b	8.19 ± 0.43 a	1.19 ± 0.11 a
V - side front	0.73 ± 0.09 b	6.91 ± 0.43 a,b	0.91 ± 0.11 a

† a,b Least squares means in the same column with different subscripts were significantly different ($p>0.05$)

length among areas, determined by Student-Newman-Keul's multiple range test. Upper spine hair length was significantly greater ($p<0.05$) than neck, foreshoulder, hip, and hind hair length. Hair length measurements from the hip were significantly lower ($p<0.05$) than hair length measurements from the upper spine area, but did not differ from any other areas.

1.16.3 Hair Depth

One-way analysis of variance indicated no difference ($p>0.05$) in hair depth among areas of the hide. Table D1 gives least squares means and standard errors for hair depth. This may or may not be indicative of the characteristics of the depth of the hair coat on a live animal. The spherical shape of an animal, the protrusion of limbs and bones, and the ability of an animal to piloerect are all factors affecting hair depth in a live animal which are absent in a hide.

Based on the measurements of the hair coat characteristics of weight, length, and depth taken on one hide, and assuming that the variations in hair length, depth, and weight are similar for all breed types, it is concluded that the hip samples used in the main experiments were representative of the entire hide. In addition, the hip is the most accessible area for measuring the hair coat on a live animal.

APPENDIX E: COMPARISON OF HAIR WEIGHT ON THE HIP, SIDE, AND NECK

The purpose of this experiment was to determine if hair weight from the sampling site on the hip was representative of hair weight from sampling sites along the side of the body and neck.

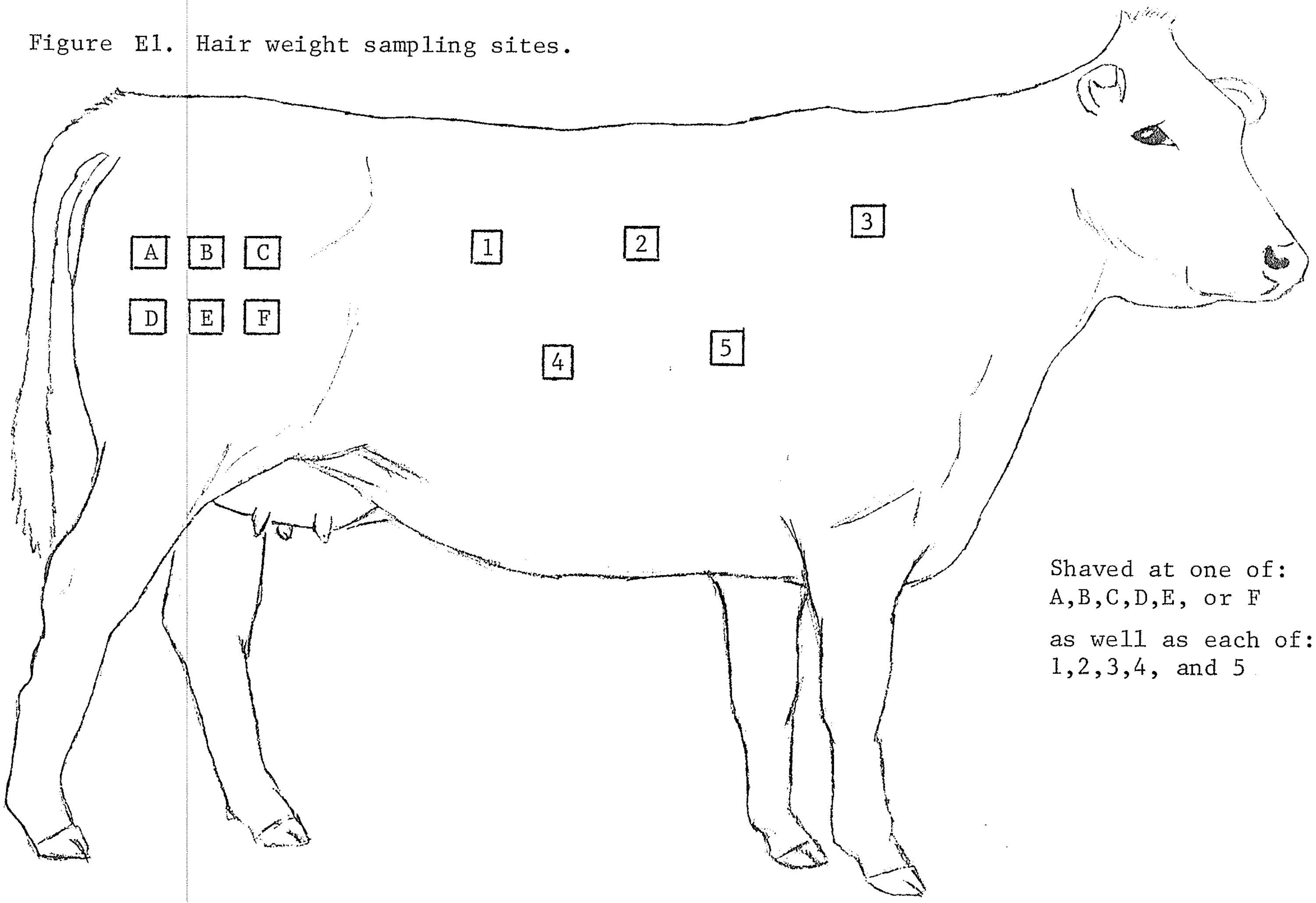
Three cows were picked at random from each of the fifteen breed crosses represented in the cow study group described in Experiment Two. During the final sampling period (February 26-27) of Experiment Two, cows were shaved at five sites along the right side of the body and neck region, in addition to the randomly assigned sampling site on the hip. The sites at which animals were shaved are shown in Figure E1.

The shaving technique and the subsequent drying and weighing of the collected hair samples were as described in Experiment One. Another evaluation of the power of representation of hair weight from the hip is described in Appendix D.

One-way analysis of variance was performed to determine the effect of sampling site upon hair weight per unit area. Student-Newman-Keul's test was used to determine where the differences among sampling sites occurred.

A correlation coefficient for hip hair weight and mean side hair weight was determined to estimate how well hair

Figure E1. Hair weight sampling sites.



Shaved at one of:
A,B,C,D,E, or F

as well as each of:
1,2,3,4, and 5

weight from the hip correlated with hair weight from the side of the body and the neck.

1.17 RESULTS AND DISCUSSION

1.17.1 Analysis of Variance and Test of Differences

One-way analysis of variance of hair weight indicated a significant difference ($p=0.0004$) among sampling sites. Table E1 shows differences in least squares means of hair weights among sampling sites, as determined by Student-Newman-Keul's test. Hip hair weight was significantly lower ($p<0.05$) than hair weight from site two and site three on the side and the neck of the animal, respectively. The five sampling sites along the side of the body and the neck, excluding the hip site, did not differ from one another with respect to hair weight. The multiple range test revealed that hair weight from the sampling sites along the side of the body and the neck, excluding the hip area, were similar; hence these data were pooled to give a mean side hair weight for each cow. Mean side hair weight was used in all subsequent analyses.

1.17.2 Correlation

Analysis of the correlation between the variables hip hair weight and mean side hair weight indicated a correlation coefficient of 0.75 ($p=0.0001$).

Table E1. Least squares means ± standard errors of hair weight per unit area from sampling sites.

SITE	HAIR WEIGHT (g/cm^2)
hip	1.05 ± 0.04 a†
1	1.21 ± 0.04 a,b
2	1.33 ± 0.04 b
3	1.29 ± 0.04 b
4	1.19 ± 0.04 a,b
5	1.20 ± 0.04 a,b

† a,b Least squares means with different subscripts were significantly different ($p < 0.05$)