TOOTH DETERIORATION IN SHEEP

A STUDY OF FARMS IN SOUTHERN NORTH ISLAND OF NEW ZEALAND

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CHAPTER 1
INTRODUCTION

Progressive deterioration of sheep's teeth on New Zealand farms has become more apparent as farming has undergone intensification. In particular it would appear that on farms where stocking rates are highest the sheep have been most seriously affected.

Historically the amount of wear of the incisor teeth has been used as a method of culling in most sheep flocks. In many affected flocks it has been common practice to cull ewes after three lambing seasons. In other situations sheep farmers have been encouraged to retain older ewes with severely deteriorated mouths but to give them preferential grazing treatment. This has amounted to culling by age and production rather than condition of teeth. Nevertheless, many producers still continue to cull by the former method believing that ewes with badly deteriorated incisors will fail to maintain condition and production during competitive management periods. Whether impairment of production is real or perceived, traditional culling by the condition of the incisors continues to be a common practice. As a result tooth deterioration has become a very severe waste to the sheep industry.

Tooth deterioration is a problem that was first described by Barnicoat (1947). Since its recognition there has been a multiplicity of aetiological factors proposed for this condition. Barnicoat stated, "Abrasion due to mechanical causes is well known both here and abroad. This problem is quite distinct from that of progressive deterioration of mouths on improved country, which is the central problem of this investigation" (Barnicoat, 1957). Other researchers disregarded this supposition after linking the problem to soil ingested and hypothesised that tooth wear resulted from abrasion by ingested soil (Healy & Ludwig, 1965). Since its presentation this theory has been generally accepted (O'Hara, 1983). It seemed to be a logical explanation of the cause of the problem but tended to disregard some of the clinical manifestations.

It is now clear that the problem needs to be re-assessed, taking into consideration other factors which affect the incisor teeth. Further it is important to study the types of farms involved and the effect of new management procedures on tooth deterioration. When progressive tooth deterioration is viewed broadly, it must be concluded that none of the previously proposed aetiologies completely satisfy the evidence shown from the clinical picture.

Research on this subject has been difficult in part due to a tendency to identify the problem as a single entity termed "tooth wear". Presently there are at least three separate identifiable conditions which may be expressed clinically as excessive loss of exposed tooth surface. Each of these conditions appear to have a separate aetiology and can occur either individually or together in the same flock.

Firstly tooth abrasion caused by ingested abrasive substances has been described overseas and in New Zealand (Barnicoat, 1957). Sheep grazing on the Rocky Mountain region of the United States of America experience this problem (Siegmund, 1979). However, this area is arid, sparsely-stocked range country which is completely the opposite to the grazing conditions encountered in New Zealand.

A second type of excessive loss of exposed tooth substance is recognized in certain developmental problems occurring during tooth formation. These problems are known to occur with nutritional excesses and deficiencies (Franklin, 1950; Bruere et al, 1979; Krook et al, 1983), parasitism (Suckling et al, 1983) and trauma (Suckling, 1980).

The third condition is the problem which has been termed progressive deterioration of sheep's teeth (Barnicoat, 1957). It is this entity which is the major problem in the southern part of the North Island of New Zealand. The majority of this thesis will address itself to this latter condition.

A logical approach to a literature review on this subject is to categorize information which supports the many proposed aetiologies. Most of the information that has accumulated since 1947 can be dealt with in this manner as most workers have investigated the problem with a view to substantiating their proposed aetiology.

Having considered the views of previous workers on the subject a new hypothesis for the cause of tooth deterioration is suggested. The relationship of soil ingestion to the cause of tooth deterioration is revised. This has resulted from close on-farm investigations which do not satisfactorily substantiate former proposed aetiologies.

The proposed aetiology has been built on information accumulated over the past thirty-eight years by other researchers, but has viewed these previous observations in a new light.

It is suggested that any proposed aetiology must satisfy the clinical picture seen and it is believed that in the past this has not always been so. Further in an applied sense the aetiology needs to be considered in close relationship to flock management and other changes within the industry which may have exacerbated the problem.

In addition to on-the-farm information, certain laboratory projects have been included which have been conducted to help understand the proposed aetiology.

CHAPTER 2

A REVIEW OF MAJOR DENTAL PROBLEMS IN NEW ZEALAND SHEEP

The major dental problems of sheep in New Zealand can be divided into two categories, those affecting the surrounding and supporting tissues of the teeth and those leading to or resulting in excessive loss of tooth substance.

Conditions affecting the surrounding and supporting dental tissues are termed periodontitis. There are reported to be two distinct conditions involved in this problem in sheep (Page & Schroeder, 1982).

The first type of periodontitis is an acute problem first observed on two farms in New Zealand in 1945. It was termed ulceromembranous gingivitis and was compared to trench mouth or Vincent's angina in man (Salisbury *et al.*, 1953). The problem occurred in four-tooth to full-mouth sheep of both sexes. Both molars and incisors were affected. The condition was characterized by severe gingivitis with ulceration. There was a foul odour from the mouth and loosening of teeth with eventual loss. *Fusiformis necrophorus* was isolated from cultures taken from affected mouths. The sheep involved lost condition and some became so emaciated that they had to be destroyed.

A similar problem was described in 1958 in the Bulls-Santoft area (Hart & MacKinnon, 1958). The condition was apparently limited to six farms. The first indication of the disease was a slowly progressive ill-thrift. The affected sheep continually worked their jaws in a chewing motion and facial swelling due to food accumulation developed in chronic cases. Examination of the mouth revealed a putrid odour, blanched swollen gums and loose and missing permanent teeth. The condition recurred for several years on the same properties with up to 11% morbidity. Four-tooth and older sheep of both sexes were affected and all sheep were of the Romney breed. The condition did not appear to be seasonal. The farms on which this syndrome recurred were described as being rolling with sandy soils which were low in phosphorus and potassium. Biochemical studies of liver, blood and serum revealed no significant findings. Cultures from affected areas revealed a large number of different types of micro-organisms. Corynebacterium pyogenes was the only known pathogen isolated and it was found only from one case. Pathological studies revealed that the disease began in the periodontal tissues and extended ultimately into the bony tissues.

A later report (Armstrong, 1960) on these investigations provided a summary of the problem. It pointed out that the problem was enzootic and had been seen in limited areas of both the North and South Island. The condition was very similar on both Islands but it was believed that more inflammation of the gum margin had occurred in the South Island sheep. It was also reported in different breeds in the South Island sheep including Romneys, Cheviots, Border Leicesters and crossbreds. Younger sheep including hoggets had also been involved in some of the South Island cases. Soil types varied greatly and there was no apparent relationship of the disease to soil type, carrying capacity or to the degree of development of the property. No specific agents were found that could have transmitted the disease to healthy sheep.

A recent case report showed an outbreak of a similar condition on two adjacent farms in the Rotorua district (Read et al., 1983).A similar condition was also seen in 1984 on Riverside farm in the Masterton area (Bruere-personal communication, 1984).

A second type of periodontitis has been reported as a chronic problem involving mainly the incisor teeth. This problem involves the weakening of tooth support tissues leading to tooth loosening and exfoliation.

The importance of periodontitis in sheep in Great Britain was highlighted by a survey of slaughter sheep (Herrtage, 1974) and a survey of the occurrence of the problem in sheep in New Zealand was undertaken in four Northland counties (Steele & Henderson, 1977). In the New Zealand study, 38% of the total number of farms in the area were surveyed and sheep on 36% of these farms were affected by periodontitis. The problem was more severe on farms with soils of red and brown loams and brown granular loams and clays. These soils usually occur in areas of high rainfall.

A composite of experiments was carried out in Scotland over a period of several years and reported in 1962 (Duckworth <u>et al.</u>, 1962). The purpose was to establish the patterns of incisor development and loss under different husbandry conditions. The results of the trial confirmed that sheep develop and lose their permanent incisors faster in some flocks than in others. In many cases sheep were found with teeth missing by 4.5 years of age. Further, it was shown that sheep from unaffected flocks placed in flocks with serious periodontitis also developed the disease in a manner similar to those of the host flock. The opposite was true when young ewes were placed from "poor tooth" to "good tooth" farms. These ewes had incisors comparable to sheep in the "good tooth" flocks. Teeth lost from sheep in these experiments were apparently undiseased. In these observations it was seen that ewes lost teeth earlier than wethers on the same farm. It was thought that this was likely a result of reproduction stress on ewes and/or differences in supporting tissues of teeth. The observation also confirmed that there was a forward drift of the occlusal position of incisors with age and that the feeding of turnips hastened the shedding of the incisors. Observations of sheep on various vitamin D and phosphorus levels yielded no significant changes from normal with regard to periodontal tissues.

Radiographic studies were carried out as a continuation of these observations (Benzie & Cresswell, 1962). These radiographic studies generally confirmed the results of the clinical observations that the permanent incisors on "poor tooth" farms were commonly found to be migrating from their sockets early after eruption. This has also been observed in New Zealand (Bruere-personal communication, 1984). This migration of permanent incisors from their sockets was often evident before radiographic changes of the surrounding mandibular bone were apparent or before widening of the periodontal membrane had occurred. However, erosion of the periphery of the incisor alveolar bone quickly followed and erosion of incisor alveolar bone was noted to be severe in flocks where turnips were fed. In these studies the incisor alveolar bone was apparently well-mineralized for sheep of the type involved which seemed to indicate that generalized calcium and phosphorus deficiencies did not play an important role in the early shedding of permanent incisors by sheep in these flocks.

Investigation of proposed possible aetiologies has formed a basis for much of the research on periodontitis. Early researchers proposed a mechanical aetiology of periodontal disease (Markham & Lyle-Stewart, 1962). Three stages were suspected in premature loss of incisors including proclination, jiggling and denudation of bone around the tooth socket. Three causative factors were hypothesised: 1. Reduction of molar height of bite by continual attrition where molar eruption is insufficient to maintain height of bite; 2. Trauma of the incisors in rumination where occlusion was faulty; 3. Cropping stresses in traumagenic diets. These authors attempted conservation methods in sheep mouths by grinding the incisors to improve tooth stability.

Lack of adequate dental exercise was suggested as a contributing cause of periodontitis. This resulted from experiments involving two different stocking rates of sheep on pastures receiving two different levels of superphosphate applications (Porter et al., 1970). The incidence of periodontitis was highest in the low stocked groups on pasture receiving the higher rate of superphosphate. It was postulated that the condition may occur as a result of grazing feeds which required little time for biting, ingesting and cudding. The highest incidence of the disease coincided with highest live weights of sheep, longest mean tooth length, lowest levels of blood, wool and pasture selenium and highest levels of manganese and chromium in both rye grass and wool. A decrease in the incidence of the disease was reported between the second and the fifteenth days following selenium administration.

Other studies have emphasized the nutritional causes of periodontal disease. A subclinical calcium and phosphorus dietary deficiency was postulated to be involved in premature loss of permanent incisors (Gunn, 1969). Either calcium or phosphorus was supplemented to groups of sheep grazing areas low in these minerals. Control groups were grazed on the same type of pastures without supplementation. Sheep which were given either a calcium or phosphorus supplement had fewer loose or missing teeth than did the control animals. It was suggested that the subclinical mineral deficiency may have led to a weakening of alveolar bone and a subsequent premature loosening and loss of the permanent incisor teeth.

Another study (Suckling et al., 1974) involved a farm where early tooth loss had been observed for many years. A trial was instigated using different levels of lime on pastures and periodontal changes were observed. After two years in most ewes on the non-limed pasture, the movement forward anterior to the pad and looseness of the incisor teeth were marked while the teeth in sheep on limed pastures did not show the same degree of mobility. However, the sheep on limed pastures were on a higher general plane of nutrition due to greater pasture production following lime applications. Thus, the direct effect of calcium supplementation was obscure. The stocking rate had to be increased on the limed pasture to utilize additional pasture growth, hence another variable was introduced which further confused the observations.

It has been suggested that in seeking to explain the early loss of incisors, attention should be given to the epithelial attachments of the tooth. To this end histological sections of central incisor teeth and the surrounding tissues of sheep from flocks rarely affected by periodontitis and from flocks commonly affected by premature loss of incisors were compared. In the sheep from farms severely affected by periodontitis there was a progressive deepening of the lingual sulcus leading to the formation of periodontal pockets (Dalgano & Hill, 1961; Hatt et al., 1968).

Subsequent work by these authors revealed the exposed root surface inside periodontal pockets to be covered by a thick layer of subgingival plaque from which cultures of hemolytic and non-hemolytic streptococci, fusiform bacilli, micrococci, Neiseria and Candida albicans were grown (Hatt el al., 1968).

More recently histopathological studies were performed on lower jaws of two to five year old sheep from farms where little periodontitis occurred and from farms where sheep with periodontitis was regularly seen (Cutress, 1976). In these observations supragingival plaque with a palisading appearance associated with filamentous growth was always found in the disease-prone sheep. The plaque deposits extended to the bottom of periodontal pockets. In young sheep from unaffected farms the gingival sulcus was narrow or absent and there was little or no plaque. Further if no plaque was present there was little or no pocket formation. The older sheep from unaffected farms developed the same pattern of periodontitis as sheep with clinical periodontitis with pockets and plaque present in both. However, the "periodontitis-resistant" sheep were affected to a lesser extent and at a lower frequency.

Further histopathological studies confirmed the evidence of plaque involvement in periodontitis (Spence et al., 1980). Sheep with clinical periodontitis had a higher prevalence of subgingival plaque than did unaffected sheep. Micro-organisms consisted of many types but were mainly filamentous. It was suggested that sheep develop a chronic gingivitis following an acute gingivitis during tooth eruption associated with accumulation of subgingival plaque. On farms where sheep were affected with periodontitis, plaque accumulation and chronic gingivitis were severe. The connective tissue associated with gingival inflammation was damaged leading to formation of pockets and eventually to destruction of the periodontal ligament. It was further suggested that plaque formation precedes pocketing and that plaque may be necessary for the production of gingivitis, periodontitis and pockets. Damage to the fibre of the periodontal ligament may then cause loss of support of incisors against normal grazing forces (Spence, 1978).

In a comparative review of periodontitis, it was concluded that periodontitis is a bacterial disease. It was stated, "In all mammal studies, all forms of marginal periodontitis are caused by bacteria which colonize the tooth surfaces, extend and grow into the gingival sulcus, and insinuate themselves between the tooth surface and the gingiva causing displacement and disruption of the soft tissue attachment" (Page & Schroeder, 1982). It was further stated that pocket formation was present in all cases of marginal periodontitis and that pockets could neither form nor deepen in the absence of bacteria.

Although the currently accepted aetiology of chronic periodontitis is plaque forming micro-organisms (Page & Schroeder, 1982; Curtress, 1983), it would appear warranted to direct future studies at environmental predisposing factors as was suggested by Benzie and Cresswell (1962).

The second group of major problems in sheep in New Zealand has been called "tooth wear" or tooth deterioration. This condition was first reported in sheep of certain districts in New Zealand (Barnicoat, 1947). The problem had become more pronounced in the preceding 20 to 30 years during which time a number of changes in sheep farming had taken place. These included heavy topdressing of pastures, reduced cattle to sheep ratios, introduction of European grasses, rotational grazing and the increased predominance of the Romney breed. Sheep stocking rates had increased greatly as a result. Barnicoat suggested that the problem was complex and probably involved other factors such as heredity, environment, nutrition, oral anatomy and tooth structure. In a following study, endocrine involvement, erosion by pasture juices, eruption timing and abrasion by plants or soil were also considered as possible causative factors (Barnicoat, 1957).

The continued topdressing of land with fertilizer and limestone had led to the intensification of sheep farming in New Zealand. Therefore it was not surprising that Barnicoat studied the overall effects made using different soil treatments on similar pastures and tooth wear rate was observed. Five groups of ewes were observed on varying levels of superphosphate, limestone, superphosphate-limestone and superphosphate-limestone-potash. It was concluded that there was no evidence that teeth were being eroded by the direct chemical action of fertilizers and/or limestone.

In similar experiments the effects of different fertilizer rates were compared on pasture and animal production (Suckling, 1975). The tooth wear of sheep on pastures receiving light levels of superphosphate and carrying 13.6 ewes per hectare were compared to that of sheep grazing pastures receiving high levels of superphosphate and finally carrying 17.3 ewes per hectare. The sheep at the high stocking rates and on pastures receiving the high levels of superphosphate generally had higher rates of tooth wear.

This line of investigation was again conducted by Bircham et al. (1981) who reported no differences on initial tooth length of subsequent tooth wear following pasture topdressing with varying quantities of superphosphate. However the effects of lime on tooth wear at varying stocking rates was also tested. Sheep grazing untopdressed paddocks were compared to those grazing paddocks receiving 6300 kg of lime per hectare at stocking rates of 15 ewes per hectare and 22 ewes per hectare respectively. The ewes at the lower stocking rate on paddocks receiving no lime had significantly greater tooth wear than did the ewes at the same stocking rate on the land receiving lime. There was little difference in tooth wear in ewes grazing on the unlimed and the limed paddocks at the higher stocking rate. The additional feed grown on the pastures receiving lime was considered to be responsible for the positive effect on tooth length, especially at the lower stocking rate.

Historically sheep grazed on largely unimproved scrub or tussock country with brown top-dominant pastures have had good incisor teeth. Improved pastures of perennial rye grass and white clover are the type where excessive tooth wear can be expected to occur (Barnicoat, 1957).

Grazing practices influence rate of incisor wear in sheep. Over-grazing pastures tends to promote tooth wear, and sheep which are rotationally grazed have less tooth wear than those which are set-stocked (Barnicoat, 1957). This was shown by Suckling (1954) in a field trial conducted at Te Awa Research Station over a period of four years. Fifty-five ewes were grazed under set-stocking conditions at a rate of three ewes per acre and fifty-five ewes were grazed under a controlled rotational system at the same stocking rate. The rate of tooth wear in the ewes on the controlled rotational system was significantly less than that of the set-stocked ewes. Preliminary trials at Wallaceville Animal Research Centre have produced similar results. Approximately 2.0mm of incisor wear per sheep was shown in hoggets grazed rotationally in 25 paddocks with 2 to 2.5 days break per paddock, while 3.2mm of incisor wear occurred in hoggets set-stocked at the same stocking rate (Kane et al., 1983; Kane, 1984).

Along with increased pasture production, there has been a trend in some parts of New Zealand to reduce cattle numbers and to intensify sheep production. It has been suggested that higher sheep numbers lead to increased rate of tooth wear in sheep (Barnicoat, 1947). Barnicoat (1948; 1957) and Suckling (1964; 1975) suggested that by increasing the number of cattle relative to the number of sheep, the rate of tooth wear is reduced.

A constant finding with excessive tooth wear problems has been increased stocking rates on a given property (Barnicoat, 1957; Healy & Ludwig, 1965; Arnold et al., 1966; Suckling, 1975; Bircham et al., 1981).

Hereditary factors were considered to be involved in excessive tooth wear (Barnicoat, 1948). This was demonstrated in a recent trial conducted at Rotomahana Research Station using crossbred ewes of nine genotypes derived from Romneys and Perendales. Border Leicester-derived ewes had a higher rate of wear with Merino-derived ewes showing the lowest wear rate. Romney and Perendales were intermediate in regard to wear (Meyer et al., 1983).

The correlation of environmental factors with excessive incisor wear has also been considered. The extent of the wear problem in five year old Romney ewes was highlighted in a report of the New Zealand Stock Station Agents Association (1957) and scientifically presented by Barnicoat (1957).

In both these reports excessive tooth wear was shown to be a serious problem on many North and South Island farms in New Zealand. The map prepared by the New Zealand Stock and Station Agents showed the extent of the areas where tooth wear was a problem and it was also compared to other maps relating to physical and botanical environments. There was no correlation between tooth length and geological formation, but certain generalizations could be made about topography. In general the sheep with the best mouths occurred on the higher country. It also appeared that extent of wear was related to climate and rainfall. The least-worn teeth were found in sheep from high rainfall areas (45-50 inches per annum or more) with even distribution of precipitation being crucial.

Certain soil types have also been shown to be related to the problem of excessive tooth wear. In general sheep showing the least wear were found on zonal steeper hills covered with soil related to yellow-brown earths on a shallow free-draining subsoil. Sheep grazing pumice land also tended to show little wear (Barnicoat, 1957). Healy (1969) showed a similar situation where "medium wear farms" were on yellow-brown loams and "high wear farms" were on yellow-grey earths. Information collected in Otago and Southland also indicated tooth wear to be highest on yellow-grey earths with a low phosphorus retention (Orr, 1983).

A considerable advance in the understanding of the tooth wear problem was made when Healy and Ludwig (1965) demonstrated the relationship of tooth wear to the amount of soil ingested which in turn was shown to be related to soil type and structure. From subsequent work it was seen that yellow-brown loams, yellow-brown pumice soil, yellow-brown earths, red and brown loams and brown granular clays were associated with low rates of soil ingestion. Yellow-grey earths, recent soils from silty alluvium, nodzolised yellow-brown earths and podzols in general were associated with high levels of soil ingestion (Healy, 1969).

Nutrition has played a role in certain dental problems and it has been considered in respect to tooth deterioration in sheep.

Teeth contain approximately 90% calcium phosphate with many other minerals and trace elements including Mg, Na, Sn, F, Zn, Ba, Fe, Al, Cr, Co, Sb, Mn, Au, Cl, Br and Cu (Barnicoat, 1957). With the exception of fluorine, calcium and phosphorus, little is known with respect to the role of other elements in mineralization (McConnell, 1973). Protein, energy and vitamins are also important in tooth structure and formation (Barnicoat, 1957; Luke et al., 1979).

The importance of calcium and phosphorus in the formation of teeth was clearly demonstrated by Franklin (1950). In this work, lambs fed diets low in calcium and high in phosphorus such as cereal and grains or their by-products, had dental developmental problems even though their diet was corrected in later life. These problems were prevented by the addition of calcium supplements. Other defects were reported by Franklin (1950) in sheep fed an improper ratio of Ca/P. They developed other abnormalities including delayed eruption, undershot mandibles, over-crowding of incisors and abnormal wear of molars. Further, McRoberts (1965) showed that sheep which received diets low in either phosphorus or vitamin D, or both, developed severe skeletal defects but virtually no dental defects.

The available calcium and phosphorus in pastures varies widely (Field et al., 1974). Evidence on analysis of calcium and phosphorus in herbage samples from the North and South Islands of New Zealand showed that sheep with the greatest degree of tooth wear were grazing pastures with a high level of calcium and phosphorus. Sheep showing a lower degree of tooth wear were on pastures lower in calcium and phosphorus. However, in this report, no evidence was found to suggest calcium or phosphorus deficiency, excess or imbalance to be responsible for deterioration of sheep's teeth (Barnicoat, 1957).

Interference with the absorption of minerals, in particular calcium and phosphorus may result from parasite infestation. Defects of the skeleton and teeth have been induced experimentally in this manner (Sykes & Coop, 1976; Suckling et al., 1983).

In an extensive outbreak of dental abnormalities of sheep in the Wairarapa during 1977-1978, a range of anomalies was reported (Bruere et al., 1979). The dental abnormalities were characterized by excessive wear of deciduous teeth and maleruption, excessive wear and periodontitis involving permanent teeth and dentigerous cysts. Excessive wear in adult sheep, ewe lambs and hoggets had been recognized in previous years in the farms where these conditions were recorded. Serum calcium and phosphorus levels were normal in samples collected from the most severely affected sheep at the peak of the problem.

It is now well recognized that fluorine increases structural stability of the tooth apatite by replacing the OH group of the carbonate hydroxyapatite. Adequate amounts of dietary fluorine lead to more durable teeth; however, excessive fluorine intake causes problems in developing teeth of excessive wear along with pitting, enamel hypoplasia, discoloration, delayed eruption, recession of alveolar bone and gingiva, maleruption and misshapen teeth (Franklin, 1950; Krook et al., 1983). In the mineral analysis of sheep's teeth from twenty-one farms distributed over a wide area of New Zealand, fluorine was the only material showing a wide variation in level. The fluorine content of these samples ranged from 28-320 ppm. Those teeth with low fluorine levels showed no faster wear than those with normal levels and there was no evidence of fluorosis in teeth with higher levels of fluorine (Barnicoat, 1959). In experiments using the high cereal diets low in calcium and high in phosphorus, sheep developed gross dental abnormalities very similar to those reported with natural and experimental cases of fluorosis (Pierce, 1938; Boddie, 1947). Defects seen in the Wairarapa sheep (Bruere et al., 1979) were also quite similar to those seen in fluorosis and in the sheep fed a calcium-phosphorus imbalanced diet (Franklin, 1950).

In the Wairarapa report, liver samples revealed low copper levels in sheep and cattle associated with low levels of copper and low to normal levels of molybdenum in pasture from affected farms. Molybdenum levels from kidney samples were normal in one year old heifers showing excessive wear of temporary incisors (Bruere et al., 1979). The copper dependent enzyme lysyl oxidase is essential for the synthesis of collagen. Collagen is the fibrous framework of teeth as well as many other body structures and organs (Millar, 1979). Therefore it has been suggested that copper may have played a part in the dental defects seen in the teeth of sheep in the Wairarapa district in 1977-1978.

Trials using pigs compared the effect of diets deficient in protein or calories on the development and growth of the jaws and teeth. Both groups showed retardation of the growth of jaws and teeth (Luke et al., 1979).

Certain vitamins have been identified in their relationship to skeletal mineralization. As previously mentioned, vitamin D deficient diets neither caused dental defects (McRoberts et al., 1965), nor did various levels of vitamin D2 in the diet affect the rate of tooth wear. Grazing ruminants have an adequate source of vitamin A in pasture and the water-soluble vitamins are provided by symbiosis of rumen microflora. Vitamin C deficiency has never been reported in ruminants. Therefore Barnicoat concluded that there was no clear evidence to support a hypothesis that tooth wear resulted from deficiencies of minerals or vitamins or both.

It has been suggested that tooth and oral anatomy are important when considering the durability of sheep's teeth. Barnicoat (1957) suggested that the best mouths are those with close, wide, long teeth in wide jaws with normal bites. He postulated that the length of time a tooth lasts under wear conditions was primarily dependent on the amount of tooth substance present, the size or weight of the crown, which comprises both the visible and unerupted portions of the tooth.

The similarity of tooth chemical content has already been mentioned (Barnicoat, 1959). A study on wear rate of incisor teeth from farms of known wear was carried out at Wallaceville Animal Research Centre. Although the mean abrasion rate differed from farm to farm, the differences were small and it was concluded that excessive incisor wear was not a result of an intrinsic factor in sheep teeth (Erasmuson, 1983; Erasmuson-personal communication, 1983). These results were consistent with the chemical composition findings.

Endocrine involvement as a possibility has not been reported in the literature since its mention by Barnicoat (1957).

A theory was proposed that hydroxy acids, amino acids and phosphorylated products contained in herbage might be responsible for excessive wear along with the abrasive action of fibre of this herbage (Barnicoat, 1957). An elaborate experiment was performed to test this theory. Juices from herbage on a "high wear" and "low wear" farm were compared for attack on radioactive dentine. Prepared dentine surfaces were neutron-activated to produce P32. P32 dentine was then exposed to juice from the farms and the rate at which P32 activity appeared in the juices was measured. The same teeth were exposed to a citrate buffer (pH 6.1) as a control. The phosphorus removed by the pasture juices from the high and low wear farms was not significantly different and was relatively small compared to that removed by the citrate control. It was concluded that it was unlikely that the chemical components of pasture juices were the cause of excessive tooth wear (Cutress & Healy, 1965).

Early eruption of incisors was theorized to be another possible aetiology of excessive tooth wear (Barnicoat, 1957). Nutrition has been accepted as a factor known to be involved in timing of eruption. In a study with hoggets on high plane and low plane diets, it was found that teeth in those on the higher plane of nutrition erupted earlier (Coop & Clark, 1955). Other researchers also found that those sheep receiving better nutrition in the first year of life had earlier erupting teeth than those receiving poorer nutrition (Gunn, 1967; Wiener & Purser, 1957; Aitken & Meyer, 1982). Genetic control also played a role in eruption timing (Meyer et al., 1983; Wiener & Purser, 1957; Boaz et al., 1958; Aitken & Meyer, 1982). Boaz et al. (1958) found that Scottish half-bred/Suffolk crosses showed earlier eruption than Clun/Suffolk crosses and breeding from the ewe lambs increased the age at which their permanent incisors erupted. The estimated median age (Aitken & Meyer, 1982) of eruption of the central permanent incisors for Romneys, Perendales, Suffolks and Southdowns were 475, 465, 460 and 530 days respectively. Central permanent incisors of Booroola crosses were later erupting than were Romney and Perendale which is in keeping with later eruption of Merinos (Aitken & Meyer, 1982). It was reported (Barnicoat, 1947) that there was little evidence to support the theory that teeth erupt early on country which carries poor mouths and timing of eruption accounts for little or no variation in tooth wear (Barnicoat, 1957;

Aitken & Meyer,1982; Meyer et al., 1983). This would be consistent with the information that mineralization of central permanent incisors takes place from five to seven months and that maturation is complete between ten and twelve months (Suckling, 1979).

The abrasive action of fibre in herbage under varying conditions has also been proposed as a cause of tooth wear (Barnicoat, 1957). Australian researchers hypothesised that plant opal-phytoliths could be responsible for tooth wear. It was stated that since the opal is harder than sheep's teeth, one could scarcely avoid the conclusion that these materials were a cause of wear in sheep's teeth (Baker et al., 1959).

The abrasive action of ingested soil on sheep's teeth has been generally accepted since 1965 as the main aetiology of excessive tooth wear in New Zealand (O'Hara, 1983). This conclusion was reached as a result of the extensive series of observations conducted by Healy and Ludwig (1965) in the Wairarapa district. Three farms were selected for detailed study with histories of high, medium and low tooth wear incidences. Wear status was confirmed by examination of teeth of all available five year old ewes including direct measure of central incisor teeth. Faecal samples were collected from paddocks on involved farms at approximately monthly intervals and ashed and acid washed. Acid washed residues were used as an indicator of soil ingested. Analysis of faecal samples collected over 1964-1965 showed highest soil content on the high wear farm, lowest soil content on the low wear farm and intermediate soil content on the medium wear farm. Therefore, it was concluded that ingested soil was the main agent involved in excessive tooth wear and that the degree of wear was directly related to the quantity of soil ingested by grazing animals which was shown to be highly abrasive to substances like dentine.

A lengthy review of the numerous proposed aetiologies eludes to the difficulty surrounding an understanding of the tooth deterioration problem. The quote by Barnicoat (1957) makes clear his feelings regarding the unlikely possibility of abrasion as the aetiology. Further, some practitioners, researchers and producers have been uncomfortable with this explanation. However, reconsideration of the abrasion theory has in part been surpressed by a lack of a better explanation. The material in the following chapters of this thesis will hopefully clarify some of the reasons for skepticism among this group as well as provide a possible aetiology which may better fit the clinical manifestations of the problem.

CHAPTER 3
A FIELD INVESTIGATION INTO EXTREME DENTAL DETERIORATION
A FARM STUDY NEAR WAIPUKURAU

INTRODUCTION

The intermittent nature of serious dental problems of sheep involving a number of farms over a wide area has been recorded in New Zealand on several occurrences (Bruere *et al.*, 1979; Graham-personal communication, 1984).

Such a situation occurred in the Hawkes Bay district as a result of serious drought conditions in the Spring of 1983, which continued as an exceptionally dry summer period into 1984. Dental problems were reported on a number of farms in the area and this section describes the events leading up to the dental deterioration in a flock of sheep which was very severely affected.

The farm concerned was approximately 6km south of Waipukurau in the Hawkes Bay district. For the past five or six years tooth wear had been recognized by the owner as a serious problem in the sheep grazing on this property. Although the degree of tooth deterioration observed on this farm was extreme and probably exacerbated by the severe weather conditions, it is believed that it enabled detailed clinical observations to be made which would otherwise have been overlooked. Further it highlighted the dynamic nature of tooth deterioration and the necessity to study such problems closely and over a long period of time.

FARM PROFILE

The farm involved in this study was a hill farm of 263 hectares. Approximately two-thirds of the farm was rolling arable hill and one-third was steeper hills rising to an elevation of 304.8m above sea level. The annual rainfall on this property was 914mm. The land faced mainly to the east. The soil types were Crownthorpe sandy loam and Matipiro sandy loam. The pastures were predominately perennial rye grass and white clover. As a result of the severe drought in 1983, hay was fed from January to June and the number of ewes fluctuated over the year because of the feed shortage. The ewe numbers were reduced from 3500 to 2900. The winter stocking rate was fifteen sheep per hectare. No cattle were grazed. The ewes were rotationally grazed except for the set-stocking period from the beginning of lambing until weaning. Lambing began during the second week of August. The hoggets were set-stocked during April and May and were then rotated at varying intervals.

HISTORY

The present owner purchased the farm from his father in 1972 and made some significant management changes. Coopworth rams were introduced into the Romney flock for crossbreeding. The whole farming programme became much more intensified. The stocking rate was increased and cattle numbers were decreased. The stocking rate from 1964 to 1972 had been approximately 8-9 stock units per hectare. A grazing policy of set-stocking was replaced by a rotational grazing system. Some of the statistics associated with intensification of the farm are listed in Table I. Since 1973 there had been regular applications of superphosphate fertilizer and lime to some areas of the farm in some years. The topdressing applied is listed in Table II.

Table I: Stock units per hectare, total number of cattle, lambing percentage and percentage of dry ewes on the Waipukurau farm are listed from 1975 to 1983.

Year	S/U ha.	# Cattle	Lambing %	% Drys
1983	14.8	0	80	8.0
1982	13.5	32	82	7.5
1981	15.3	79	94	6.8
1980	15.5	77	92	4.8
1979	12.8	78	105	5.4
1978	13.8	77	80	4.1
1977	13.3	78	112	4.0
1976	12.8	78	83	2.0
1975	13.5	N/A	78	N/A

THE INITIAL PROBLEM

The initial problem which led to veterinary involvement on the farm and finally to this detailed investigation was the poor growth of the replacement ewe hoggets. During the drought period the hoggets had lost an average of 5kg in body weight. This had occurred from early March to early May but the weight of the hoggets prior to this time was already lower than expected because of the serious drought. The two-tooth ewes (born in 1981) were also affected by the poor feed conditions which resulted from the drought. Even the mixed age ewes were well below the anticipated target weights of 55kg and well below the weights recorded in the same class of sheep in previous years. The mean weights for this group recorded in February, March and April 1983 were 46.5kg, 45.[illegible]kg and 44.3kg respectively.

Table II: Fertilizer and lime applied to the Waipukurau farm from 1973 through 1983.

Year	Superphosphate on Rolling Hills	Superphosphate on Steep Hills
1983	112 kg/ha. plus S	224 kg/ha.
1982	224 kg/ha. plus K	112 kg/ha.
1981	336 kg/ha. plus K	224 kg/ha.
1980	224 kg/ha. plus K	224 kg/ha.
1979	336 kg/ha. plus K	224 kg/ha.
1978	224 kg/ha. plus K	224 kg/ha.
1977	336 kg/ha. plus K	224 kg/ha.
1976	224 kg/ha. plus K	112 kg/ha. plus Mo
1975	none	none
1974	224 kg/ha. plus 2270 kg lime/ha.	224 kg/ha. plus 4540 kg lime/ha.
1973	224 kg/ha.	224 kg/ha.

CLINICAL OBSERVATIONS OF TEETH ON VARIOUS AGE GROUPS OF SHEEP

The mouths of a cross-section of each age group of sheep were inspected. A variety of dental anomalies were observed.

Lambs

The lambs were born (Spring 1983) with grossly normal incisors. These teeth began to wear at an early age at a rapid rate. The enamel and dentine continued to appear normal as the teeth decreased in size.

Hoggets

The deciduous incisors of many of the hoggets were worn to the gum line and some were even below the gum. The severity of the tooth deterioration in this group of sheep is demonstrated by Figure 1. On gross inspection the enamel of the deciduous teeth was considered to be normal provided they were large enough to be examined. Around some of the more severely affected teeth, there was a discoloration of gingival tissue with a necrotic appearance.

As deciduous incisors were examined there was strong evidence to suggest that they had not simply worn down from the wear surface but that the entire exposed surface of these teeth had been eroded as if they were melting away. The deciduous incisors were not only shortened, but were very small in overall size and in many cases were a spike or pebble-like vestige as seen in Figure 2. When these were compared to deciduous incisors from unaffected sheep of the same age from other farms (Fig. 3) the dramatic changes were obvious.

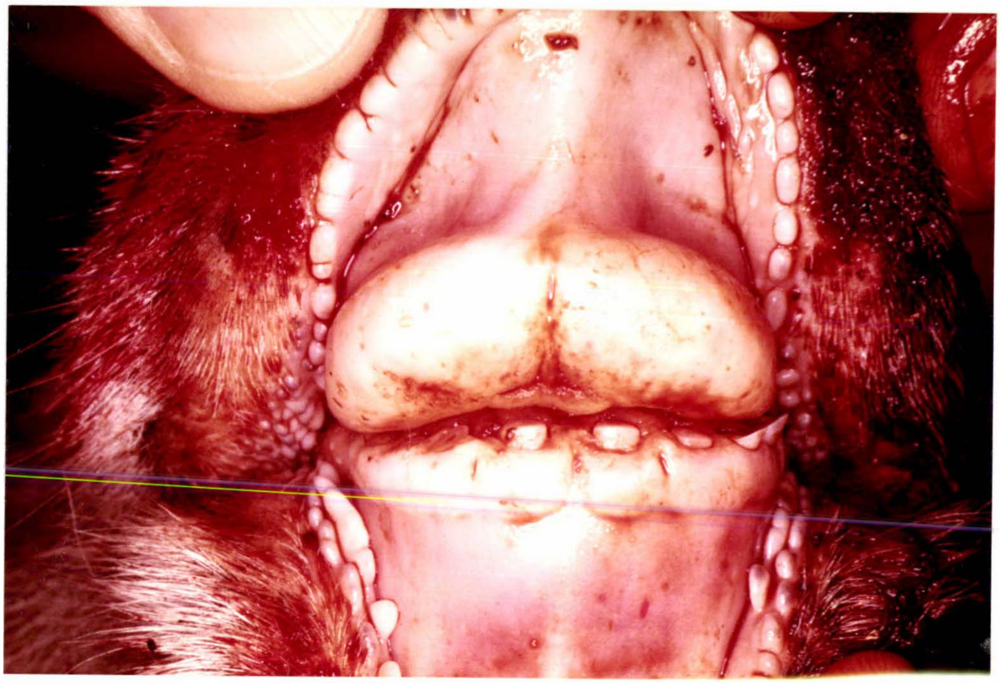

Fig. 1: Severely deteriorated deciduous incisors in a 14 month old ewe hogget on the Waipukurau farm.

Fig. 2: Severely deteriorated deciduous incisors in a 14 month old ewe hogget on the Waipukurau farm with obvious involvement of the entire exposed tooth surface.

Two-Tooth Ewes

In those sheep with recently erupted central permanent incisors there was little remaining of the deciduous incisors as usually seen in two-tooth sheep. Thus, the central permanent incisors were the only functional incisors. An unusual observation in these sheep was the fact that there was contact between the upper dental pad and the gingiva in the area of the deciduous incisor roots. Thus, limited prehension may have been possible by contact between the upper dental pad and the gums of the incisor area lateral and posterior to the central permanent incisors.

A number of enamel defects were present on the newly erupted central permanent incisor teeth of some sheep. These ranged from small areas of pitting to large areas of enamel hypoplasia as seen in Figures 4 and 5.

Figure 6 is a photograph taken in February of 1985. It demonstrates a linear area of deep pitting and enamel hyploplasia on the central permanent incisors and further clarifies this problem. It can be seen from this same figure that the enamel of the newly erupted lateral permanent incisors appeared quite normal. The linear lesion on the central incisors and the normal appearance of the lateral incisors suggested that some factor/factors possibly acting for a brief time only had influenced the formation of faulty enamel. Figure 7 demonstrates the degree to which the central incisors appear to have continued to erupt. In this photograph the central permanent incisors were affected by enamel hypoplasia but the affected portion had worn away and the remains of the central permanent incisors and the lateral permanent incisors were free of such enamel defects. In addition the tooth eventually wore past a data point originally drilled just above the gum line of the left central permanent incisor, demonstrating the rapid dissolution of tooth substance.

Fig. 3: Deciduous incisors in a 14 month old ewe hogget from the Tangimoana farm where tooth deterioration is not a problem.

Fig. 4: Enamel defects on central permanent incisors in a two-tooth ewe on the Waipukurau farm.

Fig. 5: Enamel defects on central permanent incisors in a two-tooth ewe on the Waipukurau farm.

Fig. 6: Linear enamel defects on the central permanent incisors of a four-tooth ewe on the Waipukurau farm.

Two of the sheep examined had extremely soft central permanent incisors. These teeth were chaulky in appearance and did not offer the same resistance as the teeth of other sheep when drilled to make data points. A powdery material was discharged when touched with the drill and it was noted that these teeth wore away at an extremely rapid rate and were soon near the gum line.

Another observation made on this farm and subsequently seen on other "high wear" farms supported the previously mentioned view that the incisor teeth were not only wearing away at the biting surface but were "dissolving" above and slightly below the gum margin. It was noted that certain newly-erupted permanent incisors had an almost transparent area at the tip of the tooth. This must be observed when the incisors are not in contact with the upper dental pad to avoid a false impression. The transparent tip was 1-2mm in length and portions of the tips were frequently chipped or broken. The author noted that a similar appearance could be produced by soaking teeth in concentrated citric acid for twenty-four hours as seen in Figure 8.

Another clinical observation which again supported the fact that other factors besides wear were involved was made when data points were drilled on the labial surface of the central permanent incisors. In the first cases care was taken not to drill into the pulp cavity and only enamel and dentine were drilled. In many cases after two weeks these data points were beginning to disappear and at six weeks most were totally eroded and could not be detected. It became apparent that on "high wear" farms it was necessary to drill into the pulp cavity if a permanent data point was to be established.

Mixed Age Ewes

Inspection of older sheep demonstrated evidence of a long term tooth deterioration problem. The oldest sheep on the farm were only four years of age which emphasized the culling rate as a result of tooth deterioration. In Figure 9 the mouths of four year old ewes grazing on the property are demonstrated. The incisors were short

Fig. 7: A data point nearly missing on a central permanent incisor with considerable tooth exposed below the point.

Fig. 8: Deciduous incisors which have been soaked in concentrated citric acid for 24 hours.

and small and clearly would be virtually down to the gum if the sheep had been retained another year. An example of a typical four-tooth ewe on this farm can be seen in Figure 10. The central permanent incisors had been worn to a level well below the lateral permanent incisors. These lateral incisors were without the usual support from either the deciduous incisors or the central permanent incisors. As a result it appeared that the lateral incisors also wore down quickly to the level of the central permanent incisors.

METHODS USED TO INVESTIGATE SOME OF THE CLINICAL OBSERVATIONS MADE

Trials were designed to generate information relating to certain aspects of the tooth problems. Visits to this farm were made at two-weekly intervals beginning in September 1983 through December 1983. Later visits were made at approximately monthly intervals from December 1983 through June 1984 depending on particular observations which needed to be made or materials collected. The following programme was conducted which included 100 hogget to two-tooth ewes selected at random and identified with numbered ear tags. The incisors were examined at each visit for eruption, severity of deterioration and presence of defects.

The Percentage of Faecal Ash

Ten faecal samples were collected from the area where the ewes were being run. Samples were collected every two weeks through December 1983 and thereafter they were collected at approximately monthly intervals. Faecal samples were collected with care to avoid pasture debris and other contamination. They were placed in plastic pots, identified and frozen until analysis was able to be conducted. These were analysed individually for faecal ash by the method (see Appendix I) described by Bock (1979).

Fig. 9: The incisors of a 4 year old ewe on the Waipukurau farm representative of the older sheep in this flock.

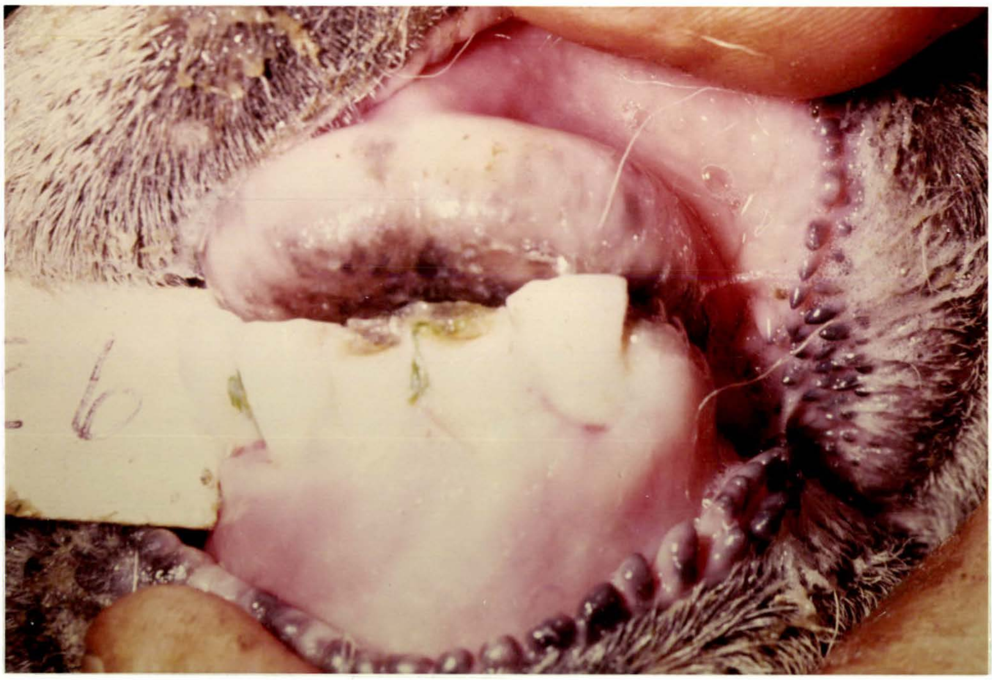

Fig. 10: The incisors of a four-tooth ewe on the Waipukurau farm with extensive deterioration of the central permanent incisors.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

Twenty-eight faecal samples were also acid washed to determine the relationship between the percentage of faecal ash and the percentage of acid insoluble residues. The method of analysis (see Appendix II) was that described by Healy and Ludwig (1965). The acid insoluble residue was expressed as a percentage of the dry weight of the faecal samples.

Observations on the Eruption Times of the Central Permanent Incisors

The eruption of the central permanent incisors was observed on the one hundred identified hoggets. Their mouths were examined at approximately two-week intervals from September 1983 until eruption was complete in all hoggets involved. The eruption of the teeth was recordéd as 0, 1/4, 1/2, 3/4 or 1 by date to denote the amount of exposed central permanent incisor. The date of birth was not known so that an estimate had to be made to determine the approximate age of eruption. For comparison eruption was finally defined as the emergence of the tooth through the gum tissue (1/4), since the grades of eruption were arbitrary and it was sometimes difficult to tell when the tooth was completely erupted.

Wear of the Central Permanent Incisors

A data point was drilled on the labial surface of the left central permanent incisor near the gingival margin. A number two carbide burr was used with a 24,000 u/min dental drill. The drill penetrated the enamel and dentine and entered the pulp cavity. An example of the data point can be seen in Figure 11. Measurements were taken at varying intervals of time from the data point to the tooth tip using dividers and a mm rule. These measurements were used as an indication of tooth wear.

Fig. 11: Data point on central permanent incisor with a visible transparent line on the tips.

RESULTS

The Percentage of Faecal Ash

The results of the faecal ash determinations are by date of collection in Table III. Percentages are recorded to the nearest .5%. The mean percentage faecal ash with standard deviation is also included. Figure 12 is a graph showing the mean percentage of faecal ash with standard deviation for the period from September 1983 to September 1984. The highest levels of faecal ash were generally measured in the late winter and spring. The notable exception was a sharp increase in faecal ash recorded in late February. The mean percentage of faecal ash for the period from September 1983 to September 1984 was 22.4%.

Table III: The percentage of faecal ash of faecal samples collected from September 1983 to September 1984 on the Waipukurau farm with mean and standard deviation.

#	15-9 1983	29-9 1983	13-10 1983	27-10 1983	10-11 1983	23-11 1983	8-12 1983	22-12 1983	5-1 1984
1	28.5	23.5	24.0	22.5	23.5	14.0	19.5	15.5	19.0
2	29.5	24.5	23.0	20.5	20.0	19.0	18.5	19.5	19.5
3	28.0	21.5	21.0	21.0	23.5	18.5	19.5	17.0	17.0
4	24.0	21.5	23.5	20.5	24.5	16.0	15.5	17.5	17.5
5	28.5	27.5	22.0	25.5	26.0	16.5	20.0	18.0	17.0
6	30.5	21.5	24.0	21.5	22.0	18.0	20.5	18.0	20.0
7	26.0	23.5	22.5	23.0	22.5	22.0	16.0	20.0	17.5
8	27.0	22.0	26.0	22.5	22.0	13.0	18.0	16.5	17.0
9	25.5	20.5	24.0	21.5	21.0	14.5	20.0	16.5	19.0
10	27.5	21.5	20.5	N/A	20.5	15.0	17.0	16.5	16.5
mean	27.500	22.750	23.050	22.056	22.550	16.650	18.450	17.500	18.000
st.d	1.9436	2.0716	1.6236	1.5701	1.8626	2.7391	1.7709	1.4142	1.2472

#	31-1 1984	25-2 1984	30-3 1984	18-4 1984	17-5 1984	20-6 1984	20-7 1984	31-8 1984	30-9 1984
1	20.0	28.5	19.0	24.5	18.5	17.5	20.0	27.0	28.5
2	19.0	30.0	20.0	25.0	17.5	20.0	19.5	25.5	26.5
3	18.5	31.5	21.0	24.0	17.0	19.0	21.5	25.5	40.0
4	17.0	34.0	18.5	23.5	18.0	17.0	20.5	28.0	37.0
5	18.0	32.0	18.5	26.0	16.5	18.0	20.0	28.0	28.5
6	18.5	32.0	20.0	25.0	21.0	24.0	17.5	28.0	42.5
7	19.0	40.0	18.0	24.0	19.5	17.5	22.0	26.0	37.0
8	18.5	32.5	20.5	23.5	18.0	18.5	19.0	27.0	37.0
9	19.0	36.5	19.5	22.0	15.0	20.0	20.0	30.0	43.0
10	18.0	28.0	22.0	21.5	20.0	17.0	18.5	26.0	35.5
mean	18.550	32.500	19.700	23.900	18.100	18.850	19.850	27.100	35.500
st.d	.79757	3.6286	1.2517	1.3703	1.7607	2.1220	1.3344	1.4298	5.8805

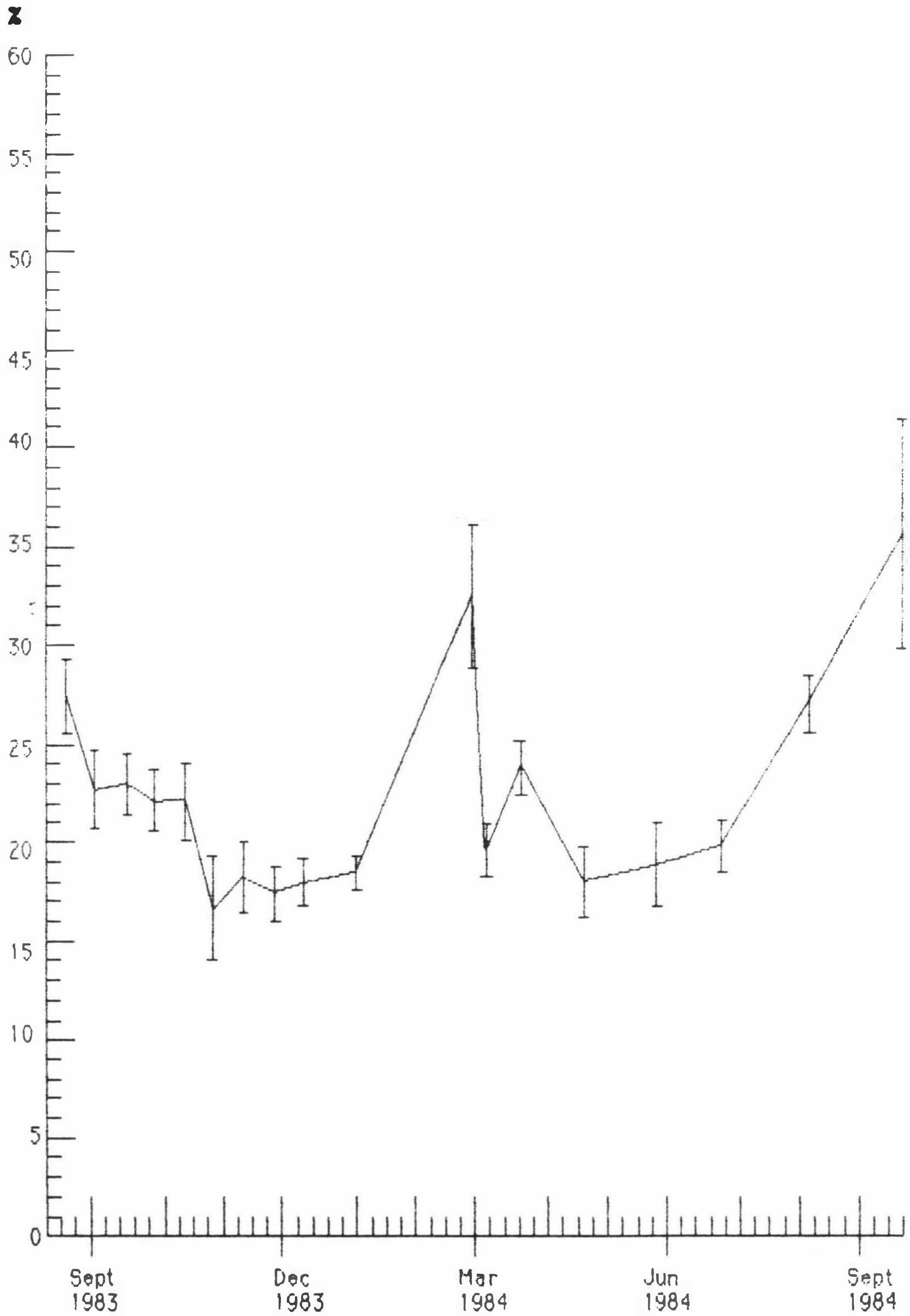

Figure 12 : Graph of mean percentage faecal ash with standard deviation from September 1983 to September 1984 on the Waipukurau farm.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

The results involving the comparison between the percentage of faecal ash and the percentage of acid insoluble residues are recorded in Table IV. The correlation is 0.752 and the variance is 86.7%. The comparison between these two indicators can thus be seen to be very close. This comparison was performed on samples taken at three separate collections. Samples 1-9 were collected on 30 March 1984, samples 10-18 were collected on 18 April 1984 and samples 19-28 were collected on 17 May 1984.

Observations on the Eruption Times of the Central Permanent Incisors

The results of observations of the eruption of the central permanent incisors are recorded in Table V. Eruption was preceded by the loosening and shedding of the central deciduous incisors. Occasionally the deciduous incisors would remain after the central permanent incisors had erupted. Preceding eruption it was noted that the gingiva would become inflamed at the area of the anticipated eruption and a blister would form. The tooth would emerge in a short time following the appearance of the blister. Eruption was also associated frequently with a minor amount of haemorrhage. If at the first observation the tooth was through the gum tissues, it would normally be completely erupted by the next observation in approximately two weeks. On the other hand if it had not completely erupted through the gum tissues on the initial observation, it would be partially erupted on the next visit. Table V records the date of visitation with the days to eruption for the central permanent incisors. The mean percentage of sheep with erupted teeth was calculated. The mean eruption time was 439 days. The dates of eruption are recorded in Table VI.

Table IV: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Waipukurau farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	19.0	11.0
2	20.0	12.0
3	21.0	11.0
4	18.5	11.5
5	20.0	11.0
6	18.0	12.0
7	20.5	12.0
8	19.5	12.5
9	22.0	11.0
10	24.5	16.0
11	25.0	16.0
12	24.0	14.5
13	23.5	16.0
14	25.0	15.0
15	24.0	15.5
16	23.5	14.5
17	22.0	14.0
18	21.5	14.5
19	18.5	10.5
20	17.5	9.5
21	17.0	10.0
22	18.0	10.5
23	16.5	10.0
24	21.0	10.0
25	19.5	8.0
26	18.0	12.0
27	15.0	12.5
28	20.0	11.0

Correlation = 0.752

Variance = 86.7%

Table V: The eruption of central permanent incisors of 100 hoggets on the Waipukurau farm with the first day of lambing day one.

Date	Days	% Erupted
15-9-83	402	8
29-9-83	416	16
13-10-83	430	35
27-10-83	444	58
10-11-83	458	71
23-11-83	471	81
8-12-83	486	90
22-12-83	500	93
1-1-84	514	96
19-1-84	528	100

Mean Eruption = 439 days

Wear of the Central Permanent Incisors

The degree of wear of the central permanent incisors has been recorded at varying intervals in Table VI. The entries preceded by a plus sign indicate increased tooth length resulting from inherent inaccuracies in the method of tooth measurement. The degree of accuracy of this method is described in a later section. Entries missing in the column from 31 January 1984 to 22 February 1985 represent teeth which had worn past the data point. The severity of enamel defects is also recorded in this table for comparison. The severity of the defects was assigned with an arbitrary rating of 0 through to 4 with 0 being the unaffected tooth and 4 being the most severely affected tooth. Grade 1 had minor pitting, grade 2 had widespread pitting, grade 3 had large shallow areas of enamel hypoplasia and grade 4 had large deep areas of enamel hypoplasia.

DISCUSSION

Discussion of Management

Since the change in ownership of this property in 1973 there have been four major management changes.

Change in Breed

There was a change from Romney sheep to Coopworth sheep. The owner reported that he had first become aware of the tooth wear problem about the time of this change in breeds. Although research has shown a breed predisposition for this condition (Meyer *et al.*, 1983), all breeds of sheep are affected. However the role of different breeds and the extent to which they contribute to the problem is probably small and certainly not the only factor in this complicated problem. Breed appears to play only a minor role in the tooth wear problem with Romney being only slightly less susceptible than Coopworth.

Change in the Grazing System

A second management change was a move from a set-stocked grazing system to a rotational grazing system. Barnicoat (1957) suggested that in general set-stocking tended to accentuate tooth wear problems when compared to rotational systems. Kane (1983) found the same to be true when he looked at more modern methods of rotational grazing. This management change could have been expected to improve tooth wear problems.

Table VI: Tooth wear in cm on the Waipukurau farm with the mean wear and mean daily wear calculated and the eruption date and enamel defects recorded.

#	13-10 1983- 10-11 1983	11-10 1983- 8-12 1983	8-12 1983- 31-1 1984	31-1 1984- 5-3 1984	5-3 1984- 18-4 1984	31-1 1984- 22-2 1985	eruption of C.P.I.'s	enamel defects
1		.32	0	.24	.04		29-9-83	4
2		.04	.04	.02	.06		5-9-83	2
3		.01	.03	.02	.01		13-10-83	0
4	.06	.08	+.01	.05	.05		5-9-83	2
5		.07	.18	.02	.01		13-10-83	0
6		.10	.19	.02	.09		13-10-83	4
7			.01	.03	+.02		13-10-83	3
8		.01	.08	.31	+.02		5-9-83	2
9				.01	.01	.98	10-11-83	0
10				+.01	.08	.71	23-11-83	1
11		.03	.01	.07	.02		13-10-83	0
12			.02	.02	.01	.62	27-10-83	0
13		.01	.08	.01	+.01		10-13-83	0
14					.02		31-1-84	
15	.05	.01	.09	.05	.02		5-9-83	0
16		.02	.01	.01	.03		27-10-83	1
17			.03	.15			10-11-83	0
18		.06	.05	.05	0		13-10-83	0
19		.12	0	.10	.02		27-10-83	0
20			.04	.04	+.03	.58	10-11-83	0
21		0	.10	.08	.07		27-10-83	2
22				.02	0	.53	10-11-83	1
23		.09	0	.05	.05		13-10-83	0
24			.15	.03	.04		27-10-83	4
25		.07	+.01	.07	.02		29-9-83	2
26			.02	.02	+.02		27-10-83	2

Table VI: Continued.

#	13-10 1983- 10-11 1983	11-10 1983- 8-12 1983	8-12 1983- 31-1 1984	31-1 1984- 5-3 1984	5-3 1984- 18-4 1984	31-1 1984- 22-2 1985	eruption of C.P.I.'s	enamel defects
27				.07	+.03		23-11-83	0
28	.10	.20	.05	0	.03		29-9-83	2
29		.03	+.01	+.03	.08	.51	13-10-83	1
30				.04	.04	.58	23-11-83	1
31		.07	.08	.01	.01		13-10-83	1
32				.27	.04		23-11-83	0
33			+.01				10-11-83	0
34			.02	.04	.02		10-11-83	0
35		.01	.02				29-9-83	0
36	.06	.06	.08	.09	.03		5-9-83	0
37			.02	.07	.07		8-12-83	0
38	.05	.05	.02	.04	.02		5-9-83	0
39			.01	.04	0	.52	13-10-83	0
40		0	.07	.07	.03		27-10-83	0
41				.15	.02		29-9-83	3
42		0	.01	.05	.05	.63	13-10-83	1
43				.05	.04	.70	10-11-83	0
44				+.02	.03		10-11-83	0
45				.09	0		27-10-83	0
46		.03	.04		.06		27-10-83	
47				.01	.05		8-12-83	0
48		.03	.17	+.01	.04	.63	13-10-83	0
49			+.01	.01	+.01		10-11-83	0
50				.08	.04		13-10-83	2
51		+.01	.04	.15	.02		13-10-83	2
52				.08	.01		13-10-83	0
53				.01	+.03	.73	31-1-84	0
54			.03	.03	+.01		27-10-83	1
55				.02	0	.69	8-12-83	0

Table VI: Continued.

#	13-10 1983- 10-11 1983	11-10 1983- 8-12 1983	8-12 1983- 31-1 1984	31-1 1984- 5-3 1984	5-3 1984- 18-4 1984	31-1 1984- 22-2 1985	eruption of C.P.I.'s	enamel defects
56		.03	.04	.11	.01		27-10-83	0
57			0	.01	.05		27-10-83	1
58		.16	.17	.06	.06		29-9-83	3
59				0	0	.69	8-12-83	1
60		.02	.01	.08	.08	.66	13-10-83	2
61				.01	+.01	.58	31-1-84	0
62			.05	.04	.01	.79	27-10-83	0
63				.01	0		8-12-83	1
64		.08	.01	0	.01		13-10-83	0
65		.04	+.03	.04	.01	.62	13-10-83	0
66		.10	+.01	.04	.02		13-10-83	1
67			0	.01	.01		27-10-83	0
68		.03	.02	+.02	.04		13-10-83	0
69		.10	0	.04	.07		5-9-83	4
70				.14	+.03		23-11-83	0
71			+.04	.08	+.01		27-10-83	0
72			.02					
73		.04		.06	.04		29-9-83	2
74		.09	.02	0	.02		29-9-83	1
75				.05	+.01		31-1-84	0
76	.03	.08		.04	.02	.59	5-9-83	0
77		.04	0	.03	.01	.64	29-9-83	1
78		+.02	+.02	.17	.01		29-9-83	0
79		.04	0	.07	0		13-10-83	1
80	.03	.05	.02	.07	.01		5-9-83	0
81			.02	+.01	.04		10-11-83	0
82			.05	.02	+.01		10-11-83	0
83				0	.03		31-1-84	0
84	0	.13	.05	.07			5-9-83	2

Table VI: Continued.

#	13-10 1983- 10-11 1983	11-10 1983- 8-12 1983	8-12 1983- 31-1 1984	31-1 1984- 5-3 1984	5-3 1984- 18-4 1984	31-1 1984- 22-2 1985	eruption of C.P.I.'s	enamel defects
85			.01	.09	.01		10-11-83	0
86			.07	.02	.06		29-9-83	0
87		.10	+.01	.08	0		13-10-83	0
88		.06	0	.10	.05		27-10-83	0
89			.01	.02	.03		27-10-83	2
90		.09	0	.16	.05		27-10-83	4
91		.12	.07	.04	+.02		29-9-83	1
92		.06	+.03	.06	.05		13-10-83	0
93			.03	.03	.02		13-10-83	0
94		.10	.06	.21	.03		13-10-83	2
95			.04	.07	.03		27-10-83	2
96		.05	+.02	.05	.06		13-10-83	3
97		.09	.06	.01	.01		29-9-83	0
98		.06	.05	.05	.04		29-9-83	3
99	.12	.02	.01	.07	+.02		29-9-83	1
100				.03	0		23-11-83	1
mean wear	.0555	.0583	.0319	.0555	.0219	0.649		
mean daily wear	.00198	.00208	.000591	.00163	.000498	.001677		

Intensification of Sheep Farming

A third change was a move to an intensification of sheep farming and the exclusion of cattle. A number of authors have concluded that running cattle with sheep to control pasture growth and maintenance leads to less deterioration of teeth than when sheep are grazed alone (Barnicoat, 1948; 1957; Suckling, 1964; 1975). The total exclusion of cattle from this farm occurred in 1983 and the full effects of this policy on the subsequent dental problem on the sheep is hard to evaluate but may have been significant.

Increase in Stocking Rate

The fourth and probably the most significant management change was the great increase in stock numbers. These rose from 8-9 stock units per hectare in 1972 to 15 stock units per hectare in 1983; a 43% increase in winter stocking rate. With onset of the severe drought in 1983, the farm capacity was significantly exceeded. A factor which has repeatedly led to and been associated with severe incisor wear in sheep has been high stocking of farms with sheep (Barnicoat, 1957; Healy & Ludwig, 1965; Arnold *et al.*, 1966; Suckling, 1975; Bircham *et al.*, 1981). The increased wear has been reported to occur from increased soil ingestion resulting from increased stock numbers grazing the same area (Healy & Ludwig, 1965). However trials to be reported and discussed in another section of this thesis have not fully supported this latter report. Nevertheless it can be said with assurance that stocking rate and tooth wear are directly related. Therefore it is necessary that any explanation of the aetiology of this condition is associated with this observation.

Discussion of Clinical Observations

Sensitivity of Deciduous Incisors

From the present observations it would appear that the deciduous incisors are more sensitive to tooth wear than permanent incisors. This point was also noted previously by Bruere et al. (1979) when sheep on the Wairarapa were exposed to similar conditions to those described on this farm. The farmer noticed the deciduous incisors disappearing very rapidly in April and May, 1983 and by the time the author began the examinations most of these incisors were either worn to gum level or were tiny remnants of teeth. This observation on this farm and other high wear farms is very difficult to explain simply in terms of soil abrasion. Wear by abrasion would be expected to affect teeth at the point of contact with the upper dental pad. Although it is true that a wear facet develops at this point and it does decrease in length, it is also obvious that the entire exposed surface of the tooth is affected. Deciduous incisors worn below the gum line also appear to have been affected by some action other than direct abrasion. It is difficult to explain this phenomenon in terms of simple abrasion when the teeth are below the contact point with the upper dental pad which may be assumed to be essential to the abrasive process. Further the full eruption of the central permanent incisors would also appear to protect the remaining deciduous incisors from further wear if this were the case.

Enamel Defects

The enamel defects reported in this study were remarkably similar to those reported by Bruere et al. (1979) on sheep farms in the Wairarapa. The problem in the Wairarapa also followed a period of severe weather conditions which led to extreme feed shortages. The tooth defects in the sheep on the Waipukurau farm could not be seen until the eruption of central permanent incisors took place. As a consequence it is suggested that the defects were manifestations of some interference with tooth development which took place previously.

This is highly likely as the development of the central permanent incisors is completed by ten to twelve months of age (Suckling, 1979). The cause of this latter problem is difficult to understand. It has been shown that calcium deficiency (Franklin, 1950), fluoride excess (Franklin, 1950; Krook et al., 1983) and parasitism (Suckling et al., 1983) may all lead to this type lesion. It is possible that either one of these factors could have occurred under the extreme conditions seen on the Waipukurau farm in 1983.

In this study no enamel defects were recorded in either the deciduous incisors or the lateral incisors. This would certainly support the view that the severe spring conditions were associated with the enamel defects of the central permanent incisors as neither the deciduous teeth nor the laterals would have developed during this period. However it is emphasized that the deciduous incisors were very susceptible to the wear problem indicating the occurrence of two separate entities; the enamel defects involving the central permanent incisors and the wear problem involving the deciduous and permanent incisors.

Some of the enamel defects led to rapid deterioration of the central permanent incisors as seen in those sheep having "chaulky" incisors which quickly wore to the gum line. This observation is not consistent with the findings on abrasion studies at Wallaceville (Erasmuson, 1983). This may suggest that teeth with this type defect were not included in the abrasion trials as teeth from sheep on high and low wear farms often have grossly normal enamel. It is also of interest that the farm under discussion was the only farm in the area where these dramatic defects were reported or observed (Beckett-personal communication, 1984). Therefore the environmental conditions involved in the production of these defects on farms in the North Island must be severe and in this case appear to be coupled with management factors.

Demineralization of Tips of Central Permanent Incisors

The loss of opacity involving the tips of newly erupted central permanent incisors was observed in several sheep on this farm. This can be seen in Figure 11. The transparent tips appeared demineralized leaving only the clear matrix to contact the dental pad at occlusion. It is more difficult to visualize this phenomenon as a wear facet develops because of the thickness of the tooth tip. Further the occurrence of demineralization of other exposed areas of the tooth would be difficult to see for the same reason. The possibility of this being a developmental problem was considered unlikely as it was also observed in sheep on other high wear farms which did not have the severe enamel defects.

Disappearance of Shallow Data Points

Rapid disappearance of shallow drill points on the labial surface of central permanent incisors was another important observation. Erosion of drill points indicated a similar problem on other tooth areas to that of demineralization of incisor tips previously described. The necessity to enter the pulp cavity to establish a permanent data point caused discoloration of some of the drilled teeth. This was likely a result of nerve damage. Although this nerve damage may have affected rate of wear, the seriousness of the problem on this farm could be seen without tooth measurements in undrilled teeth. Teeth used for comparative studies on other farms to be reported in another section were drilled using the same method.

Discussion of the Percentage of Faecal Ash

Elevation of the percentage of faecal ash during winter and spring months is consistent with elevation of the percentage of the acid insoluble residue levels of faeces reported to have occurred during winter and spring by Healy and Ludwig (1965). The percentage of faecal ash levels from the sheep from the Waipukurau farm were never found to be extremely high with a mean of 35.55% recorded in

September, being the highest determination. It must be remembered for comparison that this figure is higher than percentage of acid insoluble residue and the difference in percentage of faecal ash determinations and the percentage of acid insoluble residue for this farm was 8%.

A high peak of the percentage of faecal ash appears with the late February determination. This was during a time when sheep were grazing kale. In this particular case, tooth wear was not measured for the exact period of kale grazing, but it was included in a longer wear time measurement. The mean daily tooth wear during this measurement was near the mean daily average for this farm and was elevated for the summer months. It was of interest that large amounts of soil were ingested while grazing crops since grazing of crops reportedly reduces tooth wear (Ludwig et al., 1966; Healy et al., 1967; Bruere & West, 1983).

Discussion of the Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

The determination of percentage faecal ash was chosen since an indicator of total soil ingested was desired. Thus, certain minerals in soil removed by acid washing would be included. This method is not totally accurate due to the digestion by the animal of some minerals and the presence of non-ashable animal waste, however methods that could have led to more accurate determinations such as radioactive tagging of soil were not feasible. Therefore, the percentage of faecal ash was used as an indicator to estimate total soil ingested.

The percentage of acid insoluble residue had been used in past work as an indicator of that part of soil apparently involved in abrasion (Healy & Ludwig, 1965). A comparison of the percentage of faecal ash and the percentage of acid insoluble residue was desirable to permit comparison between methods. Table V records the results using both methods. There is a close correlation between methods and for the purpose of this study, either appear to be adequate. The difference between the percentage of faecal ash and the percentage of acid insoluble residue for this farm was 8.0%. This value could be subtracted from percent faecal ash when comparing to trials using percentage acid insoluble residue. The laboratory time involved in doing faecal ash is far less than that for acid insoluble residue.

Discussion of Eruption Times of the Central Permanent Incisors

A lack of individual birth records made comparison of eruption and wear rates difficult. However, with the information available the generalization can be made that there was no apparent correlation between time of eruption and rate of wear. Total wear appears to be greater on teeth which erupt early because of longer exposure to wear factors. These are the same conclusions drawn in earlier trials (Meyer et al., 1983). This would also be compatible with work showing development and maturation of central permanent incisors to be complete by 10-12 months (Suckling, 1979).

Discussion of Wear of the Central Permanent Incisors

The rate of wear of central permanent incisors was generally greater in the winter and spring and less in the summer and autumn months. This correlated with higher faecal ash levels. The same general findings were recorded in earlier trials (Healy & Ludwig, 1965). The exception is the recorded period from 31 January 1984 to 5 March 1984. During part of this time there was considerable soil ingested as indicated by high faecal ash. During the period of 10 February 1984 to 19 February 1984 the sheep were grazing kale.

Teeth can be seen to wear rapidly in one period and wear very slowly in the preceding or following period. It is suggested that the development of weakened tips which then break away rapidly is a possible explanation for this phenomenon. Further, a period of stability could then occur until subsequent exposed enamel and dentine are weakened. The time of grazing on kale was quite short for the amount of wear experienced. A number of large chips on central permanent incisors were observed at this time. It is suggested that weakened tips may have broken away rapidly when in contact with large soil particles ingested. Tooth length wear dropped to the lowest level the following period. Had crop grazing been continued, a drop in tooth wear may also have been seen as weakened tips disappeared and stronger enamel or dentine was exposed.

The central permanent incisors of the two sheep reported to have "chaulky" teeth broke away rapidly. These were sheep numbers one and six in Table VI. Except for these apparently very soft teeth, there appears to be little correlation between enamel defects and rate of wear.

Five other farms were visited and observations made as a comparison and continuation of this study.

CHAPTER 4
OBSERVATIONS AND TRIALS ON FARMS
An Investigation into Tooth Wear on Five North Island Farms

INTRODUCTION

Five farms with different degrees of tooth wear in their sheep were chosen from several locations. Two of the farms were classed as low wear farms because the sheep historically had good incisors. The other three farms had sheep with serious incisor wear problems. For descriptive reasons the farms were identified by their location or farm name.

FARM PROFILES

(1) The Tangimoana Farm

This farm was classed as a control property because the sheep's teeth were considered normal with respect to tooth wear. The farm had 1100 effective hectares and was located on the west coast of the lower North Island in the Tangimoana area. Topographically it was virtually flat with some sand dunes and the elevation was just above sea level. The average rainfall was 508 mm. The soil was sandy and pastures consisted mainly of brown top with some perennial rye grass and white clover. Superphosphate-K was applied annually at a rate of 270 Kg/ha and no lime was used. Hay was produced on the farm and fed with pasture to sheep and cattle from late May through July. This supplemental feed made up approximately 50% of the diet for that time of the year. There were 5600 Romney ewes and 530 breeding cows on the farm. The stock were grazed on a rotational system except for the set-stocking of ewes for lambing. The winter stocking rate was 10 su/ha.

(2) The Riverside Farm

This farm was located 10 km north of Masterton in the Wairarapa district which is in the eastern part of the lower North Island. It contained 725 effective hectares. It was mainly easy rolling hill country with some arable areas. The farm was at an altitude of 240m. The annual rainfall for the region was 862 mm. The soil types were classified as Tauherenikau, Konini and Greytown. Perennial rye grass and white clover were the predominant grasses. The farm had been regularly topdressed with superphosphate since the change in ownership in 1979. Amounts of fertilizer used were dependent on soil levels and on production purposes and varied considerably on the farm. Silage was fed to the sheep in March, April and part of May. There were 8,402 breeding ewes and no cattle grazing the farm. The sheep were rotationally grazed except for the lambing period. The winter stocking rate was 14 su/ha. The stocking rate had increased from 9.6 su/ha in 1978.

(3) The Pohangina Farm

This farm was located 30 km north of Palmerston North in the Pohangina county of the Manawatu district. Its area was 320 hectares composed of mainly hill country but small areas were arable. The altitude of the farm was 312m and it received an annual rainfall of 1243 mm. The predominant pasture species were perennial rye grass and white clover. The farm had been heavily limed with 2245kg/ha. to 6735kg/ha. The winter stocking rate for 1983 was 12.4 su/ha. The sheep were mainly grazed on a rotational system except at lambing time when they were set-stocked. The farm had both purebred and commercial flocks of Coopworth sheep. In addition approximately 200 cattle, mainly breeding cows, were wintered. The supplementary feed was fed to the cattle only.

(4)The Ranui Farm

This farm was a hill farm located east of Masterton again in the Wairarapa county. In area it covered 270 effective hectares. The farm was easy hill country with several areas which were arable used for growing winter and summer feed crops. The elevation of the farm was from 210m to 325m. The average annual rainfall was 900 mm. Soil types were Taihape Silt Loam on the steeper gullies and Atua, Bideford and Ngaumer Silt Loam on the rolling land. The main pasture was again perennial rye grass and white clover which had been topdressed with a program of heavy use of phosphate fertilizers since 1979. No supplementary feeds were used on this farm in 1983. The farm carried 2675 Coopworth ewes and ewe hoggets, 37 steers and 42 weaners. The sheep were rotationally grazed except at lambing time. The winter stocking rate was 12.58 su/ha.

(5)The Motukai Farm

This farm was located 15 km southeast of Masterton. In area it covered 625 effective hectares which were proportioned into approximately 20 hectares of flats, 260 hectares of rolling land and 345 hectares of steeper hill country. The elevation of the farm varied from 183m to 380m. The average rainfall was 1016 mm. The pastures were predominantly perennial rye grass and white clover and superphosphate had been used extensively over several years but no lime had been used in the last six years. However, the soil pH remained 5.5 to 6.0. The farm was stocked with Coopworth-Romney cross sheep and 115 steers. The sheep were rotationally grazed except during lambing time. Silage was fed to the sheep because of dry late summer conditions in March and April, 1983. The hoggets received no supplemenatary feed. The stocking rate was 12.03 su/ha.

CLINICAL OBSERVATIONS

(1)The Tangimoana Farm

On this property the majority of sheep had excellent teeth which showed little sign of wear other than what would be expected with aging. The farmer said he had selected sheep for "good mouths" that he considered had strong broad mandibles and the incisor teeth met the upper dental pad in a normal manner (Fig. 3). Examination of ewes of all ages and hoggets revealed very few defects of any kind in the incisors. There were many six year old ewes on the farm with incisor teeth which were remarkably good for their age. The deciduous teeth of the hoggets showed no evidence of deterioration other than what could be considered normal wear.

(2)The Riverside Farm

For comparative purposes this farm was also used as a "control farm" because the sheep also had excellent incisors similar to the Tangimoana property. The deciduous incisors of the younger sheep remained in functional condition until replaced by the respective permanent incisors. There were no enamel defects in any of the sheep observed. During the period which the tooth observations were conducted a small number of older ewes developed acute periodontitis of the molar teeth. The sheep lost weight rapidly. It was believed that the problem suddenly appeared as a result of dietary stress coupled with severe parasitism (Bruere-personal communication, 1984). However, the condition did not affect the majority of the sheep.

(3)The Pohangina Farm

The Pohangina farm was a farm with a serious tooth wear problem. Mixed age ewes showed evidence of severe wear of permanent incisors and deciduous incisor teeth of ewe hoggets and two-tooth ewes were worn near or below the gum line. Erupting central permanent incisors appeared grossly normal with no evidence of enamel defects as seen on the Waipukurau farm.

Ewe hoggets on this farm were lighter in comparison to those on the Tangimoana and the Riverside farm where teeth were excellent. However, purebred ram hoggets on the Pohangina farm were 12 kgs heavier than the ewe hoggets on the same farm even though the incisor condition was similar. The ram hoggets had received better nutritional opportunities and did not appear limited by the dental problems at this stage.

Some of the observations made on the Waipukurau farm were also seen on this farm. Shallow data points drilled into the labial surface of central permanent incisors eroded and some were not visible after four to six weeks. Subsequently, it was necessary to drill into the pulp cavity in order to establish a permanent data point. The transparent tips involving central permanent incisor teeth were also seen on this farm.

(4) The Ranui Farm

The Ranui farm is another farm with a significant incisor wear problem in the sheep. The incisor teeth of the sheep on this farm were in general severely affected by wear in all ages. In the two-tooth ewes the deciduous incisors had almost disappeared completely while the central permanent incisors had begun to deteriorate significantly. In fact they were the main teeth left for biting grass and not supported in the usual manner by the deciduous incisors. In some sheep of eighteen months to two years of age the lateral incisor teeth had erupted and were longer than the central permanent incisors. This was a common finding on the high wear farms as was seen in Figure 4. The deterioration of the permanent incisors of sheep on this property was so severe that only 220 four year old ewes and 50 five year old ewes remained in the flock from a total of 2765 ewes. This indicated the seriousness of the dental problem on this property. In some sheep occasional mild pitting on the erupting central permanent incisors was seen and was consistent with enamel hypoplasia.

The erosion of shallow data points and the transparent tips involving central permanent incisors described on the Waipukurau and the Pohangina farms were also observed on this farm.

(5)The Motukai Farm

Again this was considered a "high wear" farm where the sheep incisor teeth were severely affected by wear. However from observation the deciduous teeth were not found to be worn as close to the gum line as frequently as on the Ranui farm. From a total flock of 5700 ewes there were 1000 four year old ewes, 70 five year old ewes, 20 six year old ewes and 1 seven year old ewe so that the majority of breeding ewes had produced lambs for only one or two seasons. The Romney rams brought on to this "high wear" farm from "low wear" farms experienced the same rapid incisor deterioration.

The erosion of shallow data points and the transparent tips involving the central permanent incisors described on the Waipukurau and the Pohangina farms and seen on the Ranui farm were also observed on the Motukai farm.

METHOD OF TRIALS ON THE FIVE FARMS

Beginning in October 1983 all farms were visited at approximately two-weekly intervals until late December 1983. After this time the farms were visited at approximately monthly intervals until June 1984. It was considered that these times would coincide with the eruption of the central permanent incisor teeth. In these observations 100 hogget ewes (12-14 month old) were selected at random on each farm and identified with plastic numbered ear tags. At each visit the mouths were examined for the eruption of the central permanent incisors. Eruption of these teeth was scored as was described in Chapter 3 with 0, 1/4, 1/2, 3/4, or 1 to denote the amount of exposed central permanent incisor. For comparison eruption was finally defined as the emergence of the tooth through the gum tissue (1/4) since the grades of eruption were arbitrary and it was sometimes difficult to tell when the tooth was completely erupted.

Twenty two-tooth ewes were selected at random from the original 100 hoggets. A point was drilled into the pulp cavity of the central permanent incisors near the gum line as described and shown in Figure 11. The point would be used as a reference for measuring the degree of wear from the wear facet and thus the severity of the wear problem on the individual farms could be determined objectively.

Ten faecal samples were collected on each farm at each visit. From these samples the percentage of faecal ash was determined (see Appendix I). In addition the percentage of faecal ash-acid insoluble residue was compared (see Appendix II) on 19, 29, 20, 27 and 20 samples from the Tangimoana, Riverside, Pohangina, Ranui and Motukai farms respectively.

A comparison of measurements was made on the Tangimoana farm to determine the accuracy of the method being used to measure wear. Sixteen sheep were measured for incisor wear from data point to incisor tip on the central permanent incisors. The measurements were repeated on the same teeth using the same method on the same day. Correlation coefficient and variance were calculated.

RESULTS OF THE TRIALS OF THE FIVE FARMS

(1) The Tangimoana Farm

The Percentage of Faecal Ash

In Table VII the percentage of faecal ash from the samples collected on the Tangimoana farm is recorded. The mean percentage and standard deviations for each set of data are also recorded. It is particularly pertinent to note that the highest mean faecal ash percentage and the highest individual faecal ash percentage were recorded on this farm. They were 51.0% recorded on 20 August 1984 and 69.5% recorded on June 1984 respectively. Figure 13 is a graph showing the mean percentage of faecal ash measured from October 1983 to September 1984. It can be clearly seen that there was an increase in the level of faecal ash during the winter months.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

In Table VIII the correlation of the percentage of faecal ash-percentage of acid insoluble residue for the samples collected on the Tangimoana farm is recorded. The correlation coefficient was 0.971 and the variance was 98.5%. The mean difference in the percentage of faecal ash and the percentage of acid insoluble residue was 7.57%.

Observations on the Eruption Times of the Central Permanent Incisors

The dates of eruption of the central permanent incisor teeth of 100 hoggets grazed on the Tangimoana farm are given in Table IX. The first observation was on 5 October 1983 at which time 14% of the central permanent incisors had erupted. The last sheep was observed with erupted central permanent incisors on the 2 February 1984 visit. If day one is the first day of lambing, the mean eruption time from that date was 466 days.

The Wear of the Central Permanent Incisors

The rate of wear of the central permanent incisors has been recorded in Table X. Some of the teeth appear to have increased in length from data point to tip. This actually represents inaccuracies in the method of measuring from data point to the tip of the tooth. These are designated by a plus preceding the entry. The estimated mean daily tooth wear was .000781cm. This estimate was from measurements taken from 26 January 1984 to 12 February 1985 and was the lowest rate of tooth wear recorded of any of the farms under study.

Comparison of Measurements

In Table XI two sets of tooth measurements on the same two-tooth ewes were recorded on the same day. The measurements had a high correlation which verified that the method was both repeatable and accurate.

Table VII: The percentage of faecal ash of faecal samples collected from October 1983 to September 1984 on the Tangimoana farm with mean and standard deviation.

#	5-10 1983	19-10 1983	8-11 1983	22-11 1983	6-12 1983	19-12 1983	2-1 1984	26-1 1984
1	30.0	37.0	26.0	18.0	19.0	21.0	22.0	21.0
2	24.0	38.0	22.5	24.0	23.5	19.5	20.5	23.0
3	29.0	40.0	29.0	35.5	25.5	22.0	22.0	19.0
4	34.0	43.0	19.0	23.0	20.5	18.5	23.0	22.0
5	26.0	23.0	26.5	25.0	21.0	14.5	17.5	17.5
6	30.0	29.0	20.0	23.0	21.0	19.0	20.0	24.5
7	22.0	28.0	16.5	17.5	26.0	17.0	18.5	18.0
8	24.0	29.0	38.0	28.5	22.0	16.5	19.5	20.0
9	37.5	42.5	29.5	31.5	20.5	16.5	16.5	22.5
10	25.0	26.0	23.5	50.5	24.0	19.0	N/A	20.5
mean	28.150	33.500	25.050	27.650	22.300	18.350	19.944	20.800
st.d	4.8993	7.2610	6.2381	9.7697	2.3357	2.2614	2.1858	2.2509

#	28-2 1984	20-3 1984	20-4 1984	24-5 1984	20-6 1984	20-7 1984	20-8 1984	20-9 1984
1	19.5	23.5	21.0	22.5	44.5	38.0	45.5	24.5
2	18.0	20.0	19.0	25.5	29.5	56.0	48.0	29.5
3	17.0	36.0	20.5	34.5	28.0	29.5	55.5	20.5
4	19.5	19.0	24.0	22.0	39.0	42.0	50.0	26.5
5	20.0	19.5	41.5	21.0	69.5	49.5	53.0	19.5
6	22.0	29.5	18.5	44.0	50.5	65.0	54.0	19.5
7	14.5	17.5	25.0	22.0	54.0	32.0	51.0	24.0
8	17.5	23.0	28.0	26.5	34.5	50.0	N/A	20.5
9	18.0	16.5	35.0	42.5	59.0	48.0	N/A	19.0
10	21.5	18.0	18.0	23.0	55.0	51.5	N/A	19.5
mean	18.750	22.250	25.050	28.350	46.350	46.150	51.000	22.300
st.d	2.2267	6.1520	7.7869	8.7688	13.602	10.911	3.5000	3.6225

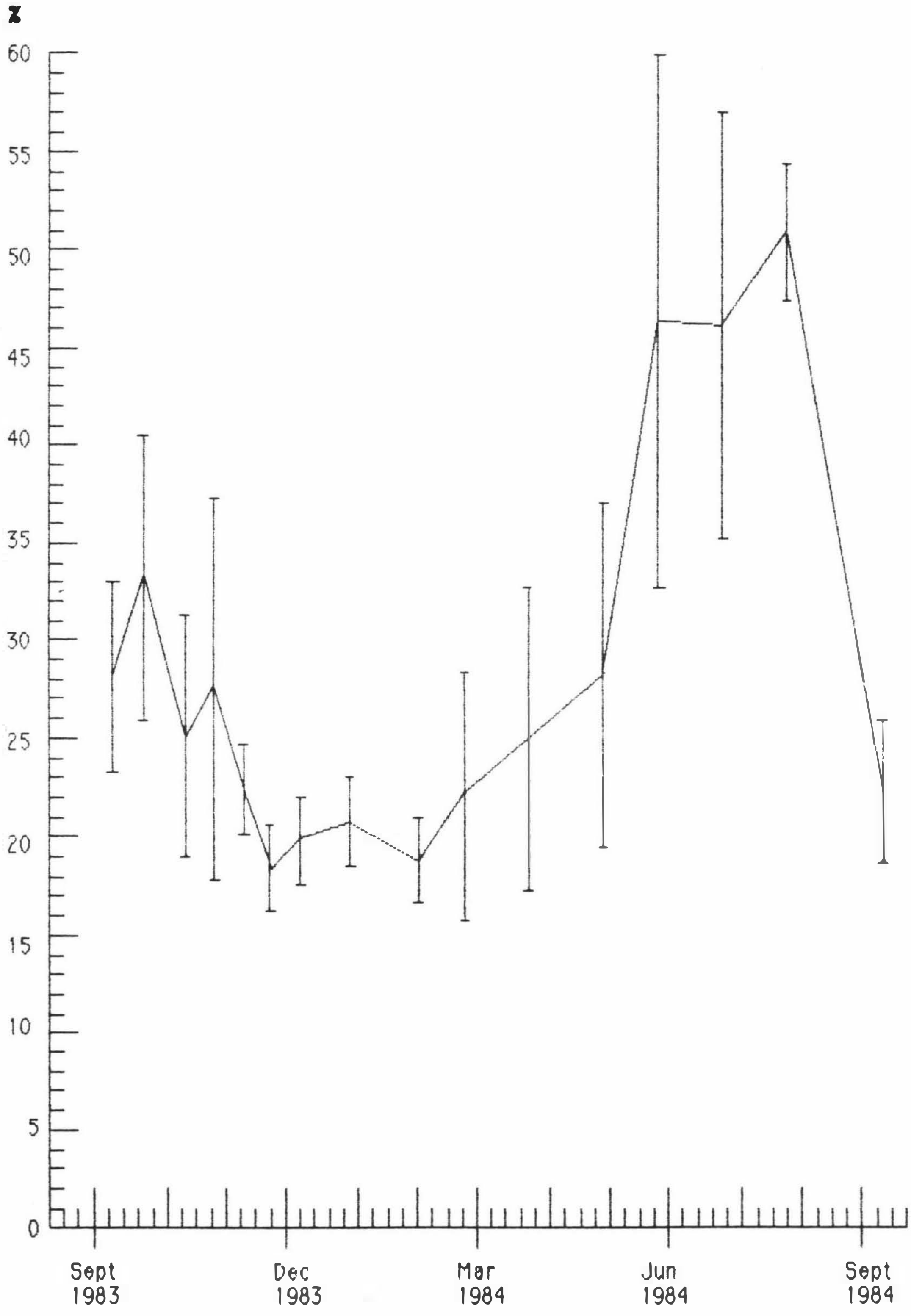

Figure 13 : Graph of mean percentage faecal ash with standard deviation from October 1983 to September 1984 on the Tangimoana farm.

Table VIII: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Tangimoana farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	21.0	13.5
2	19.0	13.5
3	20.5	14.0
4	24.0	13.0
5	41.5	32.5
6	18.5	14.5
7	25.5	18.5
8	28.0	17.0
9	35.0	29.0
10	18.0	10.5
11	22.5	13.0
12	25.5	16.0
13	34.5	27.0
14	21.0	17.5
15	44.0	37.0
16	22.0	14.0
17	26.5	18.0
18	42.5	34.5
19	23.0	15.0

Correlation = 0.971

Variance = 98.5%

Table IX: The eruption of central permanent incisors of 100 hoggets on the Tangimoana farm with the first day of lambing day one.

Date	Days	% Erupted
5-10-83	431	14
19-10-83	445	27
8-11-83	468	51
22-11-83	479	65
6-12-83	493	77
19-12-83	506	85
2-1-84	520	95
26-1-84	544	99
28-2-84	577	100

Mean eruption = 466 days

Table X: Tooth wear in cm on the Tangimoana farm with the mean wear and mean daily wear calculated.

#	26-1-84 to 28-2-84	28-2-84 to 11-4-84	26-1-84 to 12-2-85
106	+.01	.02	.26
109	0	+.01	.32
125	0	0	.28
137	+.01	.01	.16
139	.01	0	N/A
152	.02	.01	.31
154	+.03	.02	.29
157	0	0	.21
158	0	0	.15
160	+.02	.04	.45
161	.04	0	.48
164	0	+.01	.18
165	.01	.02	.38
174	.02	0	.25
175	+.02	N/A	.18
177	.08	+.01	N/A
183	+.01	.03	N/A
186	.01	.01	.30
197	0	0	.27
198	0	0	.41
mean wear	.0045	.0068	.2870
mean daily wear	.000136	.000158	.000705

Table XI: Correlation of two sets of measurements of central permanent incisors in sheep on the Tangimoana farm re-measured and recorded on the same day.

#	1 st.	2 nd.
1	.35	.34
2	.48	.48
3	.52	.50
4	.60	.60
5	.72	.72
6	.73	.74
7	.70	.70
8	.70	.70
9	.69	.69
10	.70	.71
11	.81	.81
12	.61	.62
13	.62	.60
14	.69	.67
15	.58	.59
16	.65	.69

Correlation = 0.992

Variation = 99.6%

(2) The Riverside Farm

The Percentage of Faecal Ash

In Table XII the percentage of faecal ash from the samples collected on the Riverside farm is recorded. Figure 14 is a graph showing the percentage of faecal ash measured from October 1983 to May 1984. Samples from the winter months were not available from this farm.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

In Table XIII the correlation of the percentage of faecal ash-percentage of acid insoluble residue from the samples collected on the Riverside farm is recorded. The correlation coefficient was 0.873 and the variance was 93.4%. The mean difference in the percentage of faecal ash and the percentage of acid insoluble residue was 9.4%.

Observations on the Eruption Times of the Central Permanent Incisors

The dates of eruption of the central permanent incisor teeth of 100 hoggets grazed on the Riverside farm are given in Table XIV. The first observation was on 17 October 1983 at which time 9% of the central permanent incisors had erupted. The last sheep was observed with erupted central permanent incisors on the 28 February 1984 visit. If day one is the first day of lambing, the mean eruption time from that date was 454 days.

The Wear of the Central Permanent Incisors

The rate of wear of the central permanent incisors has been recorded in Table XV. The estimated mean daily tooth wear was .000815cm. This estimate was from measurements taken from 30 January 1984 to 28 February 1985. This rate of wear was only slightly greater than the lowest rate which was recorded on the Tangimoana farm.

Table XII: The percentage of faecal ash of faecal samples collected from October 1983 to May 1984 on the Riverside farm with mean and standard deviation.

#	17-10-83	31-10-83	14-11-83	28-11-83	12-12-83
1	21.0	22.0	17.0	19.0	12.5
2	28.5	21.0	18.0	15.0	15.0
3	44.0	18.0	20.5	17.0	13.0
4	46.0	17.0	22.0	14.5	19.0
5	42.0	20.5	21.0	14.5	17.0
6	34.5	18.5	30.5	13.0	14.0
7	39.0	22.0	18.5	11.0	15.5
8	27.0	17.0	20.5	15.5	15.5
9	43.0	19.0	26.5	14.0	14.0
10	34.0	N/A	20.0	13.5	14.5
mean	35.900	19.444	21.450	14.700	15.000
st.d	8.3427	1.9913	4.1126	2.1884	1.9149

#	27-1-84	27-2-84	26-3-84	16-4-84	16-5-84
1	12.0	15.0	15.0	17.5	22.0
2	12.5	16.5	16.5	15.0	12.0
3	10.0	17.5	16.0	19.0	19.5
4	11.5	25.0	16.5	16.5	21.0
5	11.0	16.5	15.0	13.0	22.0
6	13.0	16.5	15.5	16.5	25.5
7	13.0	15.5	15.0	13.0	22.0
8	12.5	14.5	16.0	17.5	20.0
9	12.0	19.0	15.5	16.5	20.5
10	13.5	20.5	14.0	13.0	21.5
mean	12.100	17.650	15.500	15.750	20.600
st.d	1.0488	3.1539	.78173	2.1506	1.0488

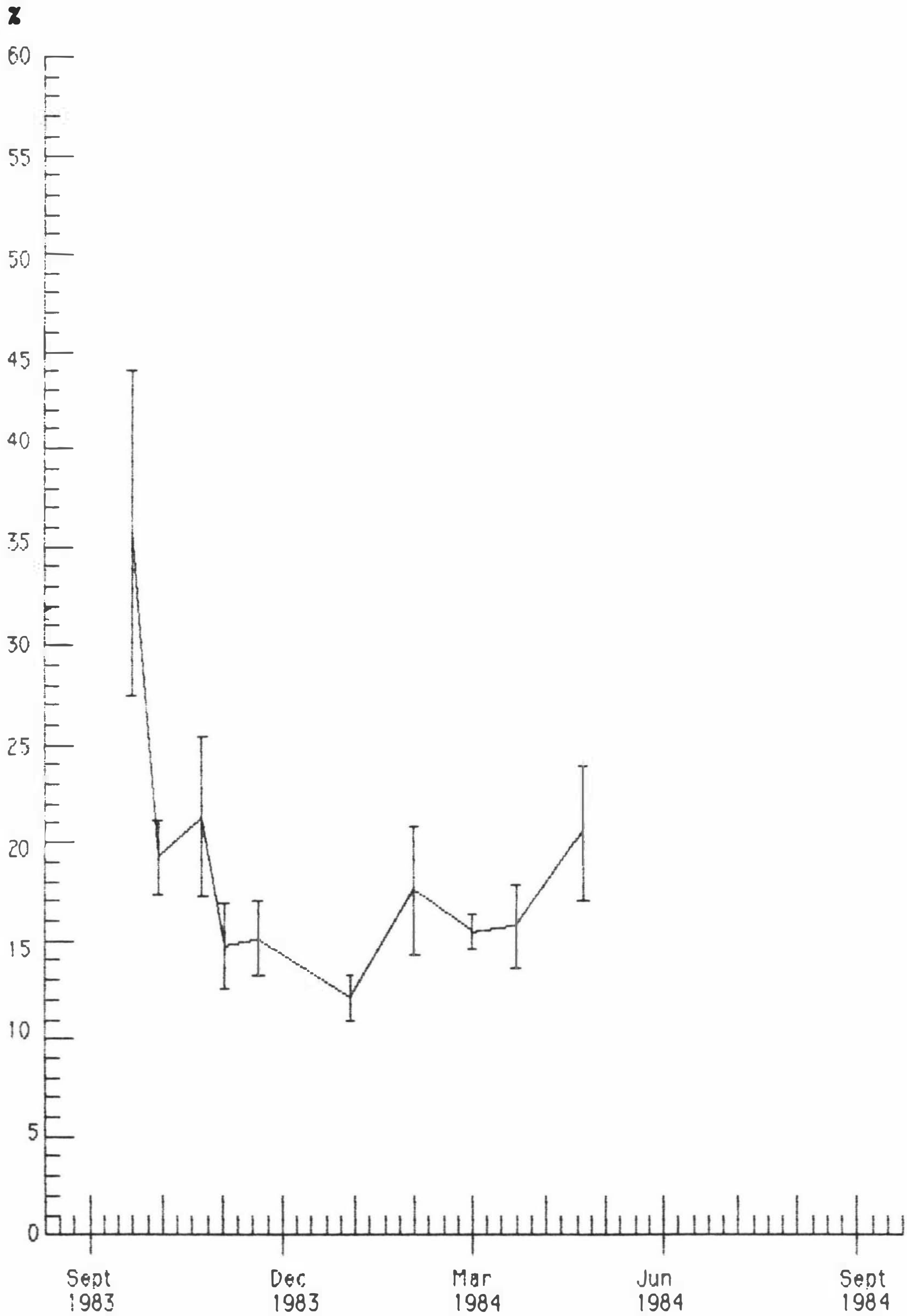

Figure 14 : Graph of mean percentage faecal ash with standard deviation from October 1983 to May 1984 on the Riverside farm.

Table XIII: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Riverside farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	15.5	4.5
2	16.5	4.0
3	16.0	4.5
4	16.5	5.0
5	15.0	4.0
6	15.5	5.5
7	15.0	4.0
8	16.0	5.0
9	15.5	4.0
10	14.0	4.5
11	17.5	7.0
12	15.0	5.5
13	19.0	6.5
14	16.5	7.0
15	13.0	6.5
16	16.5	6.0
17	13.0	4.0
18	17.5	6.0
19	16.5	9.0
20	13.0	4.5
21	22.0	12.5
22	12.0	7.5
23	19.5	12.5
24	21.0	13.5
25	22.0	14.0
26	25.5	17.0
27	22.0	14.0
28	20.0	13.0
29	21.5	14.0

Correlation = 0.873

Variance = 93.4%

Table XIV: The eruption of central permanent incisors of 100 hoggets on the Riverside farm with the first day of lambing day one.

Date	Days	% Erupted
17-10-83	412	9
31-10-83	426	18
14-11-83	440	37
28-11-83	454	50
12-12-83	468	68
26-12-83	482	78
30-1-84	517	98
28-2-84	546	100

Mean Eruption = 454 days

Table XV: Tooth wear in cm on the Riverside farm with the mean wear and mean daily wear calculated.

#	30-1-84 to 27-2-84	30-1-84 to 28-2-85
380	+.01	.47
378	0	.40
307	.01	.29
386	.01	.47
318	.01	.24
373	+.01	.28
391	0	.25
360	+.01	.28
361	+.01	.34
348	.01	
324	.02	.38
323	0	.28
336	0	.18
315	0	.26
333	.02	.34
393	+.01	
400	+.01	.31
389	.01	.37
350	.05	
356	0	
mean wear	.00400	.32125
mean daily wear	.0001428	.0008153

(3)The Pohangina Farm

The Percentage of Faecal Ash

In Table XVI the percentage of faecal ash from the samples collected on the Pohangina farm is recorded. The mean percentage and standard deviations for each set of data are also recorded. Figure 15 is a graph showing the percentage of faecal ash measured from October 1983 to August 1984.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

In Table XVII the correlation of the percentage of faecal ash-percentage of acid insoluble residue for the samples collected on the Pohangina farm is recorded. The correlation coefficient was 0.940 and the variance was 97.0%. The mean difference in the percentage of faecal ash and the percentage of acid insoluble residue was 10.1%.

Observations on the Eruption Times of the Central Permanent Incisors

The dates of eruption of the central permanent incisor teeth of 100 hoggets grazed on the Pohangina farm are given in Table XVIII. The first observation was on 21 October 1983 at which time 2% of the central permanent incisors had erupted. The last sheep was observed with erupted central permanent incisors on the 25 January 1984 visit. If day one is the first day of lambing, the mean eruption time from that date was 454 days.

The Wear of the Central Permanent Incisors

The rate of wear of the central permanent incisors has been recorded in Table XIX. The estimated mean daily tooth wear was >.001477cm. This estimate was from measurements taken from 25 January 1984 to 26 February 1985 .

Table XVI: The percentage of faecal ash of faecal samples collected from October 1983 to September 1984 on the Pohangina farm with mean and standard deviation.

#	21-10 1983	4-11 1983	18-11 1983	2-12 1983	21-12 1983	2-1 1984	25-1 1984
1	18.0	19.0	25.5	20.0	18.0	16.0	19.5
2	23.0	20.0	19.0	18.5	20.0	20.0	21.5
3	21.0	19.0	18.5	23.5	22.0	17.5	20.0
4	21.0	22.0	18.5	18.5	25.0	18.0	22.0
5	20.5	18.0	22.0	22.0	21.0	19.0	20.5
6	21.0	20.0	20.5	21.5	18.5	18.0	22.0
7	19.0	18.0	17.5	19.0	18.5	18.0	21.0
8	22.0	N/A	19.0	18.5	21.0	21.0	22.0
9	20.0	17.5	19.5	22.0	20.5	17.5	22.0
10	19.0	22.0	18.0	21.0	16.5	17.0	21.0
mean	20.450	19.500	19.800	20.450	20.100	18.200	21.150
st.d	1.4991	1.6583	2.3828	1.8020	2.4014	1.4568	.91439

#	25-2 1984	15-3 1984	3-5 1984	20-6 1984	20-7 1984	20-8 1984	20-9 1984
1	16.0	21.0	20.5	27.0	46.5	19.5	22.5
2	20.5	28.0	18.5	28.5	52.0	19.5	17.5
3	24.5	26.5	21.5	33.0	54.5	20.5	17.5
4	21.0	20.5	23.0	26.0	41.5	19.0	19.0
5	23.0	21.0	24.5	34.0	46.5	16.0	16.5
6	17.0	23.0	18.5	25.5	48.0	15.5	19.0
7	19.0	22.5	20.5	25.5	50.0	20.5	N/A
8	18.5	21.5	21.0	31.5	54.5	22.0	N/A
9	21.0	23.5	19.5	24.0	48.0	18.0	N/A
10	20.5	21.0	17.5	25.0	45.5	16.0	N/A
mean	20.100	22.850	20.500	28.000	48.700	18.650	18.667
st.d	2.5798	2.5391	2.1474	3.5901	4.1177	2.2117	2.1134

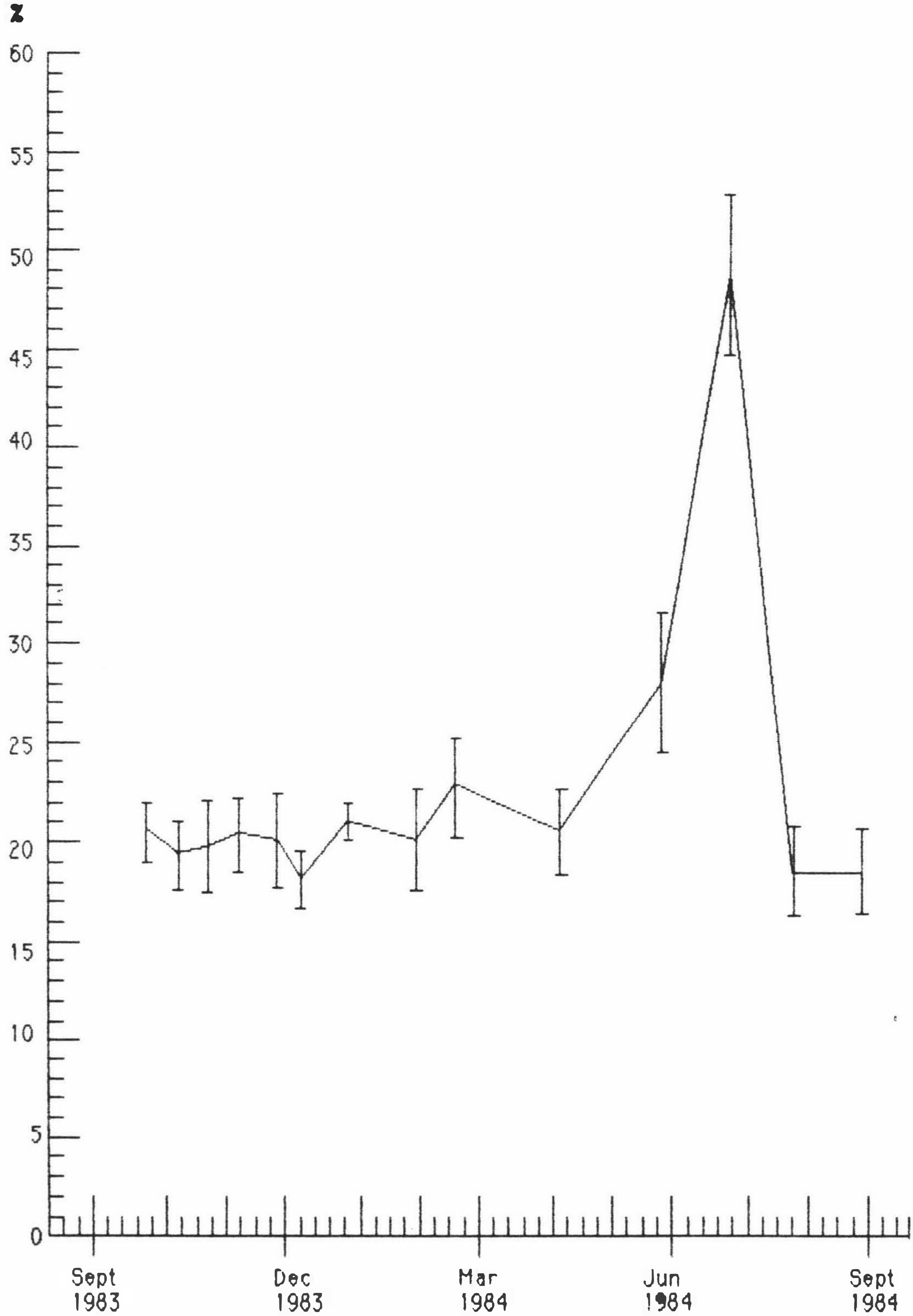

Figure 15 : Graph of mean percentage faecal ash with standard deviation from October 1983 to August 1984 on the Pohongina farm.

Table XVII: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Pohangina farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	21.0	10.0
2	28.0	17.0
3	26.5	16.0
4	20.5	12.0
5	21.0	12.5
6	23.0	12.5
7	22.5	12.5
8	21.5	13.0
9	23.5	14.5
10	21.0	10.0
11	20.5	11.0
12	18.5	8.5
13	21.5	12.0
14	23.0	12.0
15	24.5	14.0
16	18.5	9.0
17	20.5	11.0
18	21.0	10.0
19	19.5	10.0
20	17.5	8.0

Correlation = .0940

Variance = 97.0%

Table XVIII: The eruption of central permanent incisors of 100 hoggets on the Pohangina farm with the first day of lambing day one.

Date	Days	% Erupted
21-10-83	423	2
4-11-83	437	27
18-11-83	451	46
2-12-83	465	74
21-12-83	484	92
2-1-84	499	95
25-1-84	519	100

Mean Eruption = 454 days

Table XIX: Tooth wear in cm on the Pohangina farm with the mean wear and mean daily wear calculated.

#	2-12-83 to 25-1-84	25-1-84 to 6-3-84	6-3-84 to 7-6-84	25-1-84 to 26-2-85
6	.09			
16	.11			.52
74	.09	0	.19	.71
176	.06	.04	.06	.54
200	.13	0	.19	.61
218	.07	.05	.09	.65
276	.10	.08	.10	.47
282	.04	.08	.11	
493	.08	.06	.08	.50
514	.13	.04	.20	>.77
525	.09	.03	.24	>.78
541	.09	.01	.10	
610			.06	
646			.15	
657	.20			.67
665	.06	.03	.25	.49
691				.44
1088	.24	.01	.09	.81
1095	.14	.02	.19	.60
1153	.20	.02	.08	.39
1168	.28	.01	.20	
1432			.14	.43
mean wear	.12222	.03200	.14000	>.58625
mean daily wear	.00277	.000780	.001505	>.001477

(4) The Ranui Farm

The Percentage of Faecal Ash

In Table XX the percentage of faecal ash from the samples collected on the Ranui farm is recorded. The mean percentage and standard deviations for each set of data are also recorded. Figure 16 is a graph showing the percentage of faecal ash measured from October 1983 to August 1984.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

In Table XXI the correlation of the percentage of faecal ash-percentage of acid insoluble residue for the samples collected on the Ranui farm is recorded. The correlation coefficient was 0.951 and the variance was 97.5%. The mean difference in the percentage of faecal ash and the percentage of acid insoluble residue was 8.5%.

Observations on the Eruption Times of the Central Permanent Incisors

The dates of eruption of the central permanent incisor teeth of 100 hoggets grazed on the Ranui farm are given in Table XXII. The first observation was on 17 October 1983 at which time 5% of the central permanent incisors had erupted. The last sheep was observed with erupted central permanent incisors on the 27 February 1984 visit. If day one is the first day of lambing, the mean eruption time from that date was 455 days.

The Wear of the Central Permanent Incisors

The rate of wear of the central permanent incisors has been recorded in Table XXIII. The estimated mean daily tooth wear was >.001630cm. This estimate was from measurements taken from 23 January 1984 to 19 March 1985.

Table XX: The percentage of faecal ash of faecal samples collected from October 1983 to August 1984 on the Ranui farm with mean and standard deviation.

#	31-10 1983	14-11 1983	28-11 1983	12-12 1983	26-12 1983	9-1 1984	27-1 1984
1	22.0	26.5	24.0	21.0	18.5	20.0	18.5
2	29.5	25.0	28.5	24.5	17.0	18.0	16.5
3	37.0	21.5	24.0	25.0	17.5	19.5	15.5
4	31.0	26.0	23.5	27.5	21.0	21.5	16.5
5	37.5	20.5	25.5	23.5	17.0	21.0	17.5
6	31.0	22.0	20.5	23.0	18.0	17.5	20.5
7	32.5	25.0	22.5	23.0	16.5	17.5	18.0
8	30.0	23.0	21.0	23.5	15.0	19.0	19.0
9	26.5	22.5	22.5	17.0	16.0	18.0	17.0
10	31.5	23.0	25.5	24.0	23.0	23.5	17.0
mean	30.850	23.500	23.750	23.200	17.950	19.550	17.600
st.d	4.5341	2.0138	2.3600	2.7406	2.3973	2.3973	1.4491

#	27-2 1984	20-3 1984	16-4 1984	30-5 1984	20-6 1984	20-7 1984	20-8 1984
1	19.5	15.0	20.0	21.5	27.0	19.0	22.0
2	17.5	20.5	20.0	28.0	61.0	19.5	21.0
3	15.5	23.0	22.5	26.5	34.0	21.5	18.5
4	17.5	26.5	18.0	23.5	48.0	21.5	54.5
5	17.0	19.5	20.0	33.0	32.0	20.5	29.0
6	15.5	17.0	22.0	26.5	40.5	21.5	19.0
7	18.5	19.0	20.0	33.5	29.5	20.0	31.0
8	19.5	17.5	20.5	22.5	31.0	21.0	19.5
9	15.5	17.5	23.0	28.0	54.5	22.0	32.0
10	17.5	23.0	22.0	33.0	49.5	26.5	39.0
mean	17.350	19.850	20.800	27.600	40.700	21.300	28.550
st.d	1.5284	3.4645	1.5312	4.4209	11.837	2.0710	11.425

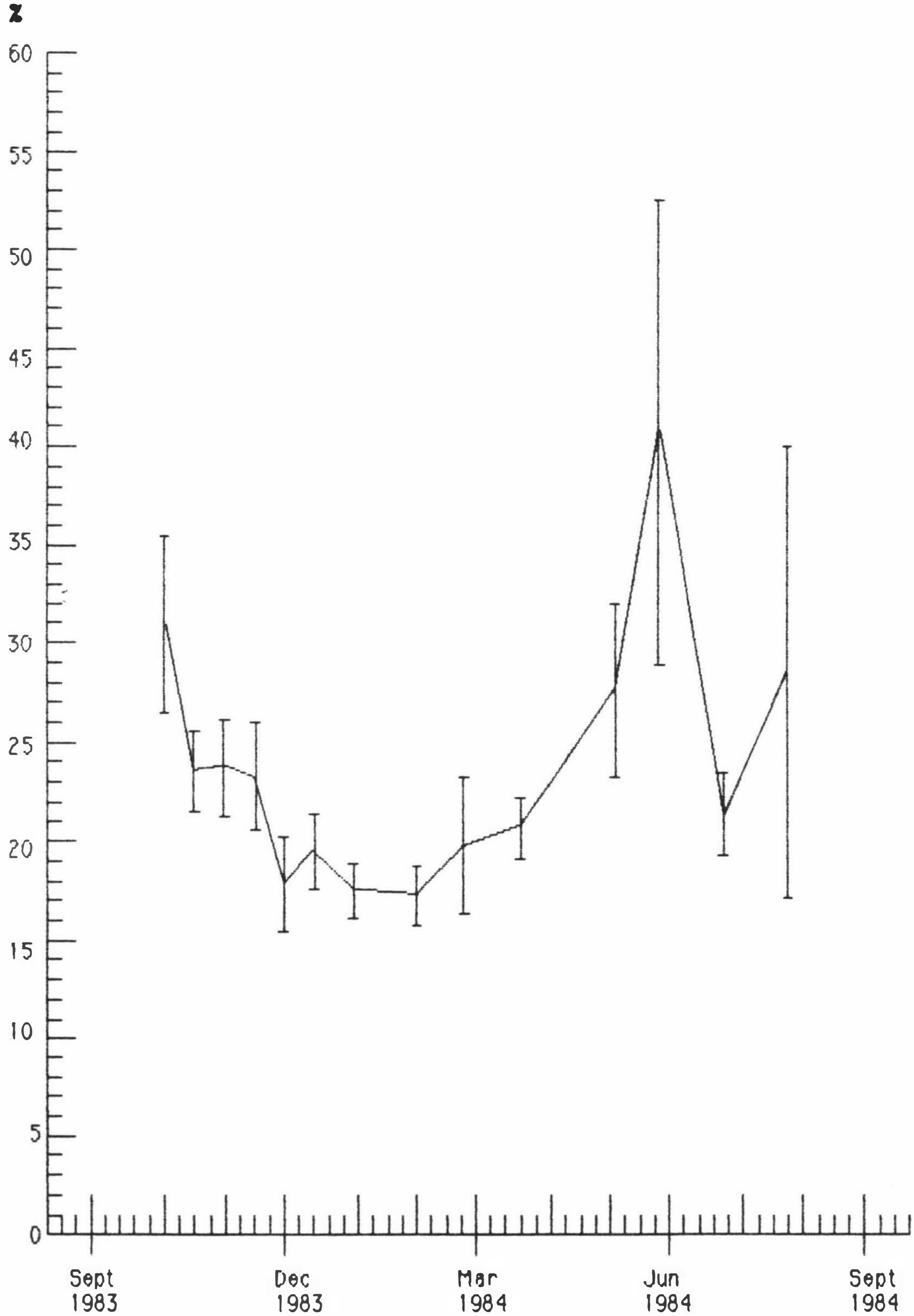

Figure 16 : Graph of mean percentage faecal ash with standard deviation from October 1983 to August 1984 on the Ranui farm.

Table XXI: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Ranui farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	15.0	9.0
2	20.5	12.5
3	23.0	15.0
4	26.5	15.5
5	17.0	8.0
6	19.0	12.0
7	17.5	11.5
8	17.5	10.5
9	23.0	15.5
10	20.0	11.0
11	22.5	12.0
12	18.0	10.5
13	20.0	11.0
14	22.0	11.5
15	20.0	10.5
16	20.5	11.0
17	23.0	13.0
18	22.0	11.5
19	21.5	14.5
20	28.0	20.5
21	26.5	17.5
22	23.5	13.5
23	33.0	24.5
24	26.5	19.5
25	22.5	15.0
26	28.0	19.0
27	33.0	24.0

Correlation = 0.951

Variance = 97.5%

Table XXII: The eruption of central permanent incisors of 100 hoggets on the Ranui farm with the first day of lambing day one.

Date	Days	% Erupted
17-10-83	412	5
31-10-83	426	12
14-11-83	440	23
28-11-83	454	49
12-12-83	468	68
26-12-83	482	79
9-1-84	496	89
23-1-84	510	94
13-2-84	531	98
27-2-84	545	100

Mean Eruption = 455 days

Table XXIII: Tooth wear in cm on the Ranui farm with the mean wear and mean daily wear calculated.

#	14-11 1983- 12-12 1983	12-12 1983- 23-1 1984	23-1 1984- 27-2 1984	27-2 1984- 16-4 1984	16-4 1984- 30-5 1984	23-1 1984- 19-3 1985
0024	.05	.07	.06			
0076	.04	.06	.01	.04	.04	.70
0105	.05	.06	.04	.11	.03	.73
0118	.04	.07	.09	.10	.06	
0188	.04	.04	.05	.07	.09	.80
0208	.02	.07	.03	.11	.05	.71
0271	.11	.09	.09	.10	.09	.69
0280	.06	.04	.03	.08	.05	.63
0283	.05	.02	.02	.02	.04	.54
0302	.07	.07	.08	.07	.06	
0362	.05	.05	.07	.06	.06	
0391	.05	.04	.06	.08	.04	
0444	.06	.02	.01	.02	.11	
0536	+.01	.04	.06	.01	0	.76
0571	.03	.02	.05	.05	.05	.53
0681	.01	.11	.04	.05	.05	.81
0684	.04	.03	.02	.08	.01	.61
0703	.04	.04	.02	.08	.06	.71
0784	.03	.08	.04	.07	.08	
0810	.02	.04	.02	.04	.06	
mean wear	.04250	.05300	.0445	.0652	.05722	>0.685
mean daily wear	.00152	.00126	.00127	.00133	.00095	>.00163

(5) The Motukai Farm

The Percentage of Faecal Ash

In Table XXIV the percentage of faecal ash from the samples collected on the Motukai farm is recorded. The mean percentage and standard deviations for each set of data are also recorded. Figure 17 is a graph showing the percentage of faecal ash measured from October 1983 to August 1984.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

In Table XXV the correlation of the percentage of faecal ash-percentage of acid insoluble residue for the samples collected on the Motukai farm is recorded. The correlation coefficient was 0.909 and the variance was 95.3%. The mean difference in the percentage of faecal ash and the percentage of acid insoluble residue was 7.4%.

Observations on the Eruption Times of the Central Permanent Incisors

The dates of eruption of the central permanent incisor teeth of 100 hoggets grazed on the Motukai farm are given in Table XXVI. The first observation was on 17 October 1983 at which time 10% of the central permanent incisors had erupted. The last sheep was observed with erupted central permanent incisors on the 27 January 1984 visit. If day one is the first day of lambing, the mean eruption time from that date was 442 days.

The Wear of the Central Permanent Incisors

The rate of wear of the central permanent incisors has been recorded in Table XXVII. The estimated mean daily tooth wear was >.001715cm. This estimate was from measurements taken from 23 January 1984 to 28 February 1985.

Table XXIV: The percentage of faecal ash of faecal samples collected from October 1983 to August 1984 on he Motukai farm with mean and standard deviation.

#	17-10 1983	31-10 1983	14-11 1983	28-11 1983	12-12 1983	26-12 1983	9-1 1984
1	30.0	19.0	22.0	23.0	17.0	15.5	17.5
2	24.0	20.5	20.5	14.5	16.5	17.0	15.5
3	44.0	28.5	18.0	N/A	17.5	15.5	16.0
4	46.0	18.0	17.0	20.0	18.0	16.0	17.0
5	39.0	19.5	16.0	13.5	16.0	17.0	16.0
6	33.0	18.5	15.5	16.0	16.0	15.0	14.5
7	43.5	21.0	16.0	15.0	15.5	15.5	16.0
8	46.0	17.0	16.0	15.0	20.0	N/A	15.5
9	29.5	20.0	20.0	15.5	14.5	N/A	15.5
10	23.0	19.0	15.5	16.0	17.0	N/A	13.5
mean	35.800	20.100	17.650	16.500	16.800	15.929	15.700
st.d	9.0060	3.1780	2.3694	3.0311	1.5129	.78680	1.1353

#	27-1 1984	27-2 1984	16-4 1984	30-5 1984	20-6 1984	20-7 1984	20-8 1984
1	16.0	16.5	16.5	19.5	30.5	41.0	25.0
2	21.0	15.0	17.5	27.5	43.5	61.0	24.5
3	24.0	16.0	22.5	25.5	33.5	38.0	27.5
4	20.5	14.0	19.5	25.5	35.0	47.0	23.0
5	18.0	15.0	21.5	21.5	31.5	36.0	21.0
6	22.5	15.5	17.0	25.5	33.0	55.0	27.5
7	19.5	16.0	20.0	19.5	31.0	35.5	29.0
8	16.5	15.5	22.0	25.5	33.0	27.0	23.5
9	17.5	15.0	17.5	19.5	38.5	31.0	24.5
10	24.5	16.0	20.0	20.5	31.0	39.5	20.0
mean	20.000	15.450	19.400	23.000	34.050	41.100	24.550
st.d	3.0276	.72457	2.1833	3.1710	4.0855	10.511	2.8718

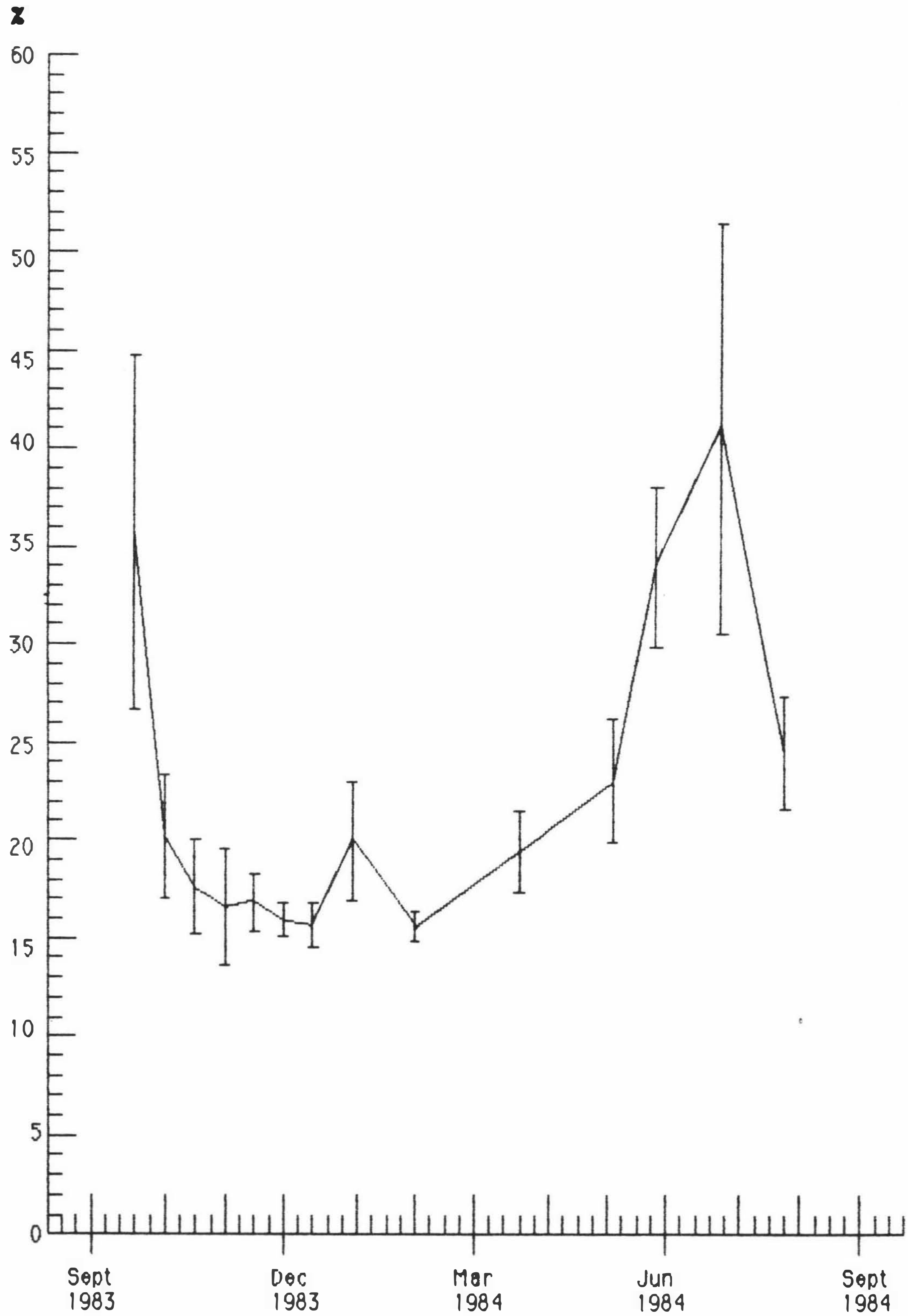

Figure 17 : Graph of mean percentage faecal ash with standard deviation from October 1983 to August 1984 on the Motukai farm.

Table XXV: The correlation between the percentage of faecal ash and percentage of acid insoluble residue on the Motukai farm.

#	% Faecal Ash	% Acid Insoluble Residue
1	16.5	10.0
2	17.5	10.5
3	22.5	14.0
4	19.5	12.5
5	21.5	11.5
6	17.0	9.0
7	20.0	12.5
8	22.0	12.5
9	17.5	9.0
10	20.0	12.0
11	19.5	13.5
12	27.5	20.5
13	25.5	16.0
14	25.5	19.5
15	21.5	15.0
16	25.5	17.0
17	19.5	14.5
18	25.5	20.0
19	19.5	12.0
20	20.5	15.0

Correlation = 0.909

Variance = 95.3%

Table XXVI: The eruption of central permanent incisors of 100 hoggets on the Motukai farm with the first day of lambing day one.

Date	Days	% Erupted
17-10-83	412	10
31-10-83	426	24
14-11-83	440	46
28-11-83	454	65
12-12-83	468	78
26-12-83	482	90
9-1-84	496	97
23-1-84	510	100

Mean Eruption = 442 days

Table XXVII: Tooth wear in cm on the Motukai farm with the mean wear and mean daily wear calculated.

#	28-11-83 to 23-1-84	23-1-84 to 27-2-84	27-2-84 to 16-4-84	23-1-84 to 28-2-85
201	.06	.04	.02	.59
208	.03	0	.03	
210	.03	+.01	.08	.65
221	.02	0	.04	.65
222	.05	.01	.08	>.70
223	.04	.04	.03	.64
234	+.01	.01	.02	.51
235	.09	0	.06	>.70
246	.09	.01	.02	
257	.03	+.01	.03	
259	.08	.04	.11	>.87
264	.07	.01	.09	>.88
265	.09	.03	.04	.52
274	.09	.02	.06	
277	.07	.04	.06	>.80
282	.01	.07	.01	.55
285	.05	0	.08	.55
287	.04	.06	.03	
288	.10	.01	.08	>1.02
289	.06	.03	.03	
mean wear	.0545	.0200	.0500	>.68786
mean daily wear	.000956	.000571	.000943	>.001715

DISCUSSION OF FARM TRIALS

The Percentage of Faecal Ash

In Table XXVIII the mean percentage of faecal ash for the samples collected from all the farms over approximately one year are compared. The data from the Riverside farm does not include the samples collected over the winter months as these were inadvertantly destroyed. The degree of tooth wear is also recorded in this table.

There are several striking differences in this data. Firstly, at a 1% level the Tangimoana farm had a significantly higher percentage of faecal ash than any of the other farms and it had the lowest rate of incisor wear. This farm also had the lowest stocking rate with 10 su/ha. Conversely the lowest percentage of faecal ash was measured in the samples from the Riverside farm which was also defined as a low tooth wear property. Although the winter faecal samples collected on the Riverside farm were destroyed, the overall percentage of faecal ash as seen on Figure 14 was low. It is also important to note that the stocking rate on the Riverside farm of 14 su/ha was one of the highest.

Healy (1969) has shown previously that the amount of soil ingested is directly influenced by soil type and stocking rate. However in one table of this report (Healy, 1969) there was virtually no difference in the amount of soil ingested between sheep grazed at 3.6 su/ac. and sheep grazed at 10.7 su/ac., a vast difference in stocking rate. If Healy's results as just described are compared with the present results from the two "low wear" farms a similar exception to his general hypothesis is noted. Sheep at the lower stocking rate (10 su/ha.) ingested large quantities of soil and sheep at the higher stocking rate (14 su/ha.) ingested smaller quantities of soil. These exceptions to the general statement of Healy (1969) suggest that the relationship between soil ingestion to soil type and stocking rate and soil ingestion to tooth wear may not always be as highly correlated as previously considered. Further the entire abrasion theory (Healy & Ludwig, 1965) is based on the premise that because sheep ingest large amounts of soil during the winter months and the majority of tooth wear occurs at that time of the year, then incisors must wear by the abrasive action of the ingested soil between the occlusal surfaces and the upper dental pad. Although the general relationship between the amount of soil ingested and the rate of tooth wear is recognized the exceptions in the current study encourage further investigation.

A second observation of interest was that on the high wear farms the average annual percentage of faecal ash was very similar. In each case it was lower than the levels recorded on the Tangimoana farm. It may be argued that the soil ingested on the Tangimoana farm was not as abrasive as that from the four "high wear" farms but in fact the soil on this farm was of an abrasive nature being sandy in type.

In all cases there was a significant increase in soil ingested during the winter months which was similar to previous reports (Healy & Ludwig, 1965). This high level of soil ingestion coincided with the months of the year June, July, August and September when there was a high reported loss of tooth substance.

The Correlation Between Percentage of Faecal Ash-Percentage of Acid Insoluble Residue

Table XXIX presents the mean percentage difference between faecal ash and acid insoluble residue from the faecal samples collected from the various farms in this investigation. The differences between the two were small and consistent for all the samples. It would appear that either the percentage of faecal ash or the percentage of acid insoluble residue could be used as an indicator for soil ingestion. Further if the results from this investigation were compared to those from other studies which used acid insoluble residue as a measure of ingested soil then the values from this table should be subtracted from the percentage of faecal ash.

Table XXVIII: A comparison of the mean percentage of faecal ash for approximately one year from the six farms included in this investigation with relative tooth wear status.

Farm	Mean % Faecal Ash	Degree of Wear	Dates
Tangimoana	28.5	Slight	Oct.1983-Sept.1984
Riverside	18.8	Slight	Oct.1983-May 1984
Pohangina	22.7	Severe	Oct.1983-Aug.1984
Ranui	23.8	Severe	Oct.1983-Aug.1984
Motukai	22.6	Severe	Oct.1983-Aug.1984
Waipukurau	22.4	Severe	Sept.1983-Sept.1984

The Eruption Times of Central Permanent Incisors

In Table XXX the records are presented for the mean eruption times of the central permanent incisors of the sheep observed on the six farms involved in this investigation. This information has some limitations as the individual birth date of each sheep was not known accurately and could only be estimated. The teeth of the sheep on the Waipukurau and the Motukai farms had the earliest mean eruption times while sheep on the Tangimoana farm had the latest mean eruption time. On the other three farms at Riverside, Pohangina and Ranui all

Table XXIX: A comparison of the mean percentage difference between faecal ash and acid insoluble residue from the six farms in this investigation.

Farm	Mean % Difference
Tangimoana	7.3
Riverside	9.4
Pohangina	10.1
Ranui	8.7
Motukai	7.4
Waipukurau	8.0

sheep had nearly identical mean eruption times for their central permanent incisors. No clear conclusion could be drawn from this data other than there appeared to be little correlation between severity of wear and central permanent incisor eruption time. This was similar to other research on this subject (Meyer *et al.*, 1983).

Hoggets on the Waipukurau farm had the earliest mean eruption time and experienced severe deterioration of the deciduous incisors. This was of interest since the nutrition on this farm had been poor as a result of the drought. However on the Pohangina farm a converse situation was observed. One hundred seven ram hoggets were observed to have 36.4% of the central permanent incisors erupted. This was at the same time when ewe hoggets of the same age on this farm had 5% of the central permanent incisors erupted. The ram hoggets averaged > 50kg and the ewe hoggets averaged < 38kg body weight. Although the

Table XXX: The mean eruption time of the central permanent incisors in hoggets on the six farms involved in this investigation.

Farm	Days to Eruption
Tangimoana	466
Riverside	454
Pohangina	454
Ranui	455
Motukai	442
Waipukurau	439

sex differences in rate of gain and size must be acknowledged, the body condition of the ram hoggets was noticeably better than that of the ewe hoggets. Ewe hoggets on the Tangimoana farm however, were highest in body weight of any hoggets involved in the study and were the latest to erupt their central permanent incisors. Although the relationship of high planes of nutrition to early eruption has been recognized (Coop & Clark, 1955) the confusing results in the current study suggest the possibility of other factors involved in eruption.

Wear of the Central Permanent Incisors

A comparison of the mean daily tooth wear of the sheep on the six farms involved in this investigation is given in Table XXXI. On the two "low wear" farms the rate of wear was very similar, with the teeth of the sheep on Riverside farm wearing slightly faster than the teeth of the Tangimoana farm sheep. On the other four farms the rate

Table XXXI: Calculated daily wear in cm of central permanent incisors in two-tooth ewes on the six farms involved in this investigation.

Farm	Mean Daily Wear in cm	Dates
Tangimoana	.0007510	26-1-84 to 12-2-85
Riverside	.0008153	30-1-84 to 28-2-85
Pohangina	.001477	25-1-84 to 26-2-85
Ranui	.001630	23-1-84 to 19-3-85
Motukai	.001715	23-1-84 to 28-2-85
Waipukurau	.001677	31-1-84 to 22-2-85

of wear of the central permanent incisors was similar in all cases. Of these four "high wear" farms the teeth of the Pohangina farm sheep had the lowest wear at .001477cm per day and the teeth of the Motukai farm sheep had the greatest rate of tooth wear at .001717cm per day.

To be able to fully interpret the results of these measurements of tooth wear of central permanent incisors of sheep on all farms requires prior consideration of the different ways in which teeth may be affected. The newly erupted incisors are chisel-shaped with a tapered tip. A wear facet develops at the tip of the tooth presumably as the forces which affect tooth wear begin to operate. As the incisor teeth diminish in length more and more of its biting surface is actually contacting the dental pad. The rate of wear or loss of incisor length is faster in newly erupted teeth under similar wear circumstances, than at a later stage when a larger contact surface is exposed. This latter assumption can be deduced from research conducted at Wallaceville Research Laboratory by Erasmuson (1983) in which a mechanical device was used to test and measure rates of abrasion in different teeth. Virtually the same amount of tooth substance was abraded under similar abrasive trials regardless of the size of the wear surface. Therefore it is likely that teeth with smaller wear surfaces than others would decrease in length more rapidly than teeth with larger wear surfaces when both are exposed to the same abrasive conditions for the same length of time.

From the experiments which were aimed at testing the differences in wear rate at different times of the year and when different amounts of soil had been ingested some interesting points arose. These observations were made from data points which were drilled on the labial surface of the tooth near to the gum margin shortly after the tooth had erupted. During the earlier stages of measurement the teeth were unworn and had thin tips. These decreased in length as the biting surface of the teeth bevelled off. As a result of this virtual change in tooth conformation the loss of tooth length during the summer months appeared greater than would have been expected. This feature was particularly apparent immediately following tooth eruption but in fact, the highest rate of tooth wear did occur during the winter months when soil ingestion was at its highest as was also reported by Healy and Ludwig (1965).

Frequently it was observed that the sheep on the "high wear" farms showed sudden and rapid loss of tooth substance. This rapid loss was either preceded or followed by a period when virtually no tooth wear was observed. It was considered that this phenomenon was probably attributable to the development of demineralized thin tips on the incisors which may have broken away rather eratically instead of wearing at a regular rate. Evidence of this phenomenon is frequently seen in the teeth of sheep from high wear farms and had been reported by other writers (Barnicoat, 1957).

A SUMMARY OF THE IMPORTANT FARM TRIAL OBSERVATIONS

The observations and investigations of sheep on the farms in this study led to the following conclusions:

1. Enamel defects appear to be a separate problem from tooth wear with an unexplained aetiology;
2. There are clinical signs involving tooth wear which cannot be explained by abrasion;
3. A strong correlation exists between soil ingestion and tooth wear on affected farms;
4. The ingestion of soil on certain farms may be high without the occurrence of excessive tooth wear;
5. There are farm variations in relation to the influence of stocking rate on tooth wear.

(1) Enamel Defects

The aetiology of the enamel defects could not be defined from the current investigation. The time lapse between the development of these problems and the observation of clinical signs creates a special difficulty in the study of this condition and the circumstances and factors leading to the occurrence of these problems may be reversed by the time of discovery of the condition. However, the effects of the drastic weather leading to severe feed shortages as seen in this study and by Bruere et al. (1979) suggest the possibility of an aetiology of nutritional origin.

The tooth wear problem and enamel defect problem appear to be separate entities with different aetiologies. With the exception of the two cases of sheep with chaulky central permanent incisors recorded in Chapter 3, there was a poor correlation between tooth wear and the enamel defects as recorded in Table III. Both conditions were seen on the Waipukurau farm with wear occurring on central permanent incisors with and without enamel defects and on deciduous incisors grossly free of enamel defects. These affected deciduous incisors developed before the serious drought. It is also noteworthy that wear had been a serious problem on this farm prior to the circumstances leading to the severe enamel defects. Further the enamel defects observed on the other "high wear" farms were of a minor nature and few in number. Tooth wear occurred on these farms at a rapid rate.

(2) Unexplained Clinical Signs

Two obvious clinical signs which cannot be explained by abrasion are the erosion of non-occlusal incisor surfaces and the demineralized incisor tips in sheep. Both of these entities have been described previously in Chapters 3 and 4 and were observed in sheep on all of the high wear farms in this investigation. The affected non-occlusal surfaces of incisors (Fig. 1) would suggest an erosion of enamel and dentine by a non-abrasive factor. Further, the demineralization of incisor tips indicated contact of teeth with some substance capable of dissolving dental appatite. The weakened demineralized matrix would then be susceptible to the abrasive action of soil ingested or even the normal biting of grass.

(3) The Correlation Between Soil Ingestion and Tooth Wear

The results from this investigation on those farms with excessive incisor wear in sheep support the results from the research by Healy and Ludwig (1965) that showed the rate of incisor wear to be greatest during the time of year when soil ingestion was highest. The involvement of abrasive forces in the loss of occlusal surfaces has been accepted for many years (Barnicoat, 1957) but the "melting" away of incisor surfaces does not fit the clinical picture of wear by abrasion. Although the conclusion that the ingested soil causes rapid wear of incisors in sheep is a hypothesis that is difficult to prove or disprove, the evidence supports the involvement of soil ingestion in the tooth deterioration problem.

(4) High Soil Ingestion on Low Wear Farms

The consistent finding of high soil ingestion by the sheep on the Tangimoana farm was of considerable significance. The sheep on this farm had a long history of low incisor wear which was confirmed by measurements of tooth length wear in this investigation. The ingestion of large quantities of soil with little adverse effects on incisor length appeared to contradict the basic premise of the abrasion theory. This result along with the clinical observations discussed previously appeared to be adequate justification for consideration of possible alternative factors involved in this problem. It seemed apparent that the correlation between soil ingestion and rate of tooth wear in sheep involved a non-abrasive factor. The ingestion of large amounts of soil by sheep on the Tangimoana farm without adverse effects on the incisors of sheep could be explained by the lack of this factor in the soil. Conversely, the presence of such a factor in soil on high wear farms could explain the different effect on incisors from soil ingested by sheep on these farms.

(5) Variation in Relationship of Stocking Rate to Tooth Wear

The relationship of stocking rate to tooth wear recognized and reported by many researchers (Barnicoat, 1957; Healy & Ludwig, 1965; Arnold et al., 1966; Suckling, 1975; Bircham et al., 1981) is central to the epidemiological considerations in this study. However, the results from the Riverside farm of low tooth wear in sheep on a farm with a high stocking rate led to considerable question when compared to other farms in this investigation. Although some understanding may be found in the relatively recent intensification of this property, it appeared likely that other factors were involved. Differences in the amount of soil ingested and its relationship to soil type (Healy, 1969) is one explanation of this occurrence. However soil ingestion on this farm was relatively high in October 1983. Therefore it appears likely that there is another way in which soil type affects the influence of stocking rate on tooth wear in sheep.

There were many questions which could not be answered by the generally accepted proposed tooth wear mechanisms. Therefore a search was instigated for another possible aetiology which could satisfy the clinical observations as well as the results of this investigation.

CHAPTER 5

SOLUBILIZATION OF SHEEP'S TEETH

An Alternative Hypothesis on the Loss of Tooth Substance

INTRODUCTION

The currently accepted aetiology for what has been termed "tooth wear" by abrasion in New Zealand sheep has failed to satisfy the clinical picture seen on "high wear" farms. Some of the clinical signs involving sheep incisors observed consistently on "high wear" farms (Chapters 3 & 4) could not be explained by abrasive mechanisms. The effects of the condition on both occlusal and non-occlusal incisor surfaces of deciduous and permanent teeth were documented. There was an obvious "melting away" of the deciduous incisors with the resulting vestige resembling a tiny rounded pebble prior to its total disappearance (Fig. 2). The vestige was often without a wear facet as it was affected on the entire exposed surface and in some cases did not even contact the upper dental pad. Further the transparent tips observed on the central permanent incisors of sheep on "high wear" farms indicated the possible involvement of agents which were capable of demineralizing teeth. In addition to the clinical observations the trial results revealed the highest soil ingestion on the farm experiencing the lowest rate of tooth wear and the lowest stocking rate. This appeared to contradict the basic premise of the "tooth wear" by abrasion theory. Therefore the inconsistencies in the clinical picture presented along with many of the results from the trials conducted on the farms in this project stimulated a search for an alternative explanation of this problem.

Although the clinical signs indicate the involvement of a non-abrasive agent, the direct relationship between soil ingestion and rate of wear has been reported (Healy & Ludwig, 1965) and was observed in the current trials. The influence of stocking rate on tooth deterioration has also been reported on many occasions (Barnicoat, 1957; Arnold et al., 1966; Healy & Ludwig, 1965; Suckling, 1975; Bircham et al., 1981). As a result it was felt that other hypotheses should be proposed which could satisfy criteria dictated by past research, as well as clinical observations and farm trials. Thus the proposed hypothesis must involve aetiological agents which are present in the soil, which are able to dissolve tooth substance and which are influenced by the stocking rate on the involved farm.

HYPOTHESIS

A complex ecological system exists involving grazing stock and soil micro-organisms. These soil microbes are in a dynamic state and they are influenced by many environmental factors. The number and mass of these micro-organisms fluctuates with food supply, moisture, temperature, pH and other factors (Ouastel, 1955). Further it has been demonstrated that animal manure is an excellent source of food for these organisms (Seegerer, 1953; Ramaswami et al., 1979). With the addition of these organic foods to soil, there is a marked increase in microbial mass and production. A relative increase of actinomycetes and fungi with a relative decrease in bacteria also occurs (Shepherd, 1952; Pathak, 1954). Sheep deposit millions of kilograms of manure and urine on New Zealand farms annually. The higher the stocking rate the greater the quantity deposited per hectare.

Soil micro-organisms produce a number of substances capable of solubilizing certain highly insoluble minerals. These substances include organic acids such as butyric, lactic, acetic, citric, oxalic and fumaric (Jensen, 1917; Waksman, 1932; Muromtsev, 1955; Aristovaskaja, 1956). This solubilizing process can occur in acid, neutral or alkaline soil (Muromtsev, 1958). Although some bacteria can produce these substances, actinomycetes and fungi have been demonstrated to be the most effective producers (Rose, 1954;

Muromtsev, 1958).

One of the highly insoluble minerals which can be dissolved by this process is phosphate rock (Fred, 1919; Muromtsev, 1958; McConnell, 1973). This is the major way by which this mineral is made available to plants when applied as a fertilizer in this form. Rock phosphate, tooth enamel and dentine are very similar in chemical composition and crystalline structure. They all belong to the mineral class of apatite (Gruner et al., 1937; Berry and Mason, 1959) and they can all be solubilized by contact with organic acids (Barnicoat, 1957; Muromtsev, 1958).

It is hypothesised that sheep incisors contact these solubilizing substances present in the soil micro-environments during ingestion of large amounts of soil at certain times of the year. Incisors are demineralized by these substances and the matrix easily broken away. It is further suggested that molars are not affected as saliva dilutes and neutralizes the effects of these agents. The higher the stocking rate and subsequent manure production the higher the concentration of the affecting substances and the more rapid is the effect on the incisors. Therefore sheep on farms with a low stocking rate might ingest large quantities of soil without extreme deteriorating effects to the incisors.

DEMONSTRATIONS

Several laboratory demonstrations were performed following the development of this hypothesis. The purpose of these demonstrations was to aid in visualizing what might happen during soil-tooth contact as sheep ingest soil during grazing. They are presented purely as demonstrations and are not intended as scientific evidence.

Demonstration 1

Eight milliliters of sterile Sabouraud's dextrose agar was liquified in a water bath. One half milliliter of 10% K_2HPO_4 was added to the media followed by one milliliter of 10% $CaCl_2$. The insoluble precipitate $CaHPO_4$ formed in the media. One milliliter of the media with the precipitate was placed on a sterile microscope slide and covered with a sterile coverslip. The agar was allowed to solidify and the edge was then inoculated with Aspergillis niger. The slide was then incubated at 28 C. Within twenty-four hours a clear area could be seen around the growing colony as solubilizing substances were produced by the micro-organisms and the precipitate was dissolved. Figure 18 is a photograph of the slide.

Demonstration 2

Soil was collected from a "low wear" farm (Tangimoana farm, Feb.,1984) and from a "high wear" farm (Pohangina farm, Feb., 1984). Five samples were taken from paddocks being grazed at five separate locations on each farm. The five samples from each farm were mixed together thoroughly and filtered through a 2 mm soil sieve. A sample of soil from the mix from each farm was weighed and dried. The dried samples were then weighed and the actual dry soil equivalents were determined for each farm. Five dilutions were made with sterile water at 1:10, 1:100, 1:1000, 1:10000 and 1:100000. Samples were placed on culture plates containing Sabouraud's dextrose agar with chloramphenicol and then incubated at 28 C. Table XXXII records the results of the demonstration and Figure 19 is a photograph of the culture plates after five days incubation.

Although the results indicate higher numbers of fungi on "high wear" farms, no conclusions could be drawn without large numbers of similar trials. The dilution method of counting fungi also has some limitations as do other methods of quantitative studies.

Table XXXII: The numbers of colonies from soil at progressive dilutions from the Tangimoana farm and the Pohangina farm.

Dilutions	Tangimoana Farm	Pohangina Farm
1:10	Too Numerous to Count	Too Numerous to Count
1:100	" " " "	" " " "
1:1000	28 Colonies	35 Colonies
1:10000	4 "	9 "
1:100000	0 "	2 "

Demonstration 3

A demonstration was designed using plants as an indicator of solubilization of sheep's teeth in vitro by micro-organisms. Six pots were used in this demonstration containing a non-nutritive soilless potting media (Brooking, 1976). Pots I and II received 100 ml of defined rhizobia media containing dextrose and no phosphate. A complete fertilizer with phosphate omitted was used in watering (Brooking, 1976). The fertilizer used was North Carolina State University Phytotron Nutrient. Pots I and II also received three grams each of powdered sheep's teeth. Pots III and IV received 100 ml of the rhizobia media with dextrose and the same fertilizer. They received no powdered sheep's teeth. Pots V and VI received no dextrose but both received the same fertilizer and three grams each of powdered sheep's teeth. The potting media of pot VI was autoclaved before the beginning of the demonstration.

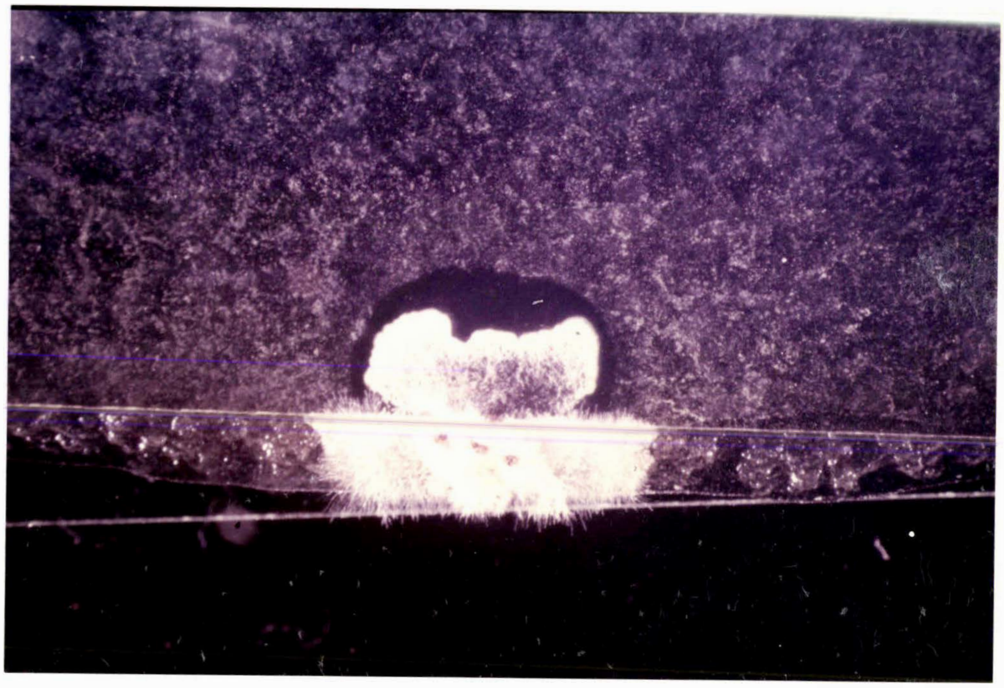

Fig. 18: Photograph of solubilized $CaHPO_4$ precipitate.

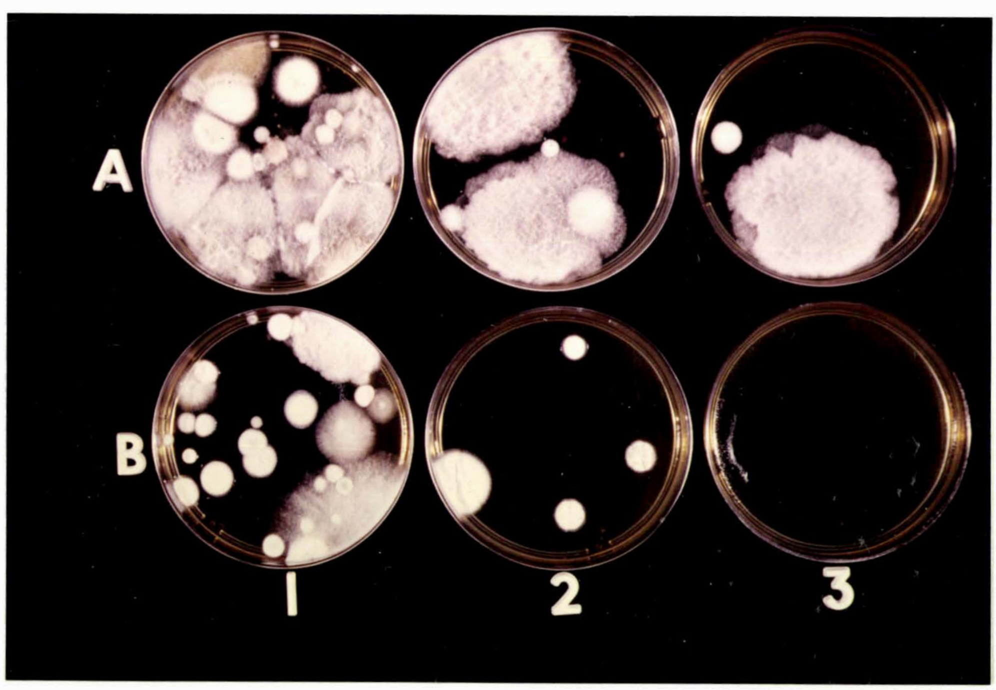

Fig. 19: A. Photograph of culture plates of soil at varying dilutions from the Pohangina farm.

B. Photograph of culture plates of soil from the Tangimoana farm at the same dilutions as the Pohangina plates.

Tomato seeds were seeded to each pot. When the plants were approximately 3cm tall they were thinned to four per pot. The pots were watered with the fertilizer mixture as needed. They were kept in the same environment and received approximately the same amount of sunlight.

Eighty-two days from the date of seeding the two middle sized plants from each pot were cut 1cm above the soil. These plants were measured for base circumference and height, then dried at 100 C and weighed. The results are presented in Table XXXIII. A photograph taken at seventy-two days is shown in Figure 20.

Table XXXIII: Measurements and weights of tomato plants after 82 days. Pots I and II contained powdered sheep's teeth and dextrose. Pots III and IV contained dextrose and no powdered sheep's teeth. Pots V and VI contained powdered sheep's teeth and no dextrose and pot VI had autoclaved soilless potting media.

Pots	Base Circumference in cm	Height in cm	Dried Weight in gm
I	2.00	44.5	2.9033
II	1.90	40.0	2.4393
III	too small	3.5	not weighed
IV	" "	7.5	" "
V	1.55	37.5	2.1533
VI	1.60	36.0	1.6029

Fig. 20: Photograph showing relative size of the tomato plants receiving the various treatments.

As can be seen from Table XXXIII plants in pots I and II performed best. Plants in pots III and IV were reduced to a small leafless stem by the end of the demonstration and plants in pots V and VI did not grow as large as those in pots I and II. Plants in pot V grew larger than those planted in the sterile potting media in pot VI.

It appeared that the dextrose media in pots I and II served as a media for micro-organisms. The microbes produced solubilizing substances which dissolved the apatite present in the form of powdered sheep's teeth making the phosphate available to the plants. Those plants in pots III and IV eventually died because there was no phosphate present. Plants in pots V and VI did not grow as well as those in pots I and II because they did not receive food for micro-organisms in the form of dextrose. Plants in pot VI were slower to start growing because of an absence of micro-organisms at the beginning of the experiment. However the media would have been contaminated as the seeds were introduced into the pots.

Since sheep's teeth are a highly insoluble apatite, plants are unable to utilize the phosphate present until it is solubilized. It appears from this demonstration that the apatite of sheep's teeth can be solubilized in soil and utilized by plants.

SUMMARY of SOLUBILIZATION HYPOTHESIS

There are two things which must take place before solubilization of incisors occurs. Firstly soil must contain high concentrations of substances capable of dissolving apatite. Concentrations of these substances are dependent on microbial mass and production which in turn is dependent on food supply and other environmental factors. Sheep manure serves as a good source of microbial food and is present in soil in quantities directly related to stocking rate. Secondly the incisors must contact the solubilizing substances present in soil. Thus excessive loss of incisor substance is related to soil ingestion but it is also dependent on soil content.

CHAPTER 6
DISCUSSION AND CONCLUSIONS ON TOOTH DETERIORATION IN SHEEP

New Zealand is unique in its approach to sheep production. The temperate climate coupled with aggressive intensification of grazing systems have precipitated serious dental problems (Barnicoat, 1947) unlikely to occur in most other sheep producing nations. Pastures grazed by sheep in colder climates are spelled from use for long periods while supplements are fed and pastures grazed by sheep in arid conditions require long periods for regrowth necessitating very long rotations. Although incisor wear occurs under some of these conditions in other countries the predisposing factors are vastly different from those experienced in New Zealand (Barnicoat, 1957).

The search for the aetiology of "tooth wear" has led to the consideration of many possibilities since the recognition of the problem as early as 1943 (Graham-personal communication, 1984). The mass of information compiled by Barnicoat (1947; 1948; 1957) ruled out many of the early hypotheses and eluded to non-abrasive agents (1957). However the logic of the soil abrasion theory (Healy & Ludwig, 1965) apart from the clinical occurrence of the condition led to a long period of acceptance of this explanation (O'Hara, 1983). Fortunately the continued questioning of this theory in light of the clinical findings presented on many affected sheep properties promoted continued study of this problem (Bruere and West, 1983). The observation of devastating enamel defect problems in conjunction with "tooth wear" in sheep on farms experiencing severe droughts as reported by Bruere et al. (1979) and in the present report further complicated the understanding of dental problems in sheep and stimulated greater interest in this area.

The severe tooth deterioration problem observed in the sheep on the Waipukurau farm may have been a rather extreme case. However it is likely that there were other farms in the same area which following the 1983 drought conditions also had sheep with dental problems. The numbers of sheep affected and the seriousness of the condition probably would vary from farm to farm. Overall the situation was probably similar to the cases reported in the Wairarapa by Bruere et al. (1979). The results from the Waipukurau farm and the Wairarapa farms indicated the enamel defects to be a distinct condition which could occur with tooth wear. The defects ranged from minor pitting of enamel to severe enamel hypoplasia and chaulky, soft incisors (Figs. 4, 5 & 6). The aetiology of this problem was unknown. However, if the time of tooth formation was considered it is likely that the problem developed during the period of the severe drought when poor nutrition, mineral imbalances or deficiencies occurred at a vital time as the permanent incisors were being formed. Research has shown that calcium imbalances and fluoride excesses (Franklin, 1950) may produce similar lesions to those observed on the farm in Waipukurau and as reported by Bruere et al. (1979). Other factors such as parasitism may also have been involved in these problems. Parasitism as previously reported is also capable of producing enamel defects (Suckling et al., 1983). Either of these factors or a combination of these and other possible factors must be considered. It does appear however, that the most likely aetiology was of nutritional origin precipitated by the severe weather conditions.

As reported in Chapter 3 the eruption of the central permanent incisors on the Waipukurau farm occurred earlier than observed in sheep of the same age on other farms. A similar situation was also noted in many of the sheep observed in the Wairarapa in 1977 by Bruere et al. (1979). Contrary to these two separate observations, Aitken and Meyer (1982) noted that early eruption of the central permanent incisors actually resulted with improved nutrition. The reason for these differences in eruption times is obscure; however, excessive wear of deciduous teeth does not appear to be the cause of early eruption since sheep on other "high wear" farms in this study did not experience the same effect. Further it is not likely that early eruption of the central permanent incisors of sheep on the

Waipukurau farm would have been the cause of excessive tooth wear since maturation and development is complete by 10 to 12 months and eruption occurred after this time (Suckling, 1979). The fact that early erupting incisors would be exposed to "wear forces" earlier and "wear" begin sooner is obvious.

On many New Zealand farms excessive loss of exposed incisor surface is a common problem involving many sheep and causing considerable economic loss (Bircham et al., 1981). Further it would appear that the cause of this problem is an extrinsic agent which is directly related to soil ingestion and stocking rate.

Evidence from farm observations indicated the likelihood of an aetiological agent which caused deterioration of tooth substance by direct contact with the incisors. Further it had been observed that sheep brought from "low wear" farms onto "high wear" farms soon take on the dental characteristics in regard to "tooth wear" of the indigenous sheep. The same is true of sheep moved from "high wear" farms to "low wear" farms (Bruere et al., 1979). More evidence was provided to substantiate the likelihood of an extrinsic agent involved in this problem with the abrasion tests performed at Wallaceville Animal Research Centre (Erasmuson, 1983). These tests showed a similar rate of wear for all teeth from "high and low wear" farms tested under the same abrasive conditions.

Although most tissues are dynamic and change relatively fast in response to environmental influences, teeth are stable after development and maturation and change of structure and composition vary only slightly. Thus factors such as heredity (Barnicoat, 1957; Meyer et al., 1983), nutrition (Franklin, 1950; Barnicoat, 1957), early eruption (Barnicoat, 1957; Aitken & Meyer, 1982; Meyer et al., 1983), endocrine (Barnicoat, 1957) and other intrinsic factors do not appear to be the major cause of "tooth wear" and the dramatic effects observed on incisors in sheep on "high wear" farms were apparently caused by an extrinsic agent.

The examination of extrinsic agents possibly involved in the "tooth wear" problem was a considerable part of early research. The heavy use of fertilizers and lime was investigated thoroughly (Barnicoat, 1957; Suckling, 1975; Bircham et al., 1981) with little positive correlation except as they influenced stocking rate by increased pasture production. Further the change to high producing perennial rye grass and white clover was also considered (Barnicoat, 1957). The involvement of plant acids produced by plants was a plausible explanation (Barnicoat, 1957) however this theory was ruled out by results from tests by Cutress and Healy (1965).

Other extrinsic factors were proposed as possible aetiological agents including plants and soil as abrasives.

Baker et al. (1959) proposed plant opal-phytoliths as the causitive agent for "tooth wear" however the difference between sheep incisors on farms with the same herbage was difficult to explain by this hypothesis. Further the clinical signs described in Chapters 3 and 4 of this thesis were not indicative of abrasive change.

The abrasion by soil ingestion theory presented by Healy and Ludwig (1965) became widely accepted after its presentation and it was virtually unchallenged for twenty years (O'Hara, 1983). The clinical observations and trials which have led to a reconsideration of this generally accepted aetiology have been presented in Chapters 3, 4 and 5 of this study.

The search for an extrinsic agent contained in soil and influenced by stocking rate thus appeared to be a logical approach toward understanding the "tooth wear" problem. Chapter 5 is the presentation of the solubilization hypothesis as a proposed explanation of the aetiology of this condition. Further supporting evidence exists for this hypothesis in the ability to explain the mechanisms of reported management practices.

Reducing the stocking rate is one of the most effective ways to control the "tooth wear" problem (Barnicoat, 1957; Suckling, 1975). As reported earlier in this thesis, reduction of sheep numbers leads to deminished amounts of food for soil micro-organisms and decreased production of solubilizing substances. Reduced content of soil solubilizing substances along with decreased soil contact (Healy, 1969) could explain the influence of reduced stocking rate on "tooth wear".

It has also been reported that rotation grazing decreases "tooth wear" in comparison to set-stocking (Barnicoat, 1957; Kane et al., 1983). The resting of paddocks between stocking would give time for the utilization of animal waste by soil micro-organisms and a subsequent return to normal equilibrium (Pathak, 1954). The longer the rotation the greater the positive effect could be expected on the condition.

Another reported management practice has been the liming of pastures. This practice appears to be most important at relatively low stocking rates (Bircham et al., 1983). It is suggested that liming may alter soil pH affecting the mass and production of soil micro-organisms (Waksman, 1932).

It has also been reported that running cattle with sheep is another way of reducing "tooth wear" (Barnicoat, 1957; Suckling, 1975). Since cattle manure is not readily distributed and the influence on soil micro-organisms is a local effect, the contaminated soil is avoided by grazing stock. As the manure begins to disintegrate, the micro-organisms are using the food provided and will begin to return to a normal state of production. The overall effect is the same as pasture rotation with the resting of a small area within the paddock. Further greater pugging of soil by cattle may lead to an increased surface of exposed soil reducing the concentration of manure to soil surface. Pugs in the soil also provide a place where manure can be distributed and soil may be less likely to be ingested.

Finally supplementary feeding can have a dramatic effect on the preservation of incisors when timed to coincide with periods of high soil ingestion (Ludwig et al., 1966; Healy et al., 1967; Bruere & West, 1983). Grazing crops such as choumoellier and turnips may lead to considerable soil ingestion however such soil has been rested from grazing and may not contain the high micro-organism populations found in high stocked pastures. Resting soil from grazing and subsequent animal waste products tends to depress the level of soil micro-organisms by reducing their food supply (Pathak, 1954). A similar effect is attained by turning soil thus spreading the effect of the surface manure (Varga & Gyurko, 1955). Feeding hay, grain and silage limits contact with contaminated soil. Even when fed on the ground, the time required to eat is minimal compared to grazing.

The proposal of other soil related factors involved in "tooth wear" encourages a new examination of "high wear" and "low wear" soil. Although the rate of incisor "wear" is directly related to stocking rate the influence of stocking rate is variable from farm to farm. For example the study of soil on the Riverside farm with a high stocking rate-"low tooth wear" could yield important information. It is already known that certain clays have a greater capacity to bond organic matter than others (Hester, 1948). Further drainage and other factors involved in removing organic matter from soil surface may be important in the understanding of soil influence on this problem.

It is also important in light of this study that involvement of earthworm cast in "tooth wear" problems be considered. It is already known that earthworm cast are higher in micro-organisms, particularly actinomycetes, than soil prior to passage through earthworms (Ruschmann, 1953). It is also interesting to note that the total weight of earthworms is positively correlated with pasture production; therefore those pastures which are able to carry high stocking rates would likely be high in earthworms. Maximum earthworm weights are present during winter months when soil ingestion is highest and when "tooth wear" is most severe (Sears, 1953; Waters, 1955). A closer investigation of earthworm involvement in "tooth wear" thus seems appropriate as it appears that they have the effect of concentrating solubilizing substances near the surface of the soil.

The clinical observations and trials in this investigation elude to the existence of an entity which involves the demineralization of exposed incisor surface followed by abrasion of unprotected matrix in sheep. These observations along with data from current trials appear to be justification for further research into this problem. Fresh hope of a solution can be envisioned with a better understanding of all of the involved factors.

APPENDIX I

DRY-ASHING IN AN OPEN VESSEL (Bock, 1979)

For the determination of ash content of faecal samples.

Materials.

1. Ceramic Crucibles
2. Desiccator
3. Oven
4. Furnace
5. Balance

Method.

1. Store crucibles in desiccator.
2. Weigh crucibles.
3. Place samples in crucibles.
4. Place in oven at 100-105 C overnight.
5. Store crucibles in desiccator.
6. Weigh crucibles with dried samples and subtract crucible weight.
7. Place in furnace at 550 C overnight.
8. Store crucibles in desiccator.
9. Weigh crucibles with ash and subtract crucible weight.
10. $$\text{Ash\%} = \frac{\text{weight of ash}}{\text{weight of dried sample}} \times 100$$

Result.

The method of dry-ashing gives a good idea of the level of non-volatile inorganic material in a sample.

APPENDIX II

ACID-INSOLUBLE ASH (Healy & Ludwig, 1965; Bock, 1979)

For the determination of acid-insoluble residues of ash from faecal samples which have been ashed.

Materials.

1. Ashed sample
2. 10 ml test tubes
3. 3N HCl
4. Distilled water
5. Hot water bath
6. Centrifuge
7. Oven
8. Balance

Method.

1. Weigh test tube
2. Put weighed ashed sample in test tube
3. Add 8 ml of 3N HCl and agitate
4. Heat in water bath for 30 min.
5. Centrifuge 10 minutes at 3000 rpm
6. Discard supernatant liquid
7. Repeat two more times with 3N HCl then wash with distilled water
8. Dry in oven at 105 C
9. Weigh tube with sample and subtract the weight of the tube
10. $$\% \text{ Acid Insoluble residue} = \frac{\text{weight of acid insoluble residue}}{\text{weight of dried sample}} \times 100$$

Result.

The method of acid-washing gives a good idea of acid-insoluble residue in a sample.

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