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**A STUDY OF GRASS SILAGE PRESERVATION WITH
PARTICULAR REFERENCE TO THE USE OF
SODIUM METABISULPHITE
AS AN ADDITIVE**

**A Thesis Presented in Partial Fulfilment of
the Requirements for the Degree of
Master of Agricultural Science
in the University of New Zealand.**

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CHAPTER I

INTRODUCTION

The problems of preserving roughages for the feeding of livestock during unfavourable periods of pasture growth are perennial. The preservation of legumes and grasses as hay of high quality is governed mainly by two factors: ideal curing weather and stage of maturity of the crops. The inability of the farmer to control these factors results in heavy nutrient losses in the hays during the curing process.

The development of an alternate process of preservation has been the objective of investigators for many years. Artificial drying of protein rich herbage results in the best preservation with least storage loss but, as yet, the process involves a large capital outlay and high operating costs. This at present eliminates it from consideration by the average farmer. The preservation of early harvested material as silage seems to be the most logical approach to the solution of the problem because of the high efficiency of the process for timely handling.

Although silage-making appears to offer the best method of preserving protein rich herbage, many unsolved problems contribute to the uncertainty of the process and hinder its widespread adoption. Ensilage of immature herbage is invariably accompanied by high nutrient losses during the storage period. These losses, resulting mainly from inefficient chemical reactions within the silage, are such that usually only about 65 to 75 per cent of the dry matter ensiled is available for feeding at the termination of the storage period. Such losses equalize to a large extent

the possible saving of nutrients from field losses and weather damage which result when haymaking is used as a method of harvesting and storage.

The realization of the magnitude of nutrient losses from early harvested grass-legume silage provided the main incentive for research in this field. Improved methods of silage production, based on the principle of controlling undesirable chemical reactions and encouraging desirable reactions within the mass, have received considerable attention in recent years. A wealth of literature exists on the use of additives as a means of achieving these aims and thereby reducing nutrient losses during storage. Of the various additives employed for the production of high quality silage from protein rich crops, several have proved to be of value under certain conditions. As yet, however, no one additive has been found capable of general adoption by dairy farmers as a whole, either because of the cost of installation or technical ability necessary for the operation.

Several chemicals, which may bring about partial sterilization of the mass, have recently been introduced as additives in silage-making. American investigators have reported that the treatment of immature herbage at ensiling time with sodium metabisulphite markedly reduced storage losses and improved the quality of the resultant silage. Their results seemed sufficiently encouraging to warrant further research. Experimental work, to be detailed presently, was thus undertaken to assess the value of sodium metabisulphite as an additive in silage-making under New Zealand conditions. The programme of work commenced in 1954 with a preliminary field scale trial in which the effect of metabisulphite

treatment on the nutritive value and chemical composition of silage made from mature herbage was determined. A more extensive investigation was conducted the following season in which metabisulphite-treated and untreated immature and more mature silages were compared as to the nutrient losses incurred during storage, their nutritive value and chemical composition.

CHAPTER II

REVIEW OF LITERATURE

The following review is confined to grass silage, the term being applied to silage composed of those green crops, either legume or grass, which might alternatively be used for hay or pasture. The subject is considered under four main sections. The first section is confined to a brief outline of the changes which occur in fresh herbage following ensiling. The second section is devoted to a study of the nutrient losses which occur in silage made without treatment. The third section deals with the use of additives as a means of reducing nutrient losses occurring in the process. In the final section, the effect of additive treatment on the digestibility and palatability of the resultant silage is considered.

A. THE ENSILAGE PROCESS

1. Definition of the Product

Silage has been defined as a succulent fodder made from fresh herbage crops by storing them in a suitable container with the exclusion of air (Watson and Ferguson 1937); a preserved fodder that has acquired an aromatic odour and acid taste without putrefactive or mouldy flavours (Babcock and Russel 1900); and, a moist feed conserved in the absence of air (Woodward 1939). However, the most complete definition is due to Watson (1939), who emphasised the controlled nature of the process: "Silage is the name given to a succulent material produced by a process of controlled vital changes from a green crop or other material of high moisture content".

2. Changes within the Container

To devise effective means of controlling the changes which take place following ensiling, a knowledge of the course of reactions is essential. The course of reactions has been fully reviewed by Watson (1939) and more recently by Musgrave (1950) and Barnett (1954). Watson (1939) divides these reactions into, (a) those which take place before death of the plant cells as a result of physiological activity, and (b) those which take place following death of the cells and result from microbiological activity.

(a) Physiological Changes

Watson and Ferguson (1937) and Barnett (1954) stated that the plant cells of living herbage, following ensiling, rapidly exhaust the oxygen in the entrapped air. This process results in sugar breakdown with the release of carbon dioxide, water and heat (Watson 1939).

After aerobic respiration ceases, enzyme systems continue to function under anaerobic conditions (Peterson *et al.* 1925). Enzymatic action produces alcohol and simple fatty acids of which acetic acid forms the greater proportion (Watson 1939). Under the ensuing anaerobic conditions Bender *et al.* (1939) maintain that metabolic products of aerobic activity may be oxidised to acetic acid.

Concurrent with carbohydrate breakdown, tryptic enzymes are active on the protein fraction of the material (Hunter 1921). Barnett (1954) maintains that protein breakdown proceeds no further than the stage of amino acids and amides. That this breakdown to the amino acid stage is due entirely to enzyme action, has been shown by Kirach (1930). In his experiments, an ensiled

crop, following sterilization, showed no protein degradation. Inoculation of the sterilized crop with a suitable microbial strain produced likewise results. On the other hand, breakdown was detected in material previously treated with toluene, a known bactericide. These results are in agreement with the earlier findings of Lamb (1917) and Hunter (1921).

Associated with carbohydrate and protein breakdown is an increase in temperature within the mass. The rise in temperature is proportional to the entrapped volume of air, which is influenced by the stage of maturity of the crop (Watson 1949). Mature material presents compression difficulties. Young succulent herbage, however, tends to pack tightly thereby reducing free oxygen and leading to restricted respiration (Watson 1939).

Temperature increases can be controlled by regulating the stage of maturity, the degree of packing, the moisture content and depth of silage (Musgrave 1950). Watson and Smith (1951) consider that a high temperature within the mass is undesirable. This leads to an increased loss of soluble carbohydrate and a lowering of digestibility, particularly of the protein fraction. This latter effect was first shown by Woodman and Hanley (1926) who worked with stack silage in which the mass rose to a temperature of 160°F. The digestibility of the crude protein fraction was given as 12, an extremely low figure when compared with percentage values of 64 and 68 reported by Watson and Ferguson (1937). Their measurements were conducted on well preserved silages made from crops of similar composition, but the temperature of the mass never rose above 100°F. Watson (1949) also maintains that low temperatures within the mass are undesirable, the resulting reactions in many cases being entirely anaerobic.

(b) Microbiological Changes

That micro-organisms are the principle agents in the fermentation of silage is demonstrated by the studies of Hunter (1921). His results show that when a crop is treated at ensiling time with 2 per cent chloroform, no essential increase in acidity occurs within the mass. If the crop is sterilized, then re-inoculated with suitable microbial strains, normal acidification takes place. These results are confirmed by the more recent findings of Rabbit (1951), who used sterile grass in place of sterilizing agents.

At ensiling time a large and mixed bacterial flora is present in the crop (Watson 1959). Once in the silo, however, the flora is considerably restricted (Barnett 1954). Allen and Harrison (1937 a) have shown that the main microfloral constituents of fresh grass are lactobacilli and coliforms. The former organism is restricted to strains of *Streptobacterium plantarum*, while *Bacillus aerogenes graminis* is attributed to be the predominant coliform. Obligate anaerobes are present in silage in small numbers, while other miscellaneous flora include micrococci, yeasts and aerobic spore formers (Allen and Harrison 1937 b). Similar findings are reported from studies conducted by Heinman et al. (1921).

Microbial fermentation processes intensify following death of the plant cells (Watson 1959). Heinman et al. (1921) differentiate these processes into three phases. The initial phase of short duration is caused by coliform bacteria whose main product is acetic acid, alcohol and lactic acid also being produced. The second phase is characterised by the presence of streptococci, which produce moderate amounts of acetic and lactic

acids. The third phase is predominated by lactobacilli, of which a slow and rapid type can be recognized. A more recent theory, postulated by Barnett (1954), agrees with the above exposition.

In the initial phase the coliform bacteria undoubtedly assist in the general chemical breakdown. Their contribution, however, is small. Allen (1936) has shown that a rise in temperature and lack of oxygen within the mass lead to their destruction. The second phase is also of short duration. Numbers of streptococci present are readily overwhelmed by the rapidly multiplying lactic acid-producing bacteria (Allen and Harrison 1937 b). That the third phase, characterised by the presence of lactobacilli, is the main one controlling changes within the silo, is agreed upon by all authorities (Watson 1939; Musgrave 1950).

The studies of Allen (1936) show a rapid increase in the numbers of lactobacilli within the first twenty four hours after ensiling. This increase continues until the seventeenth day. Thereafter, a decline in numbers of the organism follows. This decline is attributed by Watson (1939) to be due to the toxic effect of their own metabolic product, namely, lactic acid. Proliferation of lactobacilli is dependent upon the presence of a plentiful supply of soluble carbohydrate (Bender et al. 1939). Sufficient carbohydrate should be present to produce a lactic acid concentration in the region of 1 - 2 per cent of the fresh material with the formed product amounting to over 50 per cent of the organic acids present (Musgrave 1950). The attainment of this level ensures a low pH value within the mass, the degree of acidity present preventing undesirable fermentation (Bender et al. 1939).

Should an unsatisfactory degree of acidity prevail within the silo a further and undesirable fermentation phase results (Watson 1939)

Barnett (1954) attributes this phase to the activity of obligate anaerobes. Anaerobic organisms present in silage belong to the group Clostridia. Individual types isolated in the studies of Allen and Harrison (1937 a,b) include *Cl.sporogenes*, *Cl.welchii*, *Cl.putreficum* and *Cl.butyricum*.

The proliferation of anaerobic organisms in silage is governed by the availability of residual carbohydrate, protein and the restraining effect of acidity (Watson 1939). In well made silage, rich in fermentable carbohydrate, anaerobic proliferation is prevented by the increasing acidity. Virtanen (1939) in laboratory studies found that the activity of anaerobes is completely inhibited in silage at a pH of or below 4. Van Beynum (quoted Watson 1939) has shown, however, that the spores of anaerobes can tolerate an acidity of pH 3.5. It is essential, therefore, that the pH of the mass remain at a value in the region of 4, otherwise regermination of spores into active organisms can occur.

Should lactic acid production be incomplete in silage, conditions suitable for the rapid multiplication of obligate anaerobes occur early in the fermentation process. Saccharolytic types of these organisms attack complex carbohydrates with the formation of acids (Musgrave 1950). These acids are largely volatile in nature and contain a high proportion of butyric acid (Watson 1939). The organisms are also capable of decomposing lactic acid later in the fermentation process (Barnett 1954). Decomposition products formed in this reaction include butyric acid, carbon dioxide and hydrogen. Bhat et al. (1951) have shown that this decomposition process only occurs in the presence of a hydrogen acceptor. Barnett (1954) considers that certain pigments present in silage may be possible hydrogen acceptors.

The studies of Allen and Harrison (1937 a,b) have shown that protein breakdown in silage may be caused by proteolytic bacteria of the Clostridia group. Breakdown occurs under conditions similar to those required by saccharolytic types of the group for carbohydrate breakdown. The lactobacilli may also attack protein under these conditions (Hunter 1917, 1918). In both reactions, protein compounds are broken down to organic acids, amines, amides and ammonia (Russel 1908; Bender et al. 1939). A further breakdown of nitrogenous products in silage to nitric dioxide has been reported (Anon. 1949). Conditions which bring about this breakdown are not understood (Musgrave 1950). Wilson (1943) suggests the reduction of nitrates by anaerobic organisms as a possible factor.

3. Ensiling Problems associated with Immature Herbage

It is agreed upon by all authorities (Watson 1939; Musgrave 1950; Barnett 1954) that rapid acidification of the mass, through the action of lactic acid bacteria, is an essential feature of good silage. In carbohydrate-rich crops, e.g., mature herbage, lactic acid fermentation normally occurs with a decrease in pH value to the desired level. In protein-rich crops, such as young succulent herbage and legumes, Watson (1939) states that active lactic fermentation may be lacking and undesirable fermentations frequently occur.

Aldershaw (1924), Whittet (1930), Wilson and Webb (1937) and others attribute the occurrence of undesirable fermentations in ensiled immature crops, to a low content of fermentable carbohydrate in the material, coupled with a high moisture content. Barnett (1954) suggests that the quantity of elementary carbohydrates in immature herbage is not sufficient to account for the amount of lactic acid

produced in good silage, and that probably fructosan, a reserve carbohydrate, is utilized by the lactobacilli. Similar views are held by Percival (1952), on the basis that fructosan is the most easily hydrolyzed polysaccharide. The latter worker could not detect the presence of fructosan in legumes and suggests this factor as the reason for difficulties experienced in the ensilage of legume crops. Added weight is given to the above theories by the work of Norman (1936), who demonstrated an increase in the fructosan content of grass between the leafy and flowering stages and thereafter a decline with the onset of maturity.

Wilson et al. (1935) observed that leguminous plants, following ensiling, required more organic acid to reduce their pH value one unit than was required by non-leguminous material. This phenomenon, and thus difficulties experienced in the ensilage of legumes, he attributed to the buffering capacity of the high base content of legumes. Steensberg (1952) has also commented on the high buffering capacity of plant juice from young succulent crops. Wilson et al. (1935), in addition, re-emphasized that immature leguminous material may be deficient in fermentable carbohydrates. Further experimental work (Wilson and Webb 1937) did confirm that immature non-legume forage contained appreciably more fermentable carbohydrate than legume forage.

Crasemann and Heinzl (1949) maintain that adequate fermentable carbohydrate in the ensiled material is not sufficient to ensure a silage of high lactic acid content, unless surplus moisture is drained from the silo. The absence of free drainage provides suitable conditions within the container for the proliferation of undesirable anaerobes (Watson 1939).

Although the above mentioned findings suggest lack of fermentable carbohydrates, high buffering capacity, and the low dry matter content of immature herbage and legumes, as possible causes of undesirable fermentations within the silo, there is still a lack of fundamental information from which conclusive answers can be derived.

B. NUTRIENT LOSSES IN SILAGE-MAKING
BY THE ORDINARY PROCESS

1. The Nature of Nutrient Losses

Watson (1939) maintains that nutrient losses are inevitable when a green crop is ensiled. Shepherd *et al.* (1953) place such losses as occur in the process into three categories: drainage, caused by the weight of the crop pressing out moisture containing soluble forage nutrients; surface spoilage, due to heating, moulding and rotting of the material in the presence of air; and, a fermentation loss, resulting from the physiological and microbiological activities which occur within the ensiled crop. A similar partitioning of the nutrient losses which occur in the process, is adopted by Watson and Smith (1954), Musgrave (1950) and others.

2. The Measurement of Nutrient Losses

Watson (1939) and Barnett (1954) maintain that an estimate of nutrient losses, occurring in silage during the storage period, can only be obtained by careful laboratory analysis reinforced by a knowledge of the weights of dry matter ensiled and removed from the container (direct method). Early trials, conducted to estimate losses, employed crude analytical data of the fresh crop and resultant silage (Watson 1939). In these trials it was assumed that one or other of the constituents, often the crude fibre fraction, remains unchanged in the process (Le Clerc 1959; Reed and Fitch 1917; Peterson *et al.* 1935). The possible error involved, when results obtained by the use of crude analytical data are compared with values determined by the direct method, has been shown by

Watson and Ferguson (1937). Data for calculated and determined dry matter losses (stated as a percentage of the fresh crop) were given as 10.0 per cent and 18.2 per cent respectively, a difference of 8.2 per cent in favour of the direct method. Watson (1939) maintains that low calculated values result from crude fibre changes during the fermentation process. Partial breakdown of the crude fibre fraction of the ensiled material to nitrogen-free extractives and organic acids has been reported in the literature (Amos and Woodman 1924; Watson 1939). The method could not, therefore, be expected to furnish a true estimate of nutrient losses which occur in the process.

Watson and Ferguson (1937) state that digestibility data of the ensiled material and resultant silage afford some indication of the nutrient losses occurring in the process. However, for a quantitative expression of these losses, Watson (1939) considers that a knowledge of digestibility coefficients is no more efficient than crude analytical data.

Estimates of nutrient losses, reported by several workers, have been dependent upon filling a suitable bag with a known weight of the fresh crop from which a sample is taken for analysis. The results obtained are compared with the weight and analysis of the bag contents, following removal of the latter from the silo at a later date (Woodman and Hanley 1926; Camburn et al. 1938; Newlander et al. 1940). Although Allred et al. (1955) and others have obtained satisfactory results by use of this method, the technique is liable to difficulty. Excess air may be enclosed with the bagged sample. This factor results in the local development of high temperatures with the subsequent production of mouldy and charred silage (Watson and Ferguson 1937). Furthermore, Watson (1939) maintains that sample bags placed in the upper region of the silo may suffer losses

of certain soluble constituents, while bags placed in the lower region may show an increase in these fractions. Watson and Ferguson (1937) consider that the average value for all bags present in the silo is not necessarily a true measure of the mean nutrient losses which have occurred in the process, unless a large number of such bags have been widely distributed within the silage. The major disadvantage of the method, however, according to Newlander et al. (1940) and Watson (1939), is failure to take into consideration nutrient losses due to spoilage on the top and sides of the silo.

Watson and Ferguson (1937) have compared the dry matter losses from two silos using the "bag" and "direct" methods, two bags being placed in each silo. Their results are given in Table I.

Table I

Losses of Dry Matter obtained by the Bag Method and by Weighing the Total Contents of the Silo.

(percentage of fresh crop)

Silo	Based on Silo Contents	Based on Bag Weight	Difference in favour of Bag
1	21.1 } I	15.2	+ 5.9
	} II	8.5	+12.6
2	21.1 } I	16.1	+ 5.1
	} II	11.6	+ 9.6

The figures call for no comment: the lower placed bags show lower losses in both silos and all bags show lower losses than are registered in the silos. Hodgson and Knott (1940) have reported similar findings. The average dry matter losses obtained over a three year period were given as 31.5 and 14.4 per cent by the

TABLE II

Date	Description	Amount
1917	Jan 1	100.00
1917	Feb 1	100.00
1917	Mar 1	100.00
1917	Apr 1	100.00
1917	May 1	100.00
1917	Jun 1	100.00
1917	Jul 1	100.00
1917	Aug 1	100.00
1917	Sep 1	100.00

Table II

Summary of Data in the Literature for Dry Matter Loss in the
Ensilage of Grass-legume Mixtures by the Ordinary Process
(stated as a percentage of the original crop)

Author and Country of Origin	Type of Container	Percentage Loss of Dry Matter	Author and Country of Origin	Type of Container	Percentage Loss of Dry Matter
<u>U. S. A.</u>			<u>Britain contd.</u>		
Shepherd <u>et al.</u> (1953)	Tower	23.0	Watson (1939)	Pit Silo	18.2
	Trench	27.0	Barnett & Hillar (1950)	Tower	17.9
	Stack	34.0	<u>Holland</u>		
Turk <u>et al.</u> (1951)	Tower	21.0	Brouwer <u>et al.</u> (1931)	Clamp (partly above ground)	20.0
Hodgson & Knott (1937)	Tower	23.0		Clamp (completely above ground)	32.0
	Stack	23.0			
Allred <u>et al.</u> (1955)	Tower	24.7	Dijkstra (1954)	Pit Silo	24.8
<u>Britain</u>			<u>New Zealand</u>		
Brown & Heaney (1951)	Trench	23.2	Sears & Goodall (1947)	Pit Silo	34.0
Drew <u>et al.</u> (1935)	Trench	22.5		Stack	42.0
Davies <u>et al.</u> (1937)	Pit Silo	24.1	Sears (1956)	Pit Silo	29.0

direct and bag methods respectively. The ratio of the losses as determined by the two methods and excluding top spoilage is similar to figures reported by Newlander et al. (1940).

From all information available it would appear that, for an accurate estimation of nutrient losses occurring in the silage process, it is necessary to record the weights of all material ensiled and removed from the silo. The use of bags, however, may prove satisfactory provided a large number are widely distributed throughout the silage and allowance is made for spoilage.

3. The Magnitude of Nutrient Losses

(a) Total Losses

Dry Matter. Total losses of dry matter in the silage process, ranging from 4 per cent (Lowe and Gilbert 1886) and 11 per cent (Boyle and Ryan 1933) to 46 per cent of the dry matter ensiled (Sears and Goodall 1947), have been reported in the literature. The accuracy of many values reported, however, is subject to doubt. Several authors have obtained their results by use of the "bag" method (Boyle and Ryan 1933; Cornburn et al. 1938; Taylor et al. 1940; Woodman and Hanley 1926). Other workers have used crude analytical data in their estimations (Peterson et al. 1937). In other cases (Watson (1939) considers that the ensiling techniques used have been poor.

Table II shows dry matter losses which are likely to occur in the silage process in several countries. In all trials reported, immature herbage was used and the direct method of estimating nutrient losses adopted. Figures furnished indicate that dry matter losses in the process are of similar magnitude in America and Europe but higher in New Zealand. The high dry matter losses which occur in New Zealand silages, as compared with other countries, have

been commented upon by Sill and Sears (1942). It is unwise, however, to draw definite conclusions from Table II as to the comparative efficiency of the process in the various countries. Figures quoted are averages, which mask considerable variation in the results obtained by individual workers in repeated trials.

Generalizations with regard to dry matter losses occurring in the silage process, have been attempted by several workers. Watson and Smith (1951) conclude that, in good quality European silages, minimum dry matter losses are in the order of 15 - 30 per cent. Barnett (1954) mentions a 15 - 25 per cent loss of dry matter as a reasonable figure for British silages. From a study of American data, Taylor et al. (1940) conclude that a loss of 10 - 15 per cent of the total dry matter ensiled is nominal and unavoidable. Musgrave (1950) quotes 15 per cent as a minimum figure for the loss of dry matter from material ensiled under ideal conditions in America. Newlander et al. (1940) consider dry matter losses in the order of 11 - 14 per cent to be a reasonable estimate for American pit and tower silos. The estimates of the above mentioned workers are as good a guide to the dry matter losses occurring in the silage process as can be expected.

Crude Protein. Grasmann (1925) states that the loss of nitrogen in the silage process accounts for 15 per cent of the total losses. Watson and Ferguson (1937) in their experiments obtained a crude protein loss of 2.4 per cent of the total ensiled. The authors, therefore, maintain that losses of this constituent in the process are low. Barnett (1954), however, reports crude protein losses in the region of 34.6 per cent from studies conducted with small tower silos. American workers have reported crude protein losses in the process varying from 22 per cent (Camburn et al. 1944) to 37 per cent (Hodgson and Knott 1937) of the total crude protein

ensiled. In New Zealand trials, Sears and Goodall (1947) obtained crude protein losses of 42.1 and 46.3 per cent from pits and stacks respectively. It is extremely difficult, however, to draw conclusions from isolated determinations as appear in the literature for crude protein losses occurring in the process. Barnett (1954) considers that, in general, crude protein losses are relatively high when immature herbage is ensiled.

Nitrogen-free Extract and Crude Fibre. Crasemann (1925) states that of the total nutrient losses in silage, 80 per cent involve the nitrogen-free extract and crude fibre fractions. That the nitrogen-free extract fraction of ensiled material undergoes the greatest loss in any nutrient is agreed upon by several workers (Watson 1939; Musgrave 1950; Sears and Goodall 1947). Watson (1939), on the basis of his studies, maintains that crude fibre losses within the silo are of a low order. The results of Barnett (1954) and Sears and Goodall (1947) do not support this view. The former worker recorded an 18.5 per cent loss of crude fibre from young grass ensiled in a tower silo, while the latter workers obtained crude fibre losses of 17.3 and 29.3 per cent from immature herbage ensiled in pits and stacks respectively.

Ether Extract. Watson (1939) states that the ether extract fraction of green material may show an increase following ensiling. In the literature increases in the ether extract fraction of ensiled material varying from 6.9 per cent (Camburn et al. 1944) to 136.4 per cent (Watson and Ferguson 1937) are quoted. Watson (1939) attributes this observed increase in the ether extract fraction to the inclusion of organic acids resultant on the changes within the silo. Other workers, however, have reported losses in the ether extract fraction of ensiled material ranging from 4.4 per cent (Barnett 1952) to 27.8 per cent (Sears and Goodall 1947). With such

wide variation occurring between the results of different workers, it is not possible to make generalizations regarding the losses of this fraction in the silage process. The ether extract fraction, however, forms but a small part of the dry matter in silage.

Mineral Matter. Barnett (1954) considers that there is a lack of information on the total mineral matter losses occurring in the silage process. Values reported by individual workers for the total mineral matter lost by the ensiled crop, show considerable variation. In the literature losses of mineral matter of from 9 per cent (Brouwer 1930) and 24.6 per cent (Barnett 1952) to 36.8 per cent (Sears and Goodall 1947) are quoted. Watson and Smith (1951) maintain that mineral matter losses in silage are mainly confined to the drainage and involve the soluble ash constituents. The loss of mineral matter should not, therefore, be high unless seepage is excessive.

Vitamins. Bender et al. (1939) report that vitamins A, B₂, C and D are present in silage. Literature on the vitamin content of the material, however, is concentrated mainly upon the importance of carotene in its function as a precursor of vitamin A in the synthesis by the animal of this latter body.

Barnett (1954) states that in silage made under ideal conditions, vitamin C is destroyed to about 60 - 65 per cent in the process. Musgrave (1950) attributes loss of this vitamin to the action of peroxidases. Vitamins B and D are not known to undergo any appreciable changes in the silage process. These vitamins, however, are generally present in silage in small amounts (Watson 1939). Thomas et al. (1948), however, have shown that wilting of the crop prior to ensiling may increase the vitamin D content of the resultant silage.

The ensilage process results in considerable preservation of carotene (Bender et al. 1939; Barnett 1954). Several workers report that carotene retention averages from 60 - 90 per cent of the total ensiled (Monroe et al. 1946). Other workers have reported lower carotene retention within the mass (Watson 1939; Camburn et al. 1944). In the studies of Hegsted et al. (1939) and Krauss et al. (1936), carotene values for silages are reported which are higher than values obtained for the corresponding green crop. Such high values are shown by Quackenbush et al. (1938) to be caused by the presence of pigments produced in the fermentation process. These pigments are not precursors of vitamin A and are, therefore, of no biological value in this respect. Modified analytical methods for carotene, which exclude these pigments, are now in use (Bolton and Common 1941, 1942). Isolated carotene determinations for silage as appear in the literature must, therefore, be interpreted with caution and values obtained related to the analytical method adopted. In general, Barnett (1954) maintains that, if conditions within the silo are favourable, carotene retention within the mass is more than sufficient to meet the requirements of livestock.

(b) Drainage Losses

Shepherd et al. (1953) state that the magnitude of drainage losses from ensiled material is dependent upon the dry matter content of the original crop, the depth and compactness of the material within the container, and the dry matter content of the exudate. The studies of Murdoch (1954) and Jones and Murdoch (1954) have shown the existance of a definite negative correlation between the dry matter content of the ensiled crop and the amount of drainage from the silo. Drainage losses, however, may be markedly

increased by leaching, if inadequate attention is given to the sealing of the silo (Sill and Sears 1942). Hofer (1929) maintains that drainage may also account for a further and indirect loss of nutrients from the silage. In his studies the penetration of air into spaces left by the exuded sap was noted. This process caused abnormal and harmful aerobic fermentation, with a resultant loss of nutrients.

Many workers have measured the magnitude of drainage losses from ensiled herbage. Barnett and Millar (1950) report a loss in the region of 5 per cent of the initial dry matter content of ensiled material; Sears and Goodall (1947) a loss of 6.1 and 3.2 per cent dry matter from leafy material ensiled in pits and stacks respectively; Sill and Sears (1942) a loss of 2.5 per cent dry matter from herbage ensiled in pits; Shepherd *et al.* (1953) a dry matter loss ranging from 6 - 8 per cent for lucerne and meadow crops; and Archibald (1945), from a seven year study on a field-scale silo, an average loss of 0.54 per cent dry matter, with a range from 1.08 - 0.12 per cent.

In the dry matter lost through drainage are involved nitrogenous substances, mineral matter, carbohydrates and organic acids (Barnett 1954). Godden (1923) analysed samples of effluent at frequent intervals during the period of flow from herbage stored in a concrete silo. The composition of the effluent on a dry matter basis was stated as 17-28 per cent crude protein, 19-23 per cent ash, 2.3-4.3 per cent lime, 1.3-2.2 per cent phosphoric pentoxide and 0.00-2.07 per cent potash.

In general, Watson and Smith (1951) consider that drainage from the silo does not usually result in high nutrient losses, the dry matter lost seldom exceeding 3-4 per cent of the initial dry matter content of the ensiled material. However, when drainage is too

free, the crop extremely succulent or the silage subject to leaching, Shepherd et al. (1953) maintain that drainage losses may rise to 10 per cent of the initial dry matter ensiled.

(c) Spoilage Losses

Monroe et al. (1946) maintain that spoilage losses in silage vary on a percentage basis with the size, depth and nature of the container, with efficiency of compaction of the material, with precautions taken when sealing the container, and with the length of the storage period. Numerous workers have measured the magnitude of spoilage losses occurring in the process. Newlander et al. (1940) give top spoilage estimates of 6.1 per cent dry matter for silos 24 feet in height and 3.3 per cent dry matter for silos 36 feet high. At Beltsville research centre, spoilage losses ranging from 4 - 9 per cent dry matter are reported for tower silos 25 feet in height (Shepherd et al. 1953). At Cornell research centre, top and side spoilage losses in two tower silos were given as 14 and 17 per cent dry matter. These high dry matter losses were attributed to insufficient compaction of the ensiled material (Shepherd et al. 1953).

Watson (1939) states that spoilage losses in stack silage are higher than those occurring in pits and towers. This view is supported by the results of several workers who have compared spoilage losses in stack, pit and tower silage. Sears and Goodall (1947) found spoilage losses to be in the order of 2.6 and 10.2 per cent dry matter for pits and stacks respectively. Shepherd et al. (1953) reported average spoilage losses in the order of 4.9, 7 and 15 per cent dry matter for tower, pit and stack silages respectively.

Watson (1939) considers that, in general, spoilage losses cannot be avoided in stack silage and may form a high proportion of

the total losses. In pit and tower silages, on the other hand, spoilage losses should not exceed 3 - 4 per cent dry matter, provided the material is well packed and properly sealed. That spoilage losses can be materially reduced by the application of a proper seal is shown by the research of Nevens (1933). From studies conducted, the latter worker concluded that an airtight cover and the application of pressure, to consolidate the upper layer of material, are sufficient to prevent excessive surface spoilage.

(d) Fermentation Losses

Internal losses of dry matter, due to fermentation, are reported in the literature as being from 2 - 35 per cent of the initial dry matter ensiled (Taylor et al. 1940; Camburn et al. 1942; Shepherd et al. 1947, 1949, 1953; Sears and Goodall 1947; Watson 1939). It is the claim of Perkins (1943) and King (1943) that many such losses may be too high where the oven-drying method of moisture determination has been employed. Both workers maintain that the procedure drives off volatile products which are accounted for as moisture. Perkins (1943) recommends a toluene distillation method for drying the silage samples, with corrections for the amount of volatile products present.

The greatest fermentation losses normally occur in high moisture silage (Watson 1939). Shepherd et al. (1953), however, maintain that low moisture content and poor packing of the material in the container may increase the fermentation loss. The increase is attributed by these authors to result from heating and moulding of the silage. Fermentation losses in tower silage may also be lower than losses occurring in pits and stacks. Shepherd et al. (1953) in their silage studies ensiled high moisture crops. They obtained fermentation losses of 10, 11 and 12 per cent dry

matter for tower, pit and stack silage respectively. Corresponding figures for mature material were given as 7, 10 and 12 per cent respectively.

It is agreed upon by all authorities that fermentation losses must occur in the silage process (Barnett 1954). Watson (1939) maintains, however, that fermentation losses can be minimized, provided conditions are such as to control the microbiological and physiological processes in the silo. Musgrave (1950), on the basis of American data, suggests a 7 - 10 per cent fermentation loss as a minimum that can be expected in the process. Watson and Smith (1951) give a dry matter range from 9 - 22 per cent as a reasonable estimate for the minimum fermentation losses likely to occur in silages made under European conditions. Figures for fermentation losses occurring in the making of silage under New Zealand conditions are limited to those of Sears and Goodall (1947). In studies conducted over a three-year period these workers obtained fermentation losses ranging from 20.9 - 31.3 per cent dry matter for material ensiled in pits. Corresponding figures for similar material ensiled in stacks were given as ranging from 20.3 - 34.5 per cent dry matter. Such results would seem to suggest that fermentation losses occurring in the process are, in general, higher in New Zealand than those encountered under European and American conditions.

C. THE USE OF ADDITIVES IN SILAGE-MAKING

1. Definition and Classification of Additives

An additive, with reference to silage making, may be defined as: a substance added to a crop at ensiling time with the sole objective of directing the biological processes which occur within the mass into the desired channels. This purpose can be effected by stimulating the development of desirable bacteria, suppressing the growth of detrimental bacteria, or inhibiting the growth of all bacteria and other agents common to silage. Accordingly, the various additives used in silage-making can be differentiated into three classes:

- a. Addition of strong acids which increase the acidity of the mass to a point where undesirable bacterial action is checked (Direct Acidification).
- b. Addition of readily fermentable carbohydrates which form a good substratum for the desirable lactic acid bacteria (Stimulation of Lactic Fermentation).
- c. Addition of antiseptic agents which inhibit bacterial fermentation and prevent protein breakdown by enzymes (Sterilization of the Mass).

2. Additives and their effect upon Nutrient Losses

(a) Direct Acidification

The direct acidification process is based on the findings of Virtanen (1933) that detrimental decomposition processes, liable to occur in ensiled crops, are prevented by addition to the material at ensiling time of the requisite amount of acid, capable of raising the acidity of the mass to a pH value below 4.0 but not under 3.0. Although both respiration and fermentation of the material are inhibited at pH 3.0, the resultant product is harmful to stock (Virtanen 1947).

The A.I.V. Process. The research of Virtanen led to the A.I.V. method of silage-making. The process consists of the addition of a mixture of equal quantities of a 2 normal solution of sulphuric and hydrochloric acids to the fodder as it is ensiled (Virtanen 1947). Sufficient acid is added to bring the acidity of the mass between a pH value of 3.6 and 4.0. Virtanen (1936) also postulates the use of sulphuryl chloride. This substance undergoes hydrolysis and yields sulphuric and hydrochloric acids.

The success of the method is dependent upon accurate and uniform distribution of the acid throughout the ensiled crop. The amount of acid added is influenced by the nature and moisture content of the crop (Musgrave 1950). Wilson and Webb (1937) have shown that immature and legume-rich crops require more acid to lower their pH value than do other forages. Virtanen (1947), on the other hand, has demonstrated that the acid requirement for any particular forage is proportional to its dry matter content.

The container employed for the storage of A.I.V. treated material must possess free drainage. If drainage facilities are inadequate, Barnett (1954) maintains that a rise in pH value of the material will occur during the storage period and undesirable fermentations ensue. Virtanen (1938), in one experiment with A.I.V. forage, did observe a rise in pH from an initial value of 3.4 to 5.2 within a container lacking adequate drainage facilities. In a well drained silo the pH value of similarly treated material changed from 3.65 to 3.48 over a corresponding period.

Numerous workers have compared the efficiency of the A.I.V. method over the ordinary process, with regard to dry matter losses occurring during the storage period of ensiled fodder. A summary of results appearing in the literature is shown in Table III.

Table III

Percentage Losses of Dry Matter in
Ordinary and A.I.V. Silages.

(compared with the fresh crop)

Author and Country of Origin	Percentage Loss of Dry Matter	
	Ordinary Silage	A.I.V. Silage
<u>Britain</u>		
Drew <i>et al.</i> (1935)	17.3	12.6
Boyle & Ryan (1936)	11.3	7.3
Davies <i>et al.</i> (1936)	24.1	18.7
Fagan & Ashton (1937)	28.9	15.5
Watson (1939)	18.2	17.6
<u>Other European Countries</u>		
Brouwer <i>et al.</i> (1933)	16.4	9.4
Spildo (1936)	24.0	6.6
Steensberg (1948)	14.6	13.9
<u>New Zealand</u>		
Scars & Goodall (1947)	39.5	23.7

In general, figures furnished in Table III do reveal the value of the A.I.V. method in reducing dry matter losses from ensiled material. Although Watson (1939) obtained little reduction in dry matter losses from ensiled material following application of A.I.V. solution (Table III), he still claims that the method is the most efficient silage-making process. This claim is based on the marked effect that A.I.V. solution possesses in reducing protein breakdown within the silo (Watson 1938, 1939). The value of the A.I.V. method in reducing protein breakdown has been commented on by numerous workers (Huffman 1939; Virtanen 1947; Steensberg 1948). Virtanen (1937) found the non-protein nitrogen fraction in A.I.V. silage to be composed largely of peptides and

little ammonia. The opposite effect was noted in ordinary silage. The comparative absence of ammonia in A.I.V. silage has been corroborated by the work of Peterson et al. (1925). As a result of reduced protein breakdown within the silo, Le Clerc (1939) considers that the non-protein nitrogen fraction in A.I.V. silage is superior in feeding value to that in silage made without treatment.

Several workers maintain that A.I.V. treatment favours carotene retention within the silo (Monroe et al. 1946; Peterson et al. (1937; Watson 1938, 1939; Virtanen 1947). However, many high carotene values for A.I.V. silage, as reported in the literature, are open to doubt. Work on the actual silage process which will result in the best retention of carotene, is complicated by difficulties in determining what is carotene and what are related pigments (Quackenbush et al. 1938). High carotene values for A.I.V. silage, reported by Krauss et al. (1936), were attributed by the authors to be due to interfering pigments. At the same time, several workers have found A.I.V. solution to be no more efficient than no addition in conserving carotene within the silo (Huffman 1939; Drew et al. 1935). In general, a review of the literature indicates that additives are not necessarily needed for the preservation of carotene in silage. Untreated silage contains a sufficient quantity of the provitamin to meet livestock requirements (Huffman 1939; Shepherd et al. 1953).

Watson (1938) and Virtanen (1947) both claim a high retention of vitamin C in A.I.V. silage. Musgrave (1950) maintains that application of A.I.V. solution may cause a 50 per cent retention of the vitamin, which is almost completely lost in silage made without treatment. However, Barnett (1954) states that the vitamin is not a dietary necessity of adult stock, while Huffman (1939) maintains

that its presence in milk is not affected by the level in the ration. Thus, the vitamin C content of silage would appear to be of minor importance.

Other Acid Processes. Various mixtures of inorganic acids have been used as additives in silage making. The Defu process makes use of a mixture of hydrochloric and phosphoric acids (Le Clerc 1939). Dilution of the product by the correct degree gives a solution of similar concentration to that used in the A.I.V. process (Barnett 1954). Liquid phosphoric acid and solid acid materials, e.g., phosphorous pentachloride and sulphur trioxide, have also been used to lower the pH of the ensiled crop. A review of the literature does reveal that these materials successfully lower the pH of the mass, if properly used, and produce a good quality silage from protein-rich crops (Conner *et al.* 1940; Wilson and Webb 1937; Watson 1939; Barnett 1954). Nutrient losses incurred in the various processes are of a similar magnitude to those obtained by use of A.I.V. solution (Watson 1939; Ruschmann 1933; Barnett 1954).

Although direct acidification ensures certainty of a good product, several factors restrict widespread adoption of the process. In certain countries, e.g., New Zealand, the high cost of mineral acids rules out direct acidification on economic grounds (Sears and Goodall 1947). Other disadvantages of the process, mentioned by Watson (1947) are: the distribution and handling of acids in concentrated form on the farm is both dangerous and unpleasant; acids must be added uniformly to the crop and the amounts used carefully adjusted to the weight and stage of growth of the ensiled material. A further disadvantage of mineral acids in silage-making results from the effect of the treated material on the animal. The feeding of acid silage alone upsets the animal's mineral balance, causing an increase in the acidity and ammonium content of the urine

(Barnett 1954). Mineral acid silage must, therefore, be neutralized before feeding to livestock. A suitable addition of limestone to the silage, with or without sodium carbonate, is essential unless large quantities of hay are available (Virtanen 1933; Watson 1947).

To eliminate neutralization problems and reduce danger hazards, several of the weaker organic acids have been subjected to experimentation as additives in silage-making. Formic acid has been used in several European countries. Experiments have shown the resultant silage to be of high quality, while the pH of the urine of cattle fed upon it was normal (Watson 1947; Barnett 1954; Murdoch et al. 1955 a). Favourable results have also been obtained using glycollic acid as an additive (Murdoch et al. 1955 a). High cost of both additives, however, prohibits their economic use in practice (Steensberg 1948; Murdoch et al. 1955 a).

On an experimental scale, lactic acid has proved to be an effective additive and in itself is of high feeding value (Barnett 1954). Gerlach et al. (quoted Watson 1939) observed that the growth of undesirable organisms in silage was suppressed materially at a 1 per cent concentration of lactic acid and prevented at a 1.5 per cent level. Klienert (1938), who used various acids including lactic acid, claims to have obtained little difference between the silages produced. However, the use of lactic acid in practice is again not possible on the grounds of expense.

Direct acidification is widely used in Northern Europe where a systematic schooling of farmers in the complete process is given. In Britain and America the method has not been adopted to any great extent. Other methods of preservation are considered more satisfactory. In New Zealand the process is non-existent, primarily on economic grounds.

(b) Stimulation of Lactic Fermentation

Watson (1939) considers that stimulation of lactic fermentation presents a ready means of controlling the changes in the silo. It has been shown by Wilson and Webb (1937) that immature crops are liable to be deficient in fermentable carbohydrates, the substrate for lactic acid bacteria. By the addition of fermentable carbohydrates to immature material, Musgrave (1950) states that lactic acid fermentation is encouraged and undesirable fermentations are suppressed.

Molasses. The use of molasses seems to be the most desirable method of stimulating a lactic fermentation in ensiled material (Allen et al. 1937 b; Bender 1935; Bender et al. 1936; Fagan and Ashton 1937; Wilson and Webb 1937). The liquid used in silage-making contains approximately 65 per cent soluble carbohydrates, of which from 55 - 60 per cent is fermentable sucrose (Bender et al. 1939). According to Watson (1939), molasses serves not only as a preservative, but is also a source of additional nutrients.

A mass of literature exists on the use of molasses in silage-making. Some of it, however, is not conclusive (Woodward et al. 1942; Brown and Heaney 1951; Camburn et al. 1938). Axelsson (1952) attributes many inconclusive results obtained through use of molasses to one or more of several factors: insufficient addition of molasses; over dilution or uneven distribution of the product; lack of adequate drainage facilities in the container; or, application of the liquid to a crop of high dry matter content.

Early workers advocated a molasses concentration of 1 - 2 per cent of the fresh crop as being sufficient to ensure successful preservation of immature herbage (Axelsson 1952). In recent years a greater amount has been considered necessary. Bender et al. (1936) and Camburn et al. (1938) have recommended an increase in molasses

addition of up to 3 - 4 per cent of the fresh crop. Nevens et al. (1948) maintain that molasses gives too slight an effect to make the addition economical when the dry matter content of the fresh crop exceeds 30 per cent. Evidence furnished by Eriksson (1951) supports this view. The latter worker ensiled clover with a dry matter content of 35 per cent. The resultant fermentation process, nutrient losses and quality of the silage produced, were not affected by the molasses added.

Watson (1946) maintains that molasses must be uniformly distributed throughout the ensiled herbage and the amount of water added to the product restricted. Excess addition of water, according to Axelsson (1952), is injurious to a crop already high in moisture. Even if the above mentioned precautions are taken, Crasemann and Heinzl (1949) consider that the production of a silage high in lactic acid content cannot be guaranteed. Surplus moisture must be permitted to drain out of the silo.

Watson and his associates conducted an investigation into the nutrient losses suffered by a crop as a result of ensiling by the ordinary, A.I.V. and molasses methods (Watson and Horton 1936_a; Allen et al. 1937; Watson and Ferguson 1937). The average dry matter, starch equivalent and digestible crude protein losses obtained in their studies are shown in Table IV. Results do show that molasses treatment has been effective in reducing nutrient losses within the silo. The reduction in nutrient losses over untreated silage is of similar magnitude to that obtained by addition of A.I.V. solution. These results are substantiated by the findings of other European and American

Table IV

Average Losses in Grass Silage
during Storage.
(percentage of original crop)

Silage Process	Percentage Losses		
	Dry Matter	Digestible Crude Protein	Starch Equivalent
Ordinary	17	19	34
A.I.V.	15	9	26
Molasses	14	8	23

workers (Davies et al. 1937; Fagan and Ashton 1937; Hegsted et al. 1939; Johnson et al. 1941). Virtanen (1937) and Steensberg (1948), on the other hand, claim the A.I.V. method to be more efficient than molasses treatment in nutrient preservation within the silo.

In New Zealand, Sill and Sears (1942) added molasses to material ensiled in 2-ton silos. Results showed that the preservative had little effect in reducing nutrient losses. The herbage ensiled, however, was relatively mature and probably had a high fermentable carbohydrate content. In other trials (Sill and Sears 1942), with immature herbage, similar results were obtained. However, only 30 pounds of molasses were added per ton of fresh herbage. At the present time 50 - 60 pounds of molasses per ton of green material are considered as necessary to reduce nutrient losses occurring in high protein herbage (Axelsson 1952).

Conflicting reports appear in the literature regarding the efficiency of molasses treatment over other processes in reducing

vitamin losses within the silo. Several workers maintain that molasses treatment favours carotene retention (Monroe et al. 1946; Taylor et al. 1940; Camburn et al. 1942). The results of other workers show no reduction in loss of the provitamin through the use of molasses (Woodward and Shepherd 1938). Comparisons made between direct acidification and molasses addition only add to the confusion. Reports favouring higher carotene retention from acidified material (Hegsted et al. 1939; Camburn et al. 1942, 1944) and molassed material (Stone et al. 1943) both appear in the literature. In view of the already mentioned difficulties associated with the estimation of carotene (Quackenbush et al. 1938) it is not considered possible, from isolated determinations as appear in the literature, to draw conclusions in favour of any one process over another.

Molasses treatment of ensiled herbage is considered by Murdoch et al. (1955 a) and others to be a wasteful process. This claim is based on the grounds that a large proportion of the additive may be lost in seepage from the silo. In trials conducted by Murdoch et al. (1955 a), seepage losses amounting to 23 per cent of the addition were recorded. Losses in added molasses of a similar order have been reported by Dijkstra (1951) and Axelsson (1952). Murdoch (1955 b) and Huffman (1939) have also criticised the method on the basis that water is being added to a crop already high in moisture. Virtanen (quoted Woodward et al. 1939) maintains that a considerable portion of the added sugar in molasses treated silage disappears through alcoholic fermentation. This portion is thus ineffective in preserving the ensiled material. The results of Hegsted et al. (1939) and others, however, do not support this finding. Taking the above mentioned disadvantages of the molasses process into consideration,

Watson (1939) considers that a secure place still exists for molasses treatment where the crop is of high protein content.

Other Sources of Fermentable Carbohydrate. The addition of cereal grains to herbage at ensiling time, as a source of fermentable carbohydrate, has been attempted with a fair measure of success (Axelsson 1952). Grains are rich in polysaccharides which, when fermented, give less lactic acid per unit than sugars (Salisbury et al. 1949). As a result, greater quantities of grains are required for preservation of the ensiled material than when molasses is used (Axelsson 1952; Murdoch 1955 b).

An 8 - 10 per cent addition of barley or maize has resulted in the production of a well preserved silage and one of similar quality to that produced by a 3 - 4 per cent addition of molasses (Bohstedt et al. 1941; Stone et al. 1943; King 1945). In general, however, nutrient losses have been higher from grain treated silage. From an economic point of view Murdoch et al. (1955 a) and Axelsson (1952), therefore, consider that molasses is highly superior to grains as an additive. Furthermore, the grinding of grains must be fine and the resultant meals evenly distributed in the ensiled forage (Axelsson 1952). These factors, according to Watson (1946), are difficult to achieve in the field and thus further limit the use of grains as additives in silage-making.

Potatoes and dried beet pulp have been subjected to experimental and field use as additives in silage-making. A review of the literature indicates that, for successful preservation, these products must not constitute less than 30 per cent of the fresh crop (Scheffer et al. 1943; Burkard 1943; Axelsson 1952). At this application rate Axelsson (1952) considers that both additives are, in general, too expensive in relation to the

effect produced. Furthermore, Watson (1946) maintains that both products are difficult to distribute evenly throughout the ensiled crop, a factor necessary for successful preservation of the material.

The use of dairy by-products such as whey has been suggested (Allen et al. 1937; Barnett 1954). Bender et al. (1939) consider that the lactose present in whey serves as an excellent substrate for the lactic acid bacteria. However, owing to the large quantity of whey required or to the necessary partial drying to prevent high moisture addition to the ensiled fodder, whey is impractical for use as an additive in silage-making (Bender et al. 1939; Barnett 1954).

The inoculation of silage with organisms which produce lactic acid has been attempted on an experimental scale. Occasional benefits have been observed from this practice (Reid 1935; Nevens and Kuhlman 1936). In general, however, inoculation of the crop has proved to be of little value in stimulating a desirable fermentation within the mass (Bender et al. 1939; Barnett 1954). Watson (1938) and Ruffman (1939) attribute the poor results obtained by inoculation to the fact that the ensiled crop usually possesses a sufficiently large natural lactic-acid-organism flora of its own.

In conclusion, it can be said that, of the additives discussed in this section, molasses has given the best results in practice. Dried whey is next in order of effectiveness, but high cost prohibits its use on a field scale. Less effective are cereal grains, dried beet pulp and potatoes. All are too expensive in relation to their effect and too difficult to distribute evenly within the crop. Inoculation of the crop with organisms which produce lactic acid has proved ineffective.

(c) Sterilization of the Mass

Early attempts to sterilize ensiled material by the application of heat through the use of warm air, steam and electricity gave results which did not warrant further use of such methods (Hoffman 1923; Watson 1938; Musgrave 1950). In further studies, chemical antiseptic agents were added to the ensiled crop. Musgrave (1950) has listed the chemical agents subjected to test as: sulfamic acid, calcium hypochlorite, phenol, benzoic acid, borax, salicylic acid, oxalic acid, carbon disulphide, formaldehyde and carbon dioxide. All chemical agents, however, proved to be no more successful than physical methods as a means of sterilizing the ensiled crop. The final products all showed evidence of bacterial action (Watson 1938; Bender et al. 1939; Musgrave 1950).

Common salt has been subjected to test as a sterilizing agent in silage-making. The substance has been added to ensiled material in amounts varying from 0.5 to 1.0 per cent of the fresh crop (Axelsson 1952). Watson (1939) and Wilson (1948), who reviewed the literature, found the additive to have no sterilizing effect. Apparently salt increases the initial rate of drainage from the silo. Musgrave (1950) considers that this factor may have a slight beneficial effect upon lactic fermentation within the silo.

In general, early studies, involving the use of antiseptic agents in silage-making, gave such disappointing results that Watson (1938) condemned complete sterilization of the mass as an alternative process. In recent years, however, sulphur dioxide, sodium metabisulphite and miscellaneous inorganic salts have been subjected to experimentation as possible sterilizing agents in the ensilage of immature crops.

Sulphur Dioxide. Gowan et al. (1953) stated that sulphur dioxide gas combines with the moisture present in ensiled material to produce sulphurous acid. The resultant acid inhibits bacterial action within the silo. Furthermore, the gas contributes to the production of anaerobic conditions within the mass, through the action of powerful reducing properties.

Numerous studies have confirmed that sulphur dioxide possesses bactericidal properties. Krausnikov and Raev (1939) found a sulphur dioxide concentration of 0.15 per cent to be lethal in pure cultures of lactic, acetic and butyric acid bacteria. Sisaykan et al. (1944) observed the inhibition of oxidizing enzymes within ensiled material following application of the gas. Procopio (1942) treated herbage with sulphur dioxide as it was ensiled. It was noted that a 0.8 - 1.0 per cent concentration of the gas inhibited all biological and enzymatic processes within the silo. A sulphur dioxide concentration of 0.25 - 0.30 per cent, on the other hand, suppressed the action of these processes. Kroulik (1955) found that sulphur dioxide treatment of ensiled material did not inhibit bacterial growth within the mass during the first few days following ensiling. Thereafter bacterial activity was greatly inhibited. Knott (1950) also commented on early bacterial activity in silage treated with sulphur dioxide. In his studies, the pH of ensiled material fell from an initial value of 4.85 to 4.05 within 16 hours following sulphur dioxide application. This fall in pH value was taken as indicative of bacterial action within the mass.

Further chemical studies were conducted on ensiled material untreated and treated with sulphur dioxide by Knott and Skaggs (1952) and Skaggs and Knott (1952). Application of the preservative resulted in a decreased production of lactic acid, volatile acids

and ammonia within the silo. Treated material also showed lower losses of reducing substances. These findings are in agreement with those of Archibald (1953). On the basis of his results, the latter worker suggested that sulphur dioxide prevents the breakdown of sugar within the silo. Reduced sugar breakdown was attributed to the presence of the gas inhibiting the action of organisms which utilize sugars as a source of energy. It was maintained, however, that the activity of organisms which utilize more complex carbohydrates was not suppressed by the presence of sulphur dioxide in the silage.

In recent experiments the efficacy of sulphur dioxide and other additives has been compared. Furthermore, silages treated with sulphur dioxide have been compared with silages made without additives. Knott (1950) filled two silos simultaneously with an immature mixture of timothy and red clover. The two treatments were 200 pounds of corn and cob meal, and 5 pounds of sulphur dioxide, per ton of green material. Silage treated with sulphur dioxide had a higher carotene content. For corn and cob meal and sulphur dioxide silages the losses of original dry matter ensiled were given as 25.8 and 12.12 per cent respectively, a difference of 13.68 per cent in favour of sulphur dioxide treatment. Kennedy and Allred (1953) reported that silage treated with sulphur dioxide showed a decrease in fermentation losses and a higher retention of carotene, as compared with untreated material. The loss of original dry matter from treated silage, as against untreated material, was reduced by 3 to 5 per cent. In view of this negligible reduction in loss, it was concluded that the use of sulphur dioxide as an additive was not justified.

In general, experiments have shown that immature herbage treated with sulphur dioxide shows a slight reduction in fermentation

within the silo. The limited information on the behaviour of sulphur dioxide in silage-making, however, suggests that the value of its commercial application remains uncertain.

Sodium Metabisulphite. Wittwer et al. (1955) and Murdoch (1955 a) reported that the application of sulphur dioxide to ensiled forage was difficult on a farm scale. As a result, a search was made for a salt which contained a high proportion of sulphur dioxide gas and was easy to handle. This led to the use of sodium metabisulphite as an additive in silage-making. In preliminary American studies, Cowan et al. (1952) applied sodium metabisulphite in a water solution to a variety of immature grass mixtures. The resultant silages were of excellent quality and in all cases superior to similar material ensiled without additives. These promising results encouraged the conduct of further trials by numerous workers in several countries.

In chemical studies, Alderman et al. (1954, 1955) showed that metabisulphite was effective in inhibiting fermentation in silages made from immature herbage. Their results indicated that the production of acetic and lactic acids by bacterial fermentation was limited and inversely correlated with the total residual sulphite concentration in the silage. Protein breakdown was inhibited to a satisfactory degree. Butyric acid production was almost eliminated despite pH values rather higher than normal. The mean pH value for metabisulphite-treated samples was 4.49. This value was well above the pH level of 4.0 as considered desirable by Watson (1939) and Virtanen (1947) for well preserved silage. However, Alderman et al. (1954, 1955) showed that a number of individual metabisulphite-treated samples at pH values of 4.8 and 4.9, were better preserved than silages with pH values approaching the desired level of 4.0. On the basis of these results,

Alderman et al. (1955) have suggested that silages treated with metabisulphite are preserved primarily by the action of the HSO_3^- ion instead of by the acidity or H^+ ion as is usual in other conventional types of silages. Similar findings have been reported by Gordon et al. (1954) and Bateman et al. (1954). All workers, however, do not agree that lactic acid fermentation is limited in silages treated with metabisulphite. Murdoch et al. (1956) reported no decrease in lactic fermentation when the salt was applied to immature herbage, at a rate of 8 - 9 pounds per ton of green herbage. Similar findings have been reported by Archibald (1954), Allen and Ward (1955) and Sears (1955, 1956). From all available evidence it can be concluded that the application of sodium metabisulphite to immature herbage inhibits protein breakdown and butyric acid production, but the degree to which lactic acid formation is permitted within the mass is uncertain.

It has been established that butyric acid formation and protein breakdown are decreased in silages treated with sodium metabisulphite. Under these conditions it is expected that bacterial activity will be suppressed and nutrient losses from the treated silages reduced. In preliminary bacteriological studies Anderson (1956) did observe that the total number of bacteria were considerably lower in metabisulphite-treated silage than in untreated material. No further bacteriological studies on metabisulphite-treated silages have been reported in the literature. Several workers, however, have recorded the nutrient losses occurring in metabisulphite-treated and untreated silages. Other workers have compared the use of metabisulphite with other methods of silage making. The results of their findings are summarized in Table V.

In studies reported by Cowan et al. (1953) and Bratzler et al. (1953, 1954, 1955, 1956) the treatment of immature material with metabisulphite, at the rates of 8 to 10.5 pounds per ton of green herbage, resulted in a marked saving in nutrients. This saving involved mainly the carbohydrate fraction of the silage. Bratzler et al. (1956) attributed this finding to its reduced fermentation within the silo. This view is supported by the results of Archibald (1954) and Alderman et al. (1955). The use of molasses and beet pulp as additives improved the quality of the silages but did not serve to reduce nutrient losses. In general, metabisulphite silages were markedly superior to both molasses and beet pulp treated silages and untreated silages in the following respects: better colour, less smell and higher carotene retention. In view of these findings and visual observations made on numerous field scale silos, containing material treated with the salt, it was concluded that sodium metabisulphite was a valuable additive for the preservation of immature herbage.

Gordon et al. (1954), using metabisulphite-treated and untreated immature herbage, reported a reduction in dry matter losses through application of the salt (Table V). In one trial, however, (Gordon et al. 1955) no difference in dry matter loss was obtained, but losses of sugar and crude protein were lower in the treated silage. Mature herbage was ensiled, a factor which may account for the results obtained. Cowan et al. (1953), in studies with mature material, reported similar results. This they attributed to oxidation of the metabisulphite in presence of excessive air entrapped in the ensiled material. In both trials, reported by Gordon et al., metabisulphite application resulted in a silage superior both in quality and carotene content to that

where no preservative was used.

Bateman et al. (1955 a) compared silages made from an immature lucerne and grass mixture treated with metabisulphite and dried molasses beet pulp. The latter treatment resulted in a marked reduction in dry matter loss (Table V). The application of metabisulphite, however, was effective in reducing fermentation losses within the silo. The difference in total dry matter losses between the two silages was due to a high drainage loss from the metabisulphite treated material. The trial, however, supported the view that application of metabisulphite to immature forage at ensiling time leads to a high quality silage and reduces carotene loss during storage.

Kennedy and Allred (1953) conducted seven separate silage experiments in small scale silos. Preservatives used in one or more experiments were: molasses, sugar, ground whole grains, brewers' dried grains, sulphur dioxide, and sodium metabisulphite. Only grains and sulphur dioxide consistently decreased the loss of original dry matter by as much as 3 to 5 per cent below that observed for the silage with no preservative. Grains reduced drainage losses and sulphur dioxide decreased fermentation. Additional studies were conducted over a period of two years in which silages were made in field scale tower silos. The treatments were as follows: molasses, dried brewers' grains, sodium metabisulphite, and no additive (Allred et al. 1955; Wittwer et al. 1955). Results showed that metabisulphite silage was superior in appearance to the other treatments and retained a higher percentage of carotene. Observed dry matter losses from metabisulphite-treated silages were only slightly less than those recorded for silages made by the use of other additives and untreated material (Table V). The authors concluded that the small saving

in nutrients which resulted from the use of these preservatives did not justify the high net cost of their addition.

In preliminary small scale trials in New Zealand, Sears (1955) applied sodium metabisulphite to an immature ryegrass-clover mixture at a rate of 10 pounds per ton of green herbage. Treated material showed a reduction of 15 per cent in dry matter loss over similar material ensiled without additive treatment (Table V). On appearance, smell and chemical composition there was a wide difference in favour of the metabisulphite-treated silage. All untreated silages showed excessive breakdown of plant tissue (fig.1) and contained high amounts of undesirable decomposition products. Metabisulphite silages, on the other hand, showed little breakdown of plant tissue (fig.2) and contained negligible amounts of undesirable decomposition products. In additional trials, conducted the following season, chopped immature material was ensiled in two 40-ton concrete silos (Sears 1956). The treatments were: no addition, and 10 pounds of sodium metabisulphite per ton of green forage. Weighings and calculations on the dry matter basis showed a dry matter loss of 7 per cent in favour of the treated material (Table V). Both silages were well preserved and readily consumed by stock. It was concluded that the reduction in nutrient losses obtained through use of the additive were sufficient to warrant further investigation.

Murdoch et al. (1956) have furnished results for five British trials in which metabisulphite was applied at varying rates of application to unchopped and chopped immature herbage. Nutrient losses were determined in three small scale trials only (Table V). With two exceptions, addition of the salt resulted in a well preserved silage, lowered the loss of nutrients and reduced undesirable fermentation. The exceptions were a small

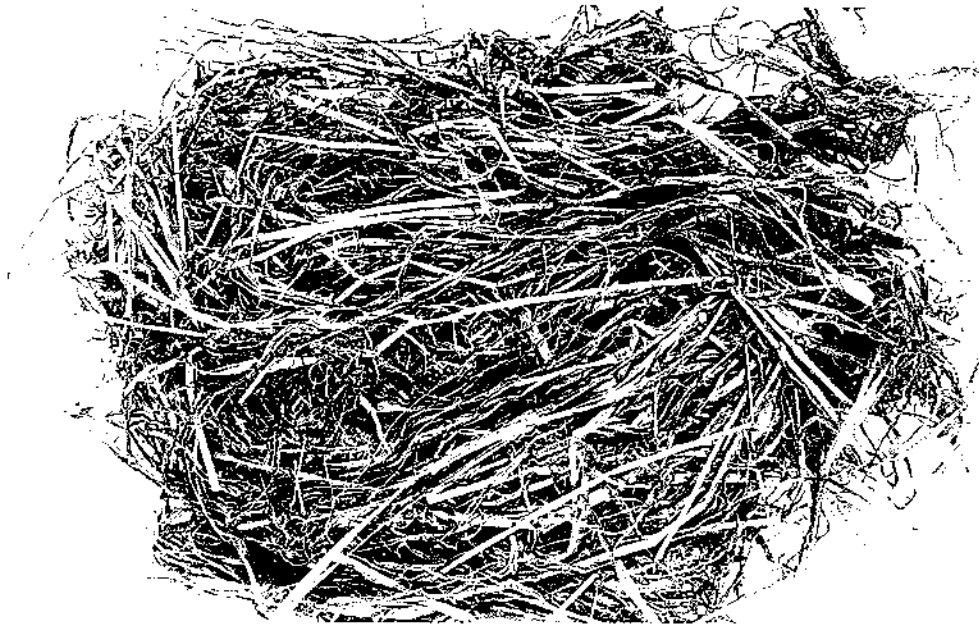


Figure 1

Sample of untreated grass silage.
(Sears, 1955)



Figure 2

Sample of grass silage treated with
sodium metabisulphite.

scale trial where the silage was inadequately protected from the weather and a field scale trial. Poor results obtained with metabisulphite in the former instance were attributed to penetration of rain water into a small quantity of silage, this resulting in a high loss of the additive in the effluent, thereby multiplying any advantage to be gained through its use. In the second instance, failure of the additive to improve the quality of the resultant silage was attributed to uneven distribution of the salt throughout the herbage and possible leaching which may have occurred within the silo.

The addition of metabisulphite at increasing rates from 9 - 16 pounds per ton of fresh herbage consistently decreased volatile acid and volatile base formation, but had little effect on lactic acid production. With the exception of the nitrogen-free extract, the difference between the losses in the untreated silage and the 9-pound application was greater than that between losses in the 9 pound and 16 pound treatments. The true protein loss was reduced when 9 pounds of metabisulphite were applied, but there was no further decrease with the 16 pounds per ton rate of application.

In two trials, reported by Murdoch et al. (1956), sodium metabisulphite was used in conjunction with another silage-making technique. In the first trial the ensiled herbage was chopped and 8 pounds of metabisulphite added per ton of green herbage. The resultant silage had a higher lactic acid content and lower volatile base content than silages produced from similar material ensiled without treatment and with the addition of 12 pounds of metabisulphite per ton of fresh herbage. In the second trial the material was wilted and 11 pounds of metabisulphite added per ton of herbage. The resultant silage was low in undesirable

decomposition products and on appearance and smell was considered to be well preserved. As no trial was conducted using wilted herbage untreated with metabisulphite it was not possible to separate the effect of the two treatments. The high quality of the final silage is of interest, however, since Cowan et al. (1953) and Alderman et al. (1955) have emphasized that the additive should not be used with wilted herbage. These workers maintain that metabisulphite may be oxidized by the excess air entrapped in wilted material and thus become ineffective in preservation of the crop.

As with all methods of silage-making there are difficulties in the use of sodium metabisulphite. Murdoch (1955 b) maintains that the major difficulty is ensuring that the salt is evenly distributed throughout the ensiled crop. The failure of metabisulphite to produce a good silage in one trial, reported by Murdoch et al. (1956), was attributed to uneven distribution of the salt. Distribution presents no problem where the powder can be applied mechanically, either by the forage harvester or by the blower at the silo. Under other systems of silage-making, Murdoch (1955 b) considers that, to obtain an intimate mixture of the salt and ensiled herbage, extra time and labour will be required - factors not readily available at silage-making time. Murdoch et al. (1956) also consider the possible leaching of metabisulphite as a further factor which may influence the use of the salt in practice.

In general, information available suggests that the addition of sodium metabisulphite to ensiled immature herbage, at a rate of 8 - 10 pounds per ton, results in a lowered loss of nutrients from the silage compared with untreated material. The reduction in nutrient losses from treated material arises from decreased

fermentation within the silo and falls mainly on the carbohydrate fraction of the silage. Several workers have also reported decreased crude protein losses from silages treated with metabisulphite. The additive may, therefore, be of considerable value in the ensilage of high protein material. In the majority of field scale trials reported, however, metabisulphite has been applied to chopped herbage. It has been shown that chopping of the herbage prior to ensiling may have a beneficial effect on the quality of silages made from immature herbage (Woodward and Shepherd 1958; Murdoch *et al.* 1955 b). This factor suggests the need for the conduct of further trials to compare the relative merits of silages made from unchopped herbage, untreated and metabisulphite-treated, before the salt can be recommended as a successful additive. Furthermore, it is not common practice to make silage from immature herbage without some form of treatment.

The limited number of trials conducted so far to compare the relative merits of sodium metabisulphite and other additives in silage-making, have produced conflicting results. Hence, further comparisons with other methods of silage-making will be necessary before the full value of metabisulphite as an additive can be assessed. For the success of the method in the field, a small quantity of metabisulphite must be distributed evenly throughout the ensiled material. Where large quantities of silage are made, speed is essential. With many systems of silage handling the proper use of metabisulphite may be difficult and hardly possible.

Miscellaneous Inorganic Salts. Various inorganic salt preparations have recently been subjected to experimentation as sterilizing agents in silage-making. Kofasalt, a mixture of calcium formate and sodium nitrite, has been used by Martin et al. (1955) in the ensilage of immature crops. Treated silages, compared with untreated material, showed less protein breakdown and reduced volatile acid formation. Nutrient losses of dry matter, crude protein and total carbohydrate were also lower in the treated silages. In further trials (Martin et al. 1955) the addition of Kofasalt to ensiled material resulted in a silage of similar quality to that obtained by the use of A.I.V. solution. These findings are supported by the results of Ulvelsi (1954) who evaluated the quality of silages made with A.I.V. solution, sulphur dioxide, Kofasalt and steamed potatoes. Treatment of the ensiled herbage with sulphur dioxide and steamed potatoes failed to produce satisfactory silages. The results of other workers, however, have shown Kofasalt to be inferior to A.I.V. solution in its effect upon silage preservation (Jensen et al. 1955; Anon. 1953).

Dijkstra (1954), using immature grass mixtures, found Kofasalt to have no favourable effect on the quality of the resultant silage. Nutrient losses were, in general, somewhat lower from silages treated with Kofasalt than untreated material. Differences, however, were not sufficient to recommend Kofasalt as a satisfactory ensiling mean. In trials conducted by Eriksson (1953), the effect of Kofasalt addition to immature lucerne at ensiling time was found to be most apparent when the crop was unwilted. Wilted material was little improved by the addition of the salt. Axelsson et al. (1955) also found wilted silage to be of similar quality to that produced by application

of Kofasalt. In additional trials (Axelsson et al. 1955) Kofasalt was added to red clover. The resultant silages gave a dry matter loss comparable to where molasses was used.

Sovilon (halogenated acetate of glycol) has been used experimentally to produce partial sterilization of ensiled material. Barnett (1955) showed the addition of Sovilon to be effective in reducing volatile acid formation in grass slurries. Murdoch et al. (1956) compared silages made with and without addition of Sovilon in a small scale field trial. Addition of the salt reduced volatile base formation and lactic acid production. Both treated and untreated silages, however, contained appreciable amounts of volatile acids. A slight reduction in dry matter losses was obtained in favour of the treated silage. This difference in nutrient losses was most marked in the carbohydrate and true protein fractions of the silage. In an additional trial, in which Sovilon was applied at varying rates of application to the ensiled herbage, results of a similar nature were obtained (Murdoch et al. 1956). Even at application rates higher than the recommended level (100 g./ton green material) the salt failed to markedly reduce nutrient losses occurring within the silo.

Sodium formate (Ensilan) and a variety of formate compounds have recently been used as additives in silage experimentation. Axelsson et al. (1953), in lucerne silage studies, reported no improvement in the quality of the resultant silage nor reduction in nutrient losses following the application of Ensilan to immature herbage. That formate compounds have no favourable influence in reducing nutrient losses and little effect in improving the quality of silage, made from immature herbage, is confirmed by the studies of Dijkstra (1954), Jensen et al. (1955)

and Anon. (1953).

In general, it may be concluded that there is some improvement in the preservation of silage following addition of Kofasalt. Evidence available, however, is insufficient to justify the use of Kofasalt as an additive on a farm scale. From limited data available on the use of formate compounds and Sovilon, as additives in silage-making, it would appear that both are inferior to other recommended silage-making techniques.

3. The Digestibility and Palatability of Additive Treated Silage

(a) Digestibility

Most farm grown foodstuffs are fed to livestock mainly at the stage of maturity. As a result, they show fairly constant chemical composition and digestibility and thus may be classified with a certain degree of accuracy. Silages, on the other hand, differ widely in physical and chemical properties. These differences are dependent upon the nature and stage of growth of the ensiled material and changes which occur in the mass during the ensilage process. Individual digestibility determinations are, therefore, essential to an accurate evaluation of their feeding value.

Watson (1939) and Monroe et al. (1946) maintain that the digestibility of the various feed constituents in well made silage and the original material are of a similar order. Where large decreases in digestibility occur, following ensiling, other than in the true protein fraction, Watson (1939) considers that the method of making is at fault. Watson and Ferguson (1937) compared the digestibility coefficients of fresh herbage and the resultant silages made without treatment in towers and

pits. Their results showed no decline in the digestibility of the dry matter, organic matter, crude protein and crude fibre fractions of the material as a result of ensiling. The ether extract fraction was more digestible in the silage than in the original material. The latter result was attributed to the greatly increased content of soluble organic acids formed during the ensilage process. The true protein and nitrogen-free extract fractions were both less digestible in the silages. The reduction in digestibility in the former case was attributed to the breakdown of true protein in the process, and in the latter to losses, as occur in the process, falling on the more digestible and hence readily fermentable fraction of the ensiled material. That the digestibility coefficients of the nutrients in well made pit and tower silage are little if at all inferior to those of the original crop, has been confirmed by the studies of several workers (Woodman 1922; Drew et al. 1938; French 1939).

In stack silage, very large differences in digestibility between the fresh crop and resultant silage often occur (Watson 1939). Watson and Horton (1936 b) compared the digestibility coefficients of the individual feed constituents in stack and tower silages made from similar herbage. A marked reduction in digestibility of the crude protein, nitrogen-free extract and crude fibre fractions occurred within the stack. Lower digestibility values recorded for stack silage were attributed by Watson and Horton (1936 b) to be due to the occurrence of high temperatures within the mass, a condition arising from extreme respiration of plant tissue. The undesirable effect of high temperature on the digestibility of the crude protein fraction in silage has been reported by numerous workers (Woodman 1925; Knott et al. 1935; Watson and Ferguson 1937; Dijkstra 1948). Hodgson

and Knott (1937) have shown, however, that the ensiling of material in stacks need not greatly depress the digestibility of the nutrients, provided care is taken in the field. Over a period of three years, similar digestibility coefficients were obtained for silages made in stacks and pits. In these investigations the stacks were weighted and sealed with earth, factors which would tend to prevent excessive heating within the mass.

Numerous workers have investigated the effect of additives on the digestibility of the nutrients in the resultant silages. Watson and Horton (1936 b), Watson and Ferguson (1937), Drew *et al.* (1938), King (1942, 1943), Monroe *et al.* (1946) and Bailey *et al.* (1955) found the addition of molasses, whey, cereal grains and mineral acids to have no marked effect on the digestibility of the dry matter in the resultant silages. Davies *et al.* (1937) and Axelsson (1952), however, reported that the addition of molasses or mineral acids to ensiled forage increased the digestibility of the final product. In trials conducted by the former worker, the order of digestibility, based on dry matter content, placed ordinary silage lowest (60.3%), molasses silage intermediate (64.3%) and acidified silage highest (68.0%). Corresponding figures for the digestibility coefficients of the crude protein fraction were given as 62.2, 62.1 and 72.1 per cent respectively. Watson (1939) and Newlander *et al.* (1940) have also reported an improved crude protein digestibility following application of mineral acids to the ensiled crop.

In recent trials, Gowan *et al.* (1953) found silage treated with sodium metabisulphite to be slightly higher than untreated silage in digestibility of the dry matter. The coefficients of digestibility were given as 66.5 and 64.8 per cent for

metabisulphite-treated and untreated grass silages respectively. Corresponding values for silages made from lucerne-grass mixtures were given as 71.3 and 65.5 per cent for the treatments listed. The addition of molasses resulted in silages of similar dry matter digestibility to those obtained following application of metabisulphite. Woolfolk et al. (1954) compared the digestibility coefficients of grass silages made with molasses, sulphur dioxide and sodium metabisulphite. The coefficients of digestibility for the dry matter were given as 61.0, 61.2 and 66.8 per cent for molasses, sulphur dioxide and metabisulphite treated silages respectively. The difference in dry matter digestibility in favour of sodium metabisulphite over the other two treatments was found to be highly significant. No significant differences were shown to exist between the three treatments in the digestibility of the crude protein fraction.

Bratzler et al. (1956) found the addition of metabisulphite to an immature mixture of red clover and lucerne to have little effect on the digestibility of the feed constituents in the resultant silage. Treatment of the ensiled material with molasses, on the other hand, increased the digestibility of the silage dry matter by 6 per cent but had no effect upon the digestibility of the crude protein fraction. Gordon et al. (1954), who treated an immature grass-legume mixture with metabisulphite and used untreated material as a control, also obtained no difference in the digestibility of the dry matter of the two silages. Wittwer et al. (1955) determined the dry matter digestibility coefficients of silages made from immature herbage treated with molasses, dried brewers' grains and sodium metabisulphite. Material ensiled without preservative addition served as a control. The digestibility of silage dry matter was given as 63.0, 64.4, 63.6

and 64.7 per cent for the silages made with molasses, brewers' dried grains, no preservative and sodium metabisulphite respectively.

Few trials have been conducted to determine the effect of addition of Kofasalt and formate compounds on the digestibility of the resultant silages. From limited information available, it would appear that these additives have little or no effect on the digestibility of the dry matter (Ulvelsi 1954; Gordon et al. 1954; Martin et al. 1955; Dijkstra 1954).

In general, although several workers have increased the digestibility of silages made from immature crops by the application of additives, the effect of the treatment has in most cases been small. It may, therefore, be concluded that, when silages are made from immature materials, provided satisfactory silage-making methods are followed, the use of additives has no major effect on the digestibility of the resultant silages.

(b) Palatability

Derivation of the term palatability implies a near relationship to the sense of taste. Where the word is used in human and animal dietetics, however, a considerably wider meaning is intended. Tribe (1950) considers that, in human and animal dietetics, the adjective "palatable" may be taken as the nutritional synonym of the word "attractive" and the palatability of a foodstuff as the sum of the factors which operate to determine whether and to what degree the food is attractive to the animal. In experimental practice, the assessment of palatability is based on two main methods. Both methods have been outlined by Jones (1952). In one, the animals have access to only one type of food and in the other, access is given to more than one type. The

former method is used to indicate the palatability group to which a particular food belongs, the latter to differentiate feeds within a group.

Watson (1950) considers well preserved silage to be a palatable, succulent and safe food for all classes of livestock. Confirmation of this view, with reference to dairy cattle, is provided by the results of numerous trials in which large amounts of silage have been fed successfully as the sole constituent of the ration. At the Rowett Research Institute, Ayrshire cows, producing 50 to 60 pounds of milk daily, consumed up to 150 pounds of silage per head per day as a sole feed. Throughout the trial period this high level of production and herd health were maintained (Watson 1950). At Jeallot's Hill research station, dairy cows were observed by Watson (1939) to consume up to 80 pounds of high protein silage daily with satisfactory results.

Variation in the relative palatability of well preserved silages made from the same crop can occur. Westover (1934) maintains that this variation is largely dependent upon the stage of maturity of the crop when ensiled. Bender et al. (1936) and Westover (1934) both found that immature herbage made more palatable silage than similar material cut at an advanced stage of maturity. Watson (1939) considers that the type of fermentation undergone in the silo may also have a marked effect on the palatability of the resultant product. He stated that silage which has undergone excessive heating is always eaten more readily than a normal silage. Graves (1929) has reported that silage exhibiting excessive undesirable fermentation may be unpalatable to stock.

Numerous studies have been conducted in which the relative palatability of silages made with and without additives has been compared. A review of the literature indicates that the addition of molasses or grains to the crop at ensiling time improves the palatability of the resultant silages (Reed and Fitch 1917; Watson 1939; Woodward et al. 1939; Waugh et al. 1943; Rupel 1944; King 1945; Axelsson 1952). Studies conducted to determine the effect of direct acidification on the palatability of the resultant silages, have produced conflicting results. Bohstedt et al. (1937), in feeding trials with dairy cattle, found the addition of A.I.V. solution to lucerne to be ineffective in improving the palatability of the resultant silage. In additional trials (Bohstedt et al. 1937), silages treated with A.I.V. solution and molasses were found to be equally palatable. Hegsted et al. (1939) also reported no difference in palatability between silages treated with molasses and A.I.V. solution. Johnson et al. (1940), who compared silages made with molasses and phosphoric acid, could not detect any difference in palatability between the treatments. This result is in agreement with the findings of Lepard and Savage (1941) and Archibald and Parsons (1940). King (1943), on the other hand, found molassed silage to be superior in palatability to that treated with phosphoric acid. Isolated reports have also appeared in the literature condemning the use of mineral acids in silage-making on the grounds that silage produced by their addition is unpalatable to stock (Woodward et al. 1942; Monroe et al. 1946; Sears and Goodall 1947). Watson (1939) maintains that the unpalatability of mineral acid silages is not common in practice and only occurs at high acidities.

In recent studies, the relative palatability of silages treated with sulphur dioxide and sodium metabisulphite has been ascertained. The treated silages have been compared with untreated material and silages made with other additives. Knott (1950) conducted feeding trials with silage treated with sulphur dioxide. The gas was applied to the ensiled crop at a rate of 5 pounds per ton of green herbage. He obtained no indication that palatability was a problem. In one experiment, dairy cows consumed in excess of 80 pounds of sulphur dioxide treated silage daily without any harmful effects. Data from Beltsville research centre, however, indicated that application rates of sulphur dioxide exceeding 6 pounds per ton of fresh herbage, tended to decrease the palatability of the resultant silages for dairy cows (Report 1950). Teere et al. (1953) determined the effect of sulphur dioxide treated silage on the vitamin synthesis in the digestive tract of ruminants. Sulphur dioxide was shown to destroy the greater proportion of thiamine present in the silage. It was claimed, however, that the ingestion of silage treated with sulphur dioxide promoted suitable conditions within the rumen for the synthesis of thiamine.

Dufour et al. (1954) compared the relative palatability of silages untreated and treated with sulphur dioxide at an application rate of 5 pounds of the gas per ton of herbage. They found no apparent difference in palatability between the two treatments. When fed to dairy stock, the daily consumption of both silages averaged 65 pounds per head. In a trial conducted by Knott (1950), cows given a free choice of silages treated with sulphur dioxide and honey, almost without exception consumed sulphur dioxide treated material.

Cowan et al. (1953) have commented on the superior

palatability of metabisulphite-treated silages over silages made without additives. In an 8-day palatability trial, 15 two-year old heifers recorded an average daily intake of 63 pounds of metabisulphite-treated silage and 18 pounds of silage made without additives. Gordon et al. (1953), Little (1954) and Bratzler et al. (1956) have also reported the preference of dairy stock for silage treated with metabisulphite, when given a free choice of silages untreated and treated with the salt.

In feeding trials with dairy cattle Bateman et al. (1955 b) found lucerne silage preserved with dried molasses beet pulp to be more palatable than similar material treated with sodium metabisulphite. Animals fed molasses beet pulp silage consumed, on the average, 70 pounds of fresh silage per head daily as against 56 pounds for animals fed metabisulphite silage. The results of Wittwer et al. (1955) have also shown metabisulphite silage to be inferior in palatability to silages made by the use of other additives and silage made without additives. Dairy cows, when given a free choice of untreated silage and silages treated with molasses, dried brewers' grains and sodium metabisulphite, showed a distinct preference for the molasses treated silage. Low intakes of metabisulphite silage recorded in the trials were attributed in part to the poor keeping quality of the product after removal from the silo.

Bratzler et al. (1955, 1956) compared the relative palatability of grass silages made with sulphur dioxide and sodium metabisulphite. In one free choice palatability trial, dairy heifers consumed an average of 58 pounds of metabisulphite-treated silage daily and 16 pounds of similar material treated with sulphur dioxide. In a second trial, metabisulphite silage was preferred to about the

same degree over excellent quality sulphur dioxide treated silage.

From limited information available on the use of Kofasalt and formate compounds in silage-making it would appear that the resultant silages are palatable (Jean-Blain 1954; Martin *et al.* 1953, 1955). Their relative palatability in comparison with silages made by other processes, however, still remains to be determined. The majority of comparative trials conducted so far have been on too small a scale to permit feeding of the silages to livestock.

In general, it may be concluded that, relative to other livestock feeding stuffs, well made grass silage is a palatable food. Free choice palatability trials conducted to compare the relative palatability of silages untreated and treated with additives, have produced conflicting results. The variable results obtained are difficult to assess, as no worker has subjected his results to statistical treatment. Furthermore, few workers, who observed intake differences in favour of any one silage, have recorded the intakes of the same animals when their choice was restricted to one silage. Witter *et al.* (1955) reported a preference for molasses silage when cows were given a free choice of silages treated with metabisulphite, molasses and dried brewers' grains respectively. In a further trial, when the same animals were given a full ration of metabisulphite-treated silage as a sole feed, the total amount consumed was similar to that recorded for the molasses silage in the previous trial. As palatability is important in animal nutrition only in the sense that it determines intake, the results of the above worker would suggest that free choice palatability tests tend to overemphasize the feeding value of a particular silage relative to the other silages offered the animals.

CHAPTER III

PRELIMINARY INVESTIGATIONS INTO THE USE OF SODIUM METABISULPHITE AS AN ADDITIVE IN SILAGE-MAKING

During the 1954-55 season a 20 ton lot of herbage, ensiled in an unlined pit on the Massey College dairy farm, was treated with sodium metabisulphite. The material was cut at an advanced stage of maturity in late November 1954, from a permanent pasture composed mainly of perennial ryegrass with some white clover and small amounts of rough-stalked meadow grass and Yorkshire fog. Sodium metabisulphite was applied to the swathe as a water spray at an application rate of 6 pounds per ton of green material. Treated herbage was thereafter picked up by the forage harvester, chopped into 4 - 6 inch lengths and transferred to an accompanying truck for transport to an unlined pit of dimensions 100' x 13' x 4.5'.

All treated material was ensiled during the first day and so placed within the pit that it formed a complete section of dimensions 20' x 13' x 4.5'. The remaining section (80' x 13' x 4.5') was subsequently filled over a 6-day period with 80 tons of similar herbage. The herbage was chopped but not treated with metabisulphite. Consolidation was obtained by rolling the ensiled material with a tractor during the ensiling process. Lengths of twine, extending from the base to the surface of the pit and spaced at regular intervals across its breadth, were placed in position between the two treatments to serve as a line of demarcation. Sealing was effected by having the pit well crowned and rolling the surface with a tractor on the day following completion of filling, a practice normally employed on the farm.

The resultant silages formed the experimental material for a preliminary investigation, the objectives of which were twofold:

1. To study the chemical composition of both silages for constituents providing information on the nature of the fermentation undergone during the storage period.
2. To estimate and compare the nutritive value of the silages on the basis of their chemical composition, digestibility and relative palatability.

The experimental work undertaken is presented in three sections: the first deals with the chemical composition of the silages; the second with their relative palatability; and the final section with their digestibility and feeding value.

A. THE CHEMICAL COMPOSITION OF THE SILAGES

To ascertain the nature of the fermentation undergone by the untreated and treated silages, samples were analysed for lactic acid, butyric acid and propionic acid contents and pH values were determined. Dry matter and carotene values were further determined and, in the case of treated material, residual sulphite.

Experimental Procedure

Description and Layout of Experimental Design

Silage can be a very variable product and no single sample is adequate for an accurate estimate of the material within the container. Consequently, 12 samples were taken at each of two depths for each silage, according to a restricted randomization block design (Cochran and Cox 1955, pp.94 et sqq.).

An area 6' x 12', marked out upon the surface of each silage

at an identical distance from each end of the pit, was subdivided into 6 blocks, each 4' x 3'. From the total depth of each silage (54") the upper 18" layer, consisting mainly of spoilage, and the lower 12" layer, were excluded, the remaining 24" in depth being divided into two equal layers. Within each block four sample points were selected from a table of random numbers, such that two samples were located in the upper and two in the lower layer. Their position in the pit was marked by driving in wooden pegs to the appropriate randomly selected depths (figs. 3, 3a, 4, 4a).

Sampling Procedure

Both ends of the pit were opened on the 31st May 1955 (177 days after the completion of filling), the two silages being fed out to the College dairy herd and experimental animals. On reaching a sample point in the feeding out process an 8" cube of silage was removed for analysis, the tip of the marker peg serving as the mid-point of the cube. A sharp knife was found to be satisfactory for removal of the samples.

Sampling was conducted over a 12-day period (16 - 18th July), the emptying of the pit being so regulated that identical samples in both treatments were obtained on the same day. Each sample, following removal from the pit, was thoroughly mixed and representative sub-samples transferred to sealed glass jars, the number of sub-samples taken being dependent upon the constituents to be determined.

Dry matter and pH determinations were conducted on all 24 samples from each silage. For volatile acid, non-volatile acid, residual sulphite and carotene, blocks 1 and 2, 3 and 4, 5 and 6 were considered as three blocks A, B and C respectively. Within

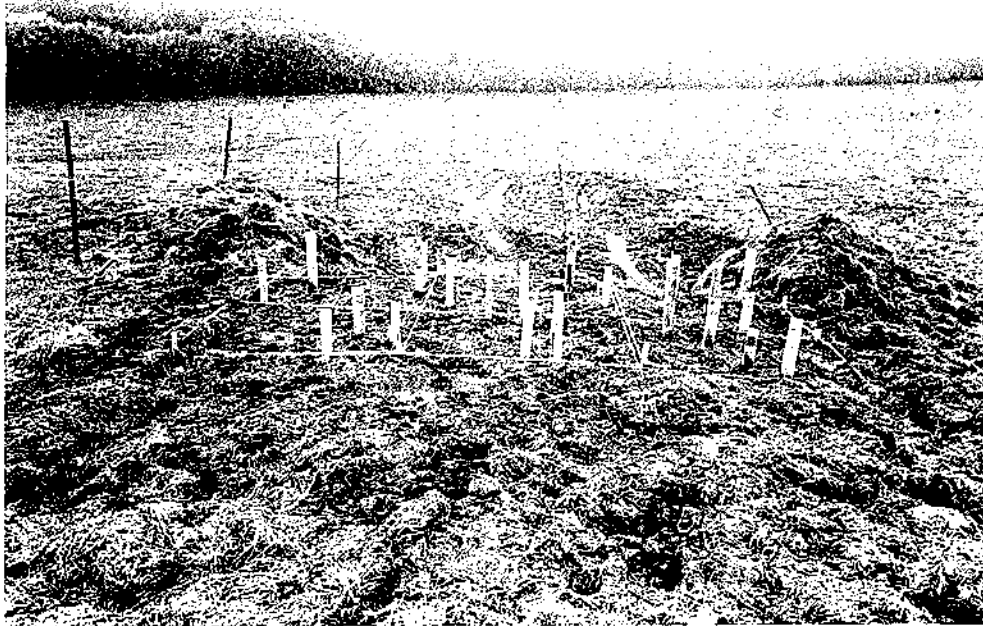


Figure 3

Layout of randomized block design for sampling the untreated silage.

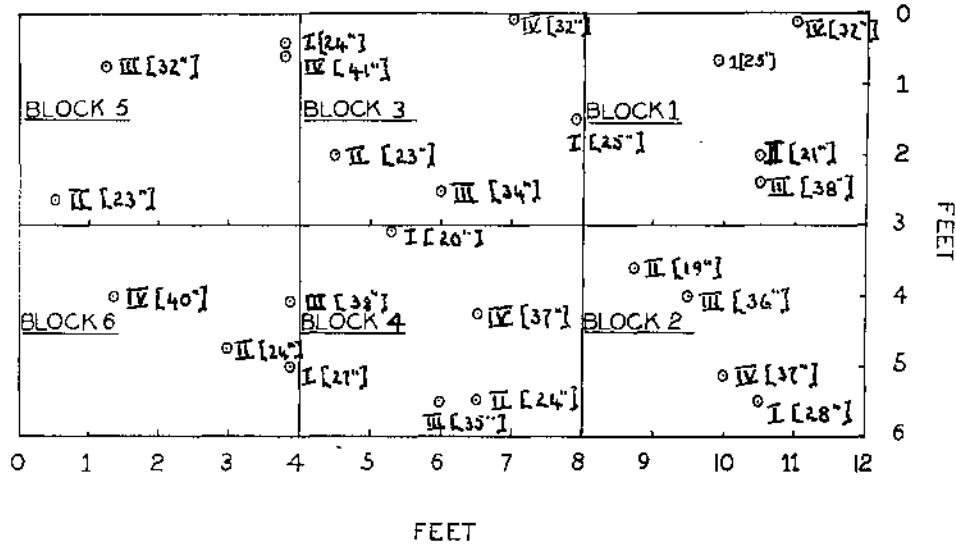


Figure 3a

Scale diagram representing the top surface of the block design on the untreated silage and indicating the location of sample points. Sample numbers and depths at which they were taken are indicated alongside.

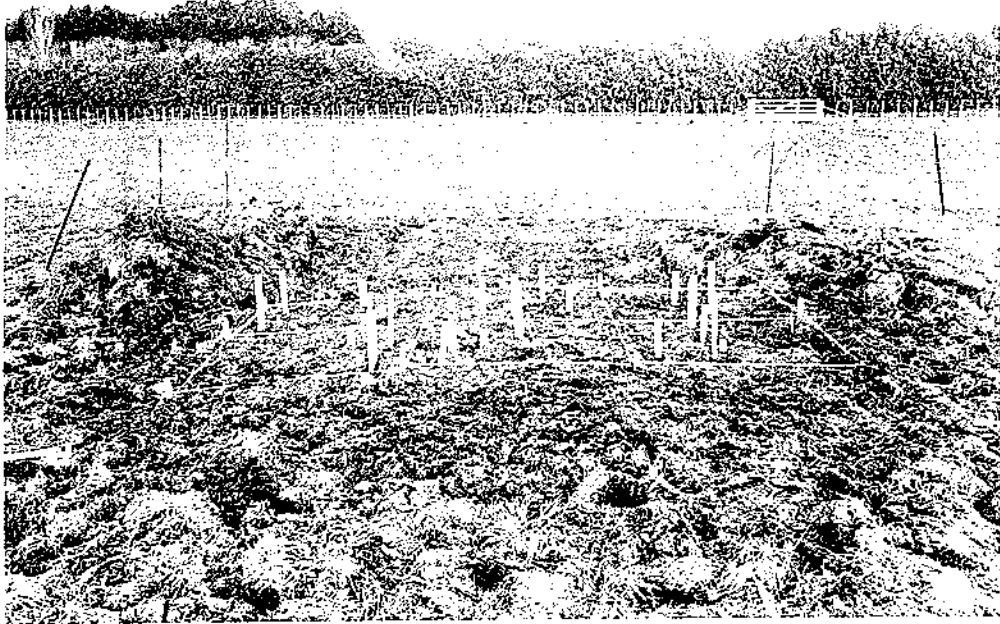


Figure 4

Layout of randomized block design for sampling the treated silage.

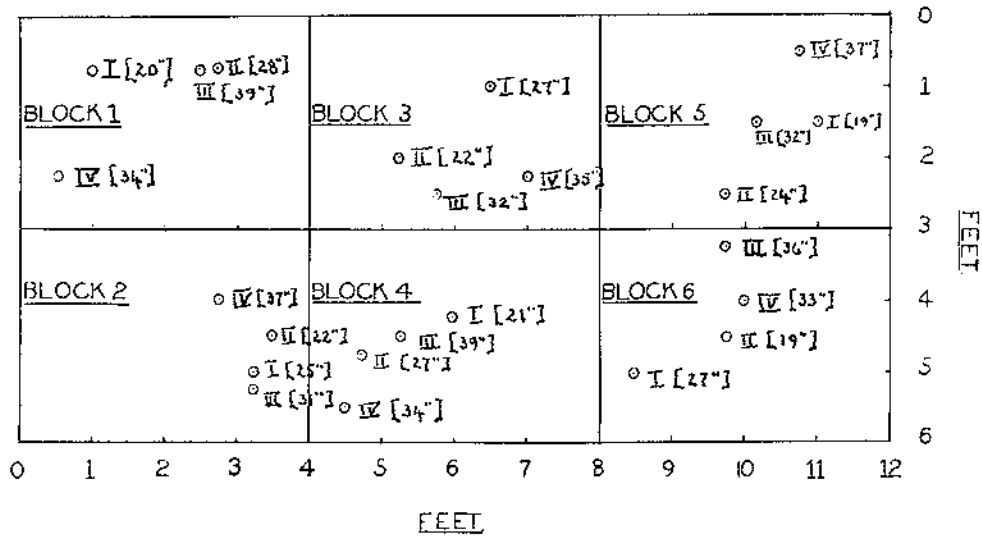


Figure 4a

Scale diagram representing the top surface of the block design on the treated silage and indicating the location of sample points. Sample numbers and depths at which they were taken are indicated alongside.

each of the latter, four sample points were present in each layer. One sample point was selected at random from each group of four for volatile and non-volatile acid determinations, giving a total of 6 samples per treatment. Two samples within each layer were similarly obtained for residual sulphite and carotene analysis, giving a total of twelve samples per treatment for each constituent.

The various analyses to which each sample was subjected are shown in Appendices I and II, for untreated and treated material respectively. Dry matter, pH and residual sulphite values were obtained for all sub-samples within two hours after their removal from the pit, while material for carotene, volatile and non-volatile acid estimations was stored in a deep-freeze cabinet and analysed at a later date. All analytical values were subjected to the Analysis of Variance Test, according to Snedecor (1955, pp.214 et seq.).

Analytical Methods

All chemical determinations were conducted on fresh laboratory samples of the silages drawn from well mixed field sub-samples.

Dry Matter Content. Two laboratory samples of 250 g. each were placed in metal trays and dried in an oven of the forced draught type at a temperature of 150°F. All samples were removed after 10 hours, allowed to cool to constant-moisture content, and weighed. No correction was made for any possible loss of volatile material which may have occurred during the drying process.

pH Value. A 100 g. sample was boiled for 5 minutes with 100 g. of distilled water and the decanted liquid cooled to room temperature. Determinations were made on the resultant water extract using a Macbeth pH meter with a glass electrode. A check on the method was conducted by extracting each sample in a press and determining

the pH on the juice obtained. As both methods gave identical results, the latter was discontinued.

Carotene Content. All determinations were made on finely chopped 5 g. laboratory samples, according to a method of Worker (1957).

Non-volatile Organic Acids. The main acid in this group, namely lactic acid, was estimated by the technique of Barker and Summerson (1941), as modified for silage by Barnett (1951a).

Volatile Organic Acids. Volatile fatty acids were determined according to the technique of James and Martin (1952), a method which permits of the separation of the individual acids. In the present investigation a measure of total volatile acidity in terms of butyric, acetic and propionic acids was obtained for each sample.

Residual Sulphite. Total sulphite (free and combined) remaining in the treated silage was estimated using an adaption of a method proposed by Barnett (1951b). To a mixture of 2 ml. $\frac{N}{10}$ iodine solution diluted with 10 ml. water, was added 1 ml. of treated silage juice, obtained by extraction of the sample in a press. Excess iodine was titrated against $\frac{N}{10}$ sodium thiosulphate solution, using starch indicator. The thiosulphate solution was re-standardized against the iodine daily and results corrected for small blanks obtainable by using extracted juice from sub-samples of untreated silage. Results were expressed in p.p.m. total residual sulphite, through the use of previously determined moisture contents for each sample.

Experimental Results

General Description of the Silages

The top spoilage layer in both silages tended to be very variable in magnitude and in sections of the pit penetrated deeply

into the underlying material. This high wastage resulted from water penetration into the mass following damage to the surface seal by the dairy herd, which broke through the surrounding fence early in the storage period.

Observations made on the colour, smell and appearance of the silages below the spoilage layer failed to detect any marked differences between them. Both silages were light brown in colour and had a strong and sweet acid smell. No sample within this layer showed any obvious smell of butyric acid or evidence of overheating. A faint colour difference, however, was detected between the treatments in the lower 18" layer of silage, treated material showing a gradual gradation to a greenish-yellow colour, while untreated material retained its uniform light brown colour.

In both silages the original material could easily be identified and, as is evident from figs. 5 and 6, which show representative samples of the two silages, there was no marked breakdown of plant tissue. The stemmy nature of the material is further illustrated.

In general, both treatments, on the basis of appearance, colour and smell, were considered as typical examples of the type of silage produced from chopped and well consolidated herbage ensiled at an advanced stage of maturity without preservative treatment.

Chemical Composition of the Silages

Dry Matter and Acidity. The mean treatment, layer and block values for the dry matter content, and pH of the two silages, are shown in Table VI. Individual determinations, made on all 24 samples selected at random within each treatment, are given in Appendices I and II for untreated and treated material respectively.



Figure 5

Sample of untreated grass silage.



Figure 6

Sample of metabisulphite-treated grass silage.

Table VI

Mean Treatment, Depth and Block Values
of the Dry Matter Content and pH
Value of the Silages

(a) Dry Matter Percentage
(air dry basis)

Depths Blocks	Untreated Silage			Metabisulphite-Treated Silage		
	Upper	Lower	Both	Upper	Lower	Both
1	14.50	15.70	15.10	16.90	19.10	18.00
2	14.60	16.55	15.57	17.80	19.20	18.50
3	16.30	17.55	16.92	20.50	19.60	20.05
4	14.35	18.85	16.60	18.90	19.55	19.22
5	16.70	17.30	17.00	17.70	19.55	18.02
6	16.40	21.05	18.72	14.95	18.75	16.85
All	15.47	17.83	16.65	17.79	19.29	18.54

(b) pH Value

Depths Blocks	Upper	Lower	Both	Upper	Lower	Both
	1	4.70	5.20	4.95	4.30	4.25
2	5.20	4.25	4.73	4.70	4.20	4.45
3	4.90	4.00	4.45	4.80	4.40	4.60
4	5.30	4.10	4.70	4.15	3.90	4.03
5	4.80	4.90	4.85	4.00	4.90	4.45
6	5.30	4.40	4.85	5.20	4.65	4.93
All	5.03	4.47	4.75	4.52	4.37	4.45

Differences between the mean values were tested by Analysis of Variance and the results presented in Table VII. There was a

Table VII

Analysis of Variance of the Mean Dry Matter and pH Values of the Silages

Source of Variation	Degrees of Freedom	Dry Matter Content			pH Value		
		Mean Square	F	Result	Mean Square	F	Result
Silages	1	42.75	10.17	**	1.021	3.21	N.S.
Depths	1	44.66	10.63	**	1.541	4.85	*
Silage X Depths	1	2.21	< 1	N.S.	0.568	1.79	N.S.
Blocks within Silages within Depths	20	4.20			0.318	2.63	*
Samples within Blocks	24	6.07			0.121		
Coefficient of Variation			14.1			7.2	

** Highly Significant ($p < 0.01$)

* Significant ($p < 0.05 > 0.01$)

N.S. Not Significant ($p > 0.05$)

highly significant difference between the mean dry matter values of $16.65 \pm 0.42\%$ and $18.54 \pm 0.42\%$ recorded for the untreated and treated silages respectively. As no dry matter input and output data were available for the silages, however, it was not possible to ascertain if more dry matter was retained in the treated material. Within each treatment the dry matter differences between the depth means were also highly significant. The dry matter content of each silage increased with depth, the increase showing a similar trend in both treatments. Visual examination

of the individual samples seemed to suggest the penetration of water as the causal factor for the lower dry matter values in the upper layers. No significant differences could be demonstrated between the mean dry matter values for the blocks at any one depth in each silage. The dry matter content of the middle portion of each silage was of similar magnitude to that in the outer portions of the pit.

No significant difference was found for the mean pH values of 4.75 ± 0.12 and 4.45 ± 0.12 which were recorded for the untreated and treated silages respectively. Both mean values were well above the desired pH level of 4.0, while several samples in each silage showed values in excess of 5.0. Within each silage, however, there was a significant difference between the mean depth values, the pH of each silage decreasing with depth. In both treatments the fall in pH value with increasing depth was of similar magnitude. No significant differences could be demonstrated for the pH values of the three blocks at any one depth within each silage.

Carotene Content. The mean treatment depth and block values of the carotene content of the two silages are presented in Table VIII. Individual values for the 12 samples analysed within each silage are shown in Appendices I and II.

Treatment with metabisulphite did not result in a higher retention of carotene within the silage. The mean values obtained for the untreated and treated silages were 2.29 ± 0.18 and 2.01 ± 0.18 μg carotene per 100 g. of fresh silage. The difference between the treatment means was small and not significant (Table IX).

Within each silage no significant differences could be demonstrated for the mean carotene contents of the material in the

upper and lower depths nor for the blocks at any one depth.

Table VIII

Mean Treatment, Depth and Block Values of the Carotene Content of the Silages
(mgm. carotene/100 g. fresh silage)

Depths Blocks	Untreated Silage			Metabisulphite-Treated Silage		
	Upper	Lower	Both	Upper	Lower	Both
A	2.15	1.65	1.90	1.55	1.80	1.68
B	2.10	2.90	2.50	1.65	2.30	1.98
C	2.05	2.90	2.47	2.20	2.55	2.38
All	2.10	2.48	2.29	1.80	2.22	2.01

Table IX

Analysis of Variance of the Mean Carotene Values of the Silages

Source	S.S.	d.f.	M.S.	F	F required		Result
					5%	1%	
Silages	0.482	1	0.482	1.22	5.32	11.26	N.S.
Depths	0.960	1	0.960	2.42	"	"	N.S.
Silages X Depths	0.001	1	0.001	< 1	"	"	N.S.
Blocks within Silages within Depths	3.167	8	0.396				
Samples within Blocks	5.770	12	0.481				
Total	10.380	23					
Coefficient of Variation				32.3			

N.S. Not Significant ($p > 0.05$)

Residual Sulphite Concentration. Mean values for the total residual sulphite (free and combined) in the treated silage at the termination of the storage period are presented in Table X. Individual values for the 12 samples analysed are shown in Appendices I and II.

Table X

Mean Depth and Block Values of the Residual Sulphite Concentration (free and combined) of the Treated Silage

(p.p.m. of fresh silage)

Blocks Depths	A	B	C	All
Upper	361	354	410	375
Lower	540	635	774	649
Both	450	494	592	512

Total residual sulphite was found to average 512 ± 49.6 p.p.m. in the fresh silage with a fairly wide variation about this mean.

The difference in residual sulphite concentration between the depth means was shown to be significant. The means and their standard errors were 375 ± 50 p.p.m. and 650 ± 50 p.p.m. in the fresh silage for the upper and lower layers of the pit respectively. As sodium metabisulphite is water soluble, the increase in concentration of the salt with depth probably resulted from a leaching effect within the pit. The fact that no significant differences in residual sulphite values were found for the block means at any one depth (Table XI) supports this view.

Table XI

Analysis of Variance of Residual Sulphite
Concentration of Treated Silage

Source	S.S.	d.f.	M.S.	F	F required		Result
					5%	1%	
Depths	226,326	1	226,326	15.31	7.71	21.20	*
Blocks within Depths	59,125	4	14,781	1.21	4.53	9.15	N.S.
Samples within Blocks within Depths	73,596	6	12,266				
Total	359,047	11					
Coefficient of Variation				21.6			

*Significant ($p < 0.05 > 0.01$)

N.S. Not Significant ($p > 0.05$)

Organic Acid Content. The mean organic acid values of the two silages, expressed in terms of acetic, butyric, propionic and lactic acids, are presented in Table XII. Individual values,

Table XII

Mean Organic Acid Content of the Silages
(individual acids as % fresh silage)

Individual Acids Treatments	Acetic Acid	Butyric Acid	Propionic Acid	Lactic Acid
Untreated Silage	0.29	0.19	0.07	0.46
Metabisulphite- Treated Silage	0.42	0.16	0.07	0.47

determined on 6 samples within each treatment, are shown in Appendices I and II for the untreated and treated silage respectively.

Moderate amounts of volatile fatty acids were present in the two silages. Analysis of the fatty acid mixtures in terms of acetic, butyric and proprionic acids showed that the former was always present in greater amounts. Although treated silage had a lower butyric acid and a higher acetic acid content, the differences between the treatment means were small and not significant (Table XIII). Both silages contained traces of proprionic acid, a characteristic of poor quality silage.

Table XIII

Analysis of Variance of Mean Butyric and Acetic Acid Contents of the Silages

Source of Variation	Degrees of Freedom	Butyric Acid			Acetic Acid		
		Mean Square	F	Result	Mean Square	F	Result
Total	11						
Between Silages	1	.0019	< 1	N.S.	.05	3.57	N.S.
Within Silages	10	.0080			.014		

N.S. Not Significant ($p > 0.05$)

There was obviously no significant difference between the mean lactic acid contents of the two silages. The mean treatment values were less than one-half the value of 1 - 2 per cent lactic acid, considered as desirable for the successful preservation of silage (see review p. 8). An examination of individual values further revealed that no one sample in either silage reached the desired pH level of 4.0.

In Table XIV the average non-volatile and volatile acid contents of the two silages are given as percentages of the total acidity and the relationship between the two types expressed as a ratio.

Table XIV

Relationship between the pH Value, Total Volatile Acidity and Lactic Acid Content of the Silages

Silage	pH	Volatile Acids (% total acids)	Lactic Acid (% total acids)	Ratio <u>non-volatile</u> volatile Acids
Untreated	4.9	54.9	45.1	1:0.82
Metabisulphite Treated	4.7	58.1	41.9	1:0.72

Watson (1939) maintains that in well made silage the volatile acids should be outweighed by the non-volatile acids, a ratio of 1:1.3 being stated as suitable. In the present study the ratio of non-volatile acids to volatile acids showed that the latter were in excess in both silages. On the basis of Watson's requirements for good silage, preservation of the two treatments cannot, therefore, be considered as satisfactory.

In individual samples a high pH value was associated with a low lactic acid content and a high volatile acid content. Correlation coefficients between these three variables are presented in Table XV.

In both silages a high lactic acid content was shown to be significantly correlated with a low pH level. Correlation coefficients between all other variables were not significant for either silage.

Table XV

Correlation Coefficients, as Determined for
Various Constituents in the Silages

<u>Comparisons</u>		r =	
Category	No. of Items	Untreated Silage	Metabisulphite-Treated Silage
pH-Lactic Acid	12	- 0.89 *	- 0.88 *
pH-Butyric Acid	12	+ 0.43 N.S.	+ 0.39 N.S.
Lactic Acid-Butyric Acid	12	- 0.75 N.S.	- 0.31 N.S.

* Significant ($p < 0.05 > 0.01$)

N.S. Not Significant ($p > 0.05$)

B. THE RELATIVE PALATABILITY
OF THE SILAGES

There are indications in the literature that palatability is an important characteristic in determining the quantity of grass silage consumed by farm animals. Accordingly, a series of three trials was conducted to determine differences in the intakes of sheep and dairy cows fed grass silages, untreated and treated with sodium metabisulphite. In the first trial, sheep had access to either untreated or treated silage; in the second trial, the same sheep were given a free choice of both silages; and in the third trial, dairy cows were given free access to both untreated and treated material.

Experimental Materials

Animals

The experimental animals used in the first trial consisted of eight full grown Romney wethers, designated 1 to 8 respectively. All animals were unaccustomed to silage. Selection was made from a group of forty wethers such that, as far as possible, the animals were homogenous with respect to age and weight and all were in good health and general condition. At the termination of the first trial, sheep nos. 2 and 8 were discarded and the remaining six animals retained for the second trial, conducted to test their preference of the untreated and treated silages.

The experimental animals employed in the cattle trial consisted of three dry non-pregnant Jersey cows, comprising one set of 4-year-old monozygous twins and one 5-year-old cow. All animals were accustomed to silage.

The identical twin cows had been previously housed indoors, while the remaining animal was unaccustomed to stall feeding conditions. All cows had been grazing a permanent ryegrass-clover paddock and, prior to the commencement of the trial, were in average condition.

Feeds

The untreated and metabisulphite-treated silages fed in the trials, came from the pit described in the previous section. To overcome differences, due to variations in fermentation at different depths, a vertical face, extending from the top to the bottom, was cut in the untreated and treated ends of the pit. Daily silage requirements were cut from the vertical faces each morning, thoroughly mixed and transported to the feeding shed.

Feeding Sheds

The sheep were housed in individual feeding pens in a wooden shed with a concrete floor. Each pen was equipped with a feeding box of the type shown in Fig.7. Wooden boards were used to raise the animals from the floor level.

The cows were housed in an airy feeding barn equipped with six feeding stalls, each containing a large metal feeding bin and drinking bowl. Sawdust was used as bedding material.

Experimental Methods

Application of Treatments

Trial 1. As the experimental sheep most probably exhibited individuality in intake, the trial was so designed that adjustment could be made to overcome this source of bias, through the use of covariance, as outlined by Snedecor (1955 pp. 318 et seq.). The eight experimental sheep were allocated to the individual pens at random and subdivided into four groups of two sheep each,

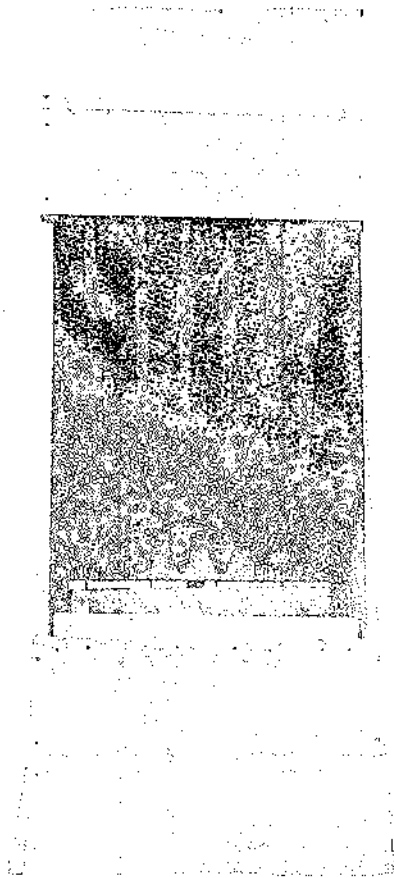


Figure 7

Feeding box used in sheep trials.

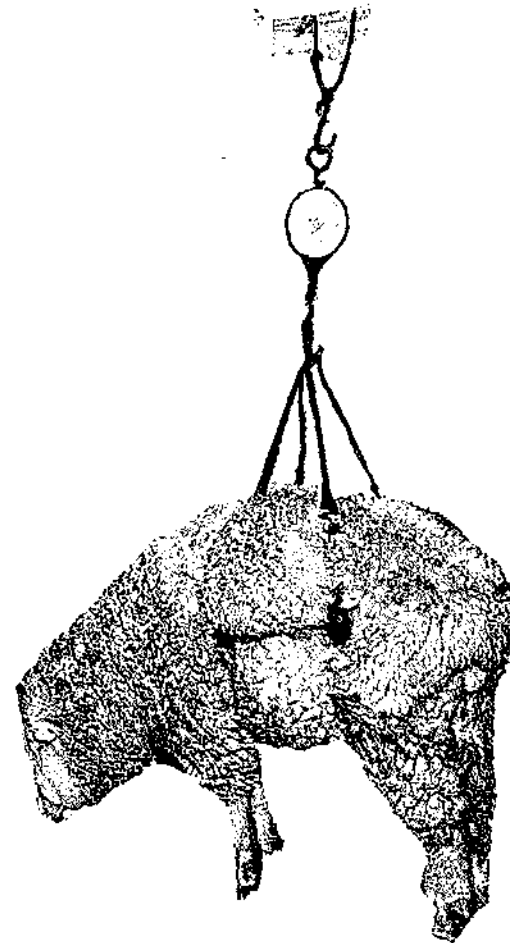


Figure 8

Weighing the experimental sheep.

according to their position in the shed. Within each group the two treatments were allocated at random, thus giving four replicates (Table XVI).

Table XVI

Grouping of the Experimental Animals
and Allocation of Treatments

Sheep No.	Group No.	Treatment
1	I	Treated silage
2		Untreated silage
3	II	Untreated silage
4		Treated silage
5	III	Untreated silage
6		Treated silage
7	IV	Untreated silage
8		Treated silage

The trial comprised four distinct periods: a preliminary period during which the diet of the sheep was gradually changed from a herbage to an all-silage one; an "initial" experimental period, in which all sheep were fed untreated silage and intakes recorded over this period used as the independent variable in the covariance analysis; a further preliminary period, during which sheep nos. 1, 4, 6 and 8 were introduced to treated silage and the remaining four animals (i.e. nos. 2, 3, 5 and 7) received untreated silage; and finally, an experimental period during which the two lots of sheep were fed their allocated silages. Intakes recorded for this latter period provided the dependent variable for the covariance analysis.

The total length of the period employed for the whole trial was as follows:

- 10 days for the preliminary period
- 7 days for the initial experimental period
- 5 days for the second preliminary period
- 10 days for the experimental period.

The trial was undertaken over the winter months, commencing on the 6th June and terminating on the 8th July, 1955.

Trial 2. All six experimental sheep were given a free choice of untreated and treated silages over a seven-day experimental period, from 9th - 16th July 1955, without the introduction of a preliminary period.

Trial 3. The entire experiment comprised two distinct periods: a preliminary period of three days duration, during which the experimental cows were introduced to the two silages; and an experimental period lasting seven days, throughout which the three cows had free access to both silages. The trial commenced on the 20th July and terminated on the 30th July, 1955.

Rations

Sheep. At the commencement of Trial 1, each sheep was fed an admixture of 16 pounds fresh herbage and 2 pounds of untreated silage. The silage component of the ration was gradually increased, with a corresponding decline in the herbage fraction, up to the eighth day of the trial, when an all-silage ration of 15 pounds was fed. This level of feeding was maintained throughout the remaining three periods of the trial. Although slightly in excess of the amount the animals could consume, the ration was not sufficient to permit excessive selection of the leafy portion of the silages. During Trial 2 each sheep was offered 10 pounds of both untreated and treated silage daily. The amount of each silage fed was only slightly in excess of that consumed by the

same animals during the experimental period of the previous trial.

Cattle. Throughout the experimental period each cow received a daily ration of 90 pounds of untreated and treated silage respectively. Though the amount of each silage given was slightly in excess of a full ration, it was not sufficient to permit excessive refusal.

Feeding and Management

Trial 1. The experimental sheep were fed daily at 8 a.m., 12 noon and 4 p.m. Feeding was on an individual basis, a third of the daily ration being placed in the feeding boxes provided at each of the above mentioned times. Between feeding times the silages were stored in a cool section of the shed and covered with damp sacking to prevent drying out of the exposed surface layers.

The daily ration of silage given each sheep was weighed, and the portion of the feed left by the individual sheep at the end of each 24-hour period was removed and weighed prior to the 8 a.m. feeding. The sheep remained in their respective pens throughout the entire trial. Fresh water was available at all times.

Trial 2. The sheep were fed once daily, at 8 a.m., and the silages kept separate by providing each animal with two feeding boxes of the type shown in fig. 7.

The amounts of each silage refused by the individual animals were weighed back daily and the feeding boxes reversed for the next 24-hour period, before a fresh supply of the silages was made available to them.

Trial 3. The experimental cows were in their respective stalls throughout the trial, except for a daily four-hour exercise period (11 a.m. to 3 p.m.) in a concrete yard adjoining the feeding shed. All animals were fed individually twice

daily, once at 8 a.m. and again at 4 p.m., and received 45 pounds of untreated and treated silage respectively at each feeding time. The two silages were put to the cows separately. To prevent mixing of the silages, each feeding bin was subdivided into two equal compartments by a length of sacking.

Individual refusals of each silage were weighed back daily prior to the morning feeding, and the compartments of each feeding bin reversed for the next 24-hour period. As the cows were unaccustomed to water bowls, they were watered twice daily. Drinking water was also available in the exercising yard. The stalls were cleaned out whilst the animals were in the yard, and fresh bedding supplied daily.

Sampling of Feeds and Refusals

In all three trials a 250 g. sample of each silage, as offered the experimental animals, and a 250 g. sample of each animal's refuse, were taken daily for dry matter determination. Samples were drawn prior to the 8 a.m. feeding time and dried in a forced-draught type oven at a temperature of 150°F. for eight hours. The resultant dry matter percentages were used to calculate the daily dry matter intakes of the experimental animals.

Weighing of Animals

The liveweight of each sheep in Trial 1 was obtained at the commencement and termination of the initial and main experimental periods. All weights were recorded prior to the 8 a.m. feeding time, by means of a spring balance and harness (fig. 8). The sheep were weighed in their respective pens by suspending the apparatus from the roof of the feeding shed, a method which gave satisfactory recordings and caused little disturbance to the animals. Changes in liveweight of the experimental animals were not recorded in Trials 2 and 3.

Collection of Data

The following records were collected in all three trials:

- (i) The weights of fresh untreated and treated silage daily offered to and refused by each experimental animal.
- (ii) The dry matter content of the silages offered the animals daily and the portion of these silages refused by the individual animals.
- (iii) The behaviour, health and general condition of the experimental animals.

Additional records on the liveweight changes of the sheep during the initial and main experimental periods of Trial 1 were also collected.

Experimental Results

Trial 1

General Observations

At the commencement of the trial, all sheep showed a steady and satisfactory intake of the silage and herbage ration offered. When silage formed the sole feed, however, appetites fluctuated considerably from day-to-day and remained so throughout all periods of the experiment. Between animals there was no apparent similarity in this daily variation in intake. Sheep transferred from untreated to treated silage in the experimental period, showed a decline in intake over the first few days and thereafter exhibited the usual daily fluctuations in appetite. Over the entire period of the trial, a general trend towards lower consumption with increasing time on the experiment was observed for all animals.

After each feeding time the animals nosed their ration about the feeding box, as if they were seeking something different. Throughout the entire trial they exhibited no well defined daily intake pattern, but tended to nibble and rest alternatively at

short intervals throughout the day.

At the commencement of the experimental period sheep no.2 developed pizzle trouble, with a resultant decline in intake. Although the condition was remedied in a few days by penicillin treatment, the animal continued to exhibit a low intake and was subsequently removed from the trial. Sheep no.8, for no apparent reason, had a consistently low appetite throughout the entire trial. The possibility of acidosis as the causal factor of low intake was investigated by means of the acetone tablet test, but gave a negative result. All other animals remained in normal health and noticeably good condition throughout the trial.

Feed Consumption

The total silage consumption of each sheep during the initial and main experimental periods is shown in Tables XVII and XVIII respectively. Values recorded for sheep no.2 were obtained by the missing plot technique, as outlined by Snedecor (1955 pp.268 et seq.). Individual day-to-day records of silage consumption, during the above mentioned periods and the intermediate preliminary period, are lodged with the Dairy Husbandry Department of Massey Agricultural College.

Over the 7-day initial experimental period, the eight experimental sheep consumed, on an average, 63.2 pounds of untreated silage. During this period the four sheep, selected to receive treated silage in the following experimental period, consumed, on an average, less than their counterparts. Mean intakes of 57.5 and 68.9 pounds being recorded for the two lots respectively.

During the 10-day experimental period, sheep fed untreated silage consumed an average of 85.6 pounds of fresh material, as compared with 64.5 pounds for those fed treated silage. The

Table XVII

Total Feed and Dry Matter Consumption and Changes in Liveweight of 8 Sheep fed Untreated Silage over a 7-day Initial Experimental Period

Sheep No.	Silage Consumed pounds	Dry Matter Consumed pounds	Liveweight at Start of Period pounds	Gain (+) or Loss (-) in Weight pounds
1	52.15	9.67	124.3	- 0.8
2	63.52*	12.07*	-	-
3	64.95	13.15	127.0	+ 2.4
4	62.00	11.39	132.4	- 0.4
5	69.35	12.89	114.0	+ 3.5
6	73.25	13.93	138.1	- 0.3
7	77.80	14.70	120.5	- 1.5
8	42.70	8.23	149.0	- 2.5

*Values obtained by Missing Plot Technique

1
02
1

Table XIX
 Analysis of Covariance and Test of Significance of
 the Adjusted Mean Silage Intakes of Sheep
 fed Untreated and Treated Silage

Source of Variation	d.f.	Sx	Sxy	Sy	Errors of Estimate			
					S.S.	d.f.	M.S.	F
Total	6	898.94	977.95	2050.97				
Treatments	1	259.01	480.75	892.32				
Within Treatments (error)	5	639.93	497.20	1158.65	772.35	4	193.09	
Treatments + Error	6	898.94	977.95	2050.97	987.07	5		
Treatments					214.72	1	214.72	1.11 N.S.

N.S. Not Significant ($p > 0.05$)

unadjusted mean fresh silage intake values for the experimental period thus showed an intake of 21.1 pounds in favour of the untreated silage.

In Table XIX is presented the analysis of covariance and test of significance of the adjusted mean intakes of the two silages. Silage intakes recorded over the initial experimental period were used as the independent variable and intakes over the experimental period. As values recorded for sheep no.2 were obtained by the missing plot technique, one degree of freedom is lost in the analysis.

The results of the analysis showed that there was no significant difference in intake between the untreated and treated silages.

Although the reduction in sum of squares due to regression was not significant (Table XX), the mean square for error was reduced from 231.73 to 193.09. This does reveal a valuable increase in the precision of the experiment through the use of covariance.

Table XX

Analysis of Error Variance in Sheep Data

Source of Variation	d.f.	S.S.	M.S.	F
Between Treatments (unadjusted intakes)	5	1158.65	231.73	
Reduction due to Regression	1	386.30	386.30	2.00 N.S.
Error for Adjusted Intakes	4	772.35	193.09	

N.S. Not Significant ($p > 0.05$)

The mean intakes of the two silages, unadjusted and adjusted for regression, are shown in Table XXI.

Table XXI

Unadjusted and Adjusted Mean Silage Intakes
over the Experimental Period

Silage	Silage Intake/Sheep (unadjusted)	Silage Intake/Sheep (adjusted)
	pounds	pounds
Untreated	85.59	81.73
Metabisulphite-Treated	64.47	68.92

Although the mean difference of 12.81 pounds fresh silage between the adjusted intakes of the two silages was not significant, the difference between the unadjusted and adjusted intakes provided further evidence that the introduction of the independent variate into the trial was beneficial.

Dry Matter Content of Feeds and Refuse

Mean dry matter values for the silages offered to and refused by each sheep, over the initial and main experimental periods of the trial, are presented in Tables XXII and XXIII respectively. Individual day-to-day dry matter values of feeds and refuse are lodged with the Dairy Husbandry Department of Massey Agricultural College.

The mean dry matter content of the untreated silage offered to the experimental animals in the initial experimental period (18.85%) was similar to that of the same silage fed in the main experimental period (19.04%). Both values were lower than that recorded for treated silage (20.06%) as fed in the main experimental period.

Table XXII

Mean Dry Matter Content of the Feed Offered to and Refused by 8 Sheep
fed Untreated Silage over a 7-day Initial Experimental Period

(stated as % fresh silage - air dry basis)

Sheep No.	1	2	3	4	5	6	7	8
Feed Analysis	18.85	18.85	18.85	18.85	18.85	18.85	18.85	18.85
Refuse Analysis	19.02	19.52	18.94	19.32	19.31	18.44	18.78	18.61

Table XXIII

Mean Dry Matter Content of the Feed Offered to and Refused by 2 Groups,
each of 4 Sheep, fed Untreated and Treated Silage respectively,
over a 10-day Experimental Period

(stated as % fresh silage - air dry basis)

Sheep No.	1	2	3	4	5	6	7	8
Silage	Metabi- sulphite Treated	Un- treated	Un- treated	Metabi- sulphite Treated	Un- treated	Metabi- sulphite Treated	Un- treated	Metabi- sulphite- Treated
Feed Analysis	20.06	19.04	19.04	20.06	19.04	20.06	19.04	20.06
Refuse Analysis	20.19	19.58	19.25	20.48	18.94	20.27	19.35	20.40

Mean dry matter values for each sheep's refuse were only slightly higher than those of the corresponding feed and very similar between animals fed the same silage, a further indication that little selection of the feed was practised. Individual day-to-day dry matter records of the feeds offered and refused were used to calculate the dry matter consumption of each sheep over the initial and main experimental periods.

Dry Matter Consumption

The total dry matter consumed by each sheep over the initial and main experimental periods is shown in Tables XVII and XVIII respectively. Values for sheep no.2 were obtained by the missing plot technique. Individual day-to-day records of dry matter consumption during the trial are lodged with the Dairy Husbandry Department of Massey Agricultural College.

During the 7-day initial experimental period, an average consumption of 12.0 pounds of dry matter was recorded for the 8 sheep. The four animals selected to receive treated silage in the following experimental period, consumed an average of 10.8 pounds of dry matter, while those selected to remain on untreated silage consumed an average of 13.2 pounds of dry matter, a difference of 2.4 pounds dry matter in favour of the latter group.

Throughout the 10-day experimental period animals fed untreated silage consumed, on an average, more dry matter than their counterparts fed treated material. Mean dry matter intakes of 16.48 and 12.26 pounds were recorded for the two groups respectively. The unadjusted mean values for the experimental period thus showed a dry matter intake of 4.22 pounds in favour of untreated silage.

Table XIV
Analysis of Covariance and Test of Significance of the
Adjusted Mean Dry Matter Intakes of Sheep
fed Untreated and Treated Silage

Source of Variation	d.f.	Sx	Sxy	Sy	Errors of Estimate		
					S.S.	d.f.	M.S.
Total	6	33.15	46.38	108.57			
Treatments	1	11.50	20.23	35.62			
Within Treatments (error)	5	21.65	26.15	72.86	41.29	4	10.32
Treatments + Error	6	33.15	46.38	108.57	43.68	5	
Treatments					2.39	1	2.39
							0.23 N.S.

N.S. Not significant ($p > 0.05$)

In Table XXIV is presented the analysis of covariance and test of significance of the adjusted mean dry matter intakes over the experimental period. Dry matter intakes over the initial experimental period were used as the independent variable. One degree of freedom is lost in the analysis for the data obtained by the missing plot technique.

The reduction in error variance, due to regression of dry matter intake over the main experimental period associated with intake over the initial period, was not significant (Table XXV). Thus, the trial demonstrated that there was no significant difference in the dry matter intakes of sheep fed ensiled and treated silage respectively.

Table XXV

Analysis of Error Variance in Sheep Data

Source of Variation	d.f.	S.S.	M.S.	F
Between Treatments (unadjusted intakes)	5	72.86	14.57	
Reduction due to Regression	1	31.57	31.53	3.06 N.S.
Error for Adjusted Intakes	4	41.29	10.32	

N.S. Not significant ($p > 0.05$)

Table XXVI shows the mean dry matter intakes of the sheep over the 10-day main experimental period, unadjusted and adjusted for regression. The difference in adjusted dry matter intakes between the two silages was 1.35 pounds. This difference was not significant.

Table XXVI

Unadjusted and Adjusted Mean Dry Matter Intakes
over the Experimental Period

Silage	Dry Matter Intake/Sheep (unadjusted)	Dry Matter Intake/Sheep (adjusted)
	pounds	pounds
Untreated	16.48	15.03
Metabisulphite-Treated	12.26	13.70

Changes in Body Weights

The initial weight and change in weight of each sheep over the initial and main experimental periods are shown in Tables XVII and XVIII respectively.

Liveweights recorded at the end of the initial experimental period, when compared with initial values, were slightly lower for all sheep except nos. 3 and 5, which showed small apparent weight gains. Individual weights recorded at the termination of the main experimental period were in all cases lower than those recorded at commencement of this period.

The four sheep fed treated silage over the main experimental period showed, on an average, an apparent weight loss of 2.3 pounds less than their counterparts fed untreated material. A number of factors, however, made it difficult to determine the effect of the two silages on liveweight. These included variation in individual intake and water consumption, initial weight of the animals, individual variations in "gut fill" and errors in weighing. The small weight differences recorded for sheep nos. 1, 3, 4, 5, 6 and 7 over the two experimental periods could be accounted for by variation in "gut fill" and errors in weighing. The weight

TABLE XXVII

	1	2	3	4	5	6	7	8	9	10
100	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
101	1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.10
102	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20
103	1.03	1.06	1.09	1.12	1.15	1.18	1.21	1.24	1.27	1.30
104	1.04	1.08	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40
105	1.05	1.10	1.14	1.18	1.22	1.26	1.30	1.34	1.38	1.42
106	1.06	1.12	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44
107	1.07	1.14	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.46
108	1.08	1.16	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48
109	1.09	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.46	1.50
110	1.10	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.52
111	1.11	1.22	1.26	1.30	1.34	1.38	1.42	1.46	1.50	1.54
112	1.12	1.24	1.28	1.32	1.36	1.40	1.44	1.48	1.52	1.56
113	1.13	1.26	1.30	1.34	1.38	1.42	1.46	1.50	1.54	1.58
114	1.14	1.28	1.32	1.36	1.40	1.44	1.48	1.52	1.56	1.60
115	1.15	1.30	1.34	1.38	1.42	1.46	1.50	1.54	1.58	1.62
116	1.16	1.32	1.36	1.40	1.44	1.48	1.52	1.56	1.60	1.64
117	1.17	1.34	1.38	1.42	1.46	1.50	1.54	1.58	1.62	1.66
118	1.18	1.36	1.40	1.44	1.48	1.52	1.56	1.60	1.64	1.68
119	1.19	1.38	1.42	1.46	1.50	1.54	1.58	1.62	1.66	1.70
120	1.20	1.40	1.44	1.48	1.52	1.56	1.60	1.64	1.68	1.72

Table XXVII

Feed Intakes of Six Sheep given a Free Choice of Untreated
and Treated Silages over a 7-day Period

	Silage Consumption in Pounds																	
	Metabieulphite-Treated						Untreated						Total					
Sheep No. Day of Trial	1	3	4	5	6	7	1	3	4	5	6	7	1	3	4	5	6	7
1	1.5	3.4	2.7	4.5	3.4	2.4	5.7	2.6	5.0	3.4	6.3	3.6	7.2	6.0	7.7	7.9	9.7	6.0
2	3.8	3.5	3.0	1.0	4.5	3.7	3.5	1.8	4.7	5.3	5.7	2.5	7.3	5.3	7.7	6.3	10.2	6.2
3	3.4	2.0	2.3	3.4	2.8	0.8	3.1	3.2	5.9	4.6	7.1	5.8	6.5	5.2	6.2	8.0	9.9	6.6
4	3.8	2.6	2.1	5.2	5.0	2.2	1.3	2.7	4.1	1.2	4.2	6.0	5.1	5.3	6.2	6.4	9.2	8.2
5	2.8	2.2	2.9	3.1	5.2	0.9	2.6	3.6	3.9	2.7	4.9	6.3	5.4	5.8	6.8	5.8	10.1	7.2
6	1.9	1.7	3.6	2.9	5.6	0.8	3.3	3.1	4.4	1.2	4.2	6.2	5.2	4.8	8.0	4.1	9.8	7.0
7	4.5	3.0	3.4	3.1	5.5	5.4	2.7	2.0	5.5	1.2	3.8	4.7	7.2	5.0	8.9	4.3	9.3	10.1
Total	21.7	18.4	20.0	23.2	32.0	16.2	22.2	19.0	31.5	19.6	36.2	35.1	43.9	37.4	51.5	42.8	68.2	51.3
Average	3.10	2.63	2.85	3.31	4.57	2.31	3.17	2.71	4.50	2.80	5.17	5.01	6.27	5.34	7.35	6.11	9.74	7.32

difference of 10 pounds recorded for sheep no.8 over the entire trial period, however, was undoubtedly in part a true weight loss, as this animal had a daily dry matter intake well below its calculated requirements.

Trial 2

General Observations

Throughout the entire experimental period, all sheep exhibited small day-to-day fluctuations in the total amount of silage consumed. This daily variation in intake showed no agreement between animals. Total silage consumption was low for all animals, indicating that they were desirous of a change in feed. The sheep tended to nibble both silages frequently throughout the day, there being no intensive feeding periods nor marked desire to concentrate entirely on one silage. During the course of the trial all sheep maintained normal health and remained in good condition.

Feed Consumption

In Table XXVII are presented figures for the daily consumption of the two silages and the total silage consumed by each sheep over the seven-day experimental period.

Over the entire experimental period the average daily intake of silage per sheep was 7 pounds, comprising 3.9 pounds of untreated silage and 3.1 pounds of treated material.

Mean daily intake differences in favour of the untreated silage, as recorded for each sheep, were regarded as a random selection from a population of sheep and days and a simple t-test (Snedecor 1955, p.62 et seq.) used to determine whether the mean of the differences in intake of the two silages was significantly greater than zero and hence if overall preference was significant.

Since the mean daily difference in intake of 0.76 ± 0.35 pounds fresh silage was shown to be significantly greater than zero, the experimental sheep, as a group, thus showed a significant preference for the untreated silage. The mean difference in intake between the two silages was small, however, and of little practical importance.

An examination of individual intakes of the two silages over the entire trial showed that sheep nos. 1, 3, 4, 6 and 7 consumed a greater amount of untreated silage, while sheep no. 5 showed a higher consumption of treated material.

When each sheep's preference was tested statistically by the above mentioned method, regarding daily intake differences in favour of untreated silage as a random selection of possible days, only in the case of sheep nos. 4 and 7 was the exhibited preference for untreated silage significant. The remaining four sheep gave intermediate results.

The data presented do show that in a trial of this type it is necessary to study the reactions of several animals to the experimental feeds, owing to their individual variation and to the fact that a single isolated animal may not behave in a normal manner.

Dry Matter Content of Feeds and Refuse

Mean values for the dry matter content of the two silages offered to and the portion refused by each sheep are shown in Table XXVIII. Individual day-to-day dry matter records of feeds and refuse are lodged with the Dairy Husbandry Department of Massey Agricultural College.

The silages, as offered the experimental sheep, were similar in dry matter content, while mean dry matter values for each sheep's refuse were similar between animals and little different

Table XXVIII

Mean Dry Matter Contents of the Feeds Offered to and Refused by Six Sheep given a Free Choice of Untreated and Treated Silage

(stated as % fresh silage - air dry basis)

Treatment	1	2	3	4	5	6	7
<u>Metablenphite-Treated Silage:</u>							
Feed Analysis	18.89	18.89	18.89	18.89	18.89	18.89	18.89
Refuse Analysis	19.34	19.27	19.17	19.00	18.95	19.09	
<u>Untreated Silage:</u>							
Feed Analysis	19.32	19.32	19.32	19.32	19.32	19.32	19.32
Refuse Analysis	19.75	19.59	19.88	19.69	19.80	19.60	

Table XXIX

Dry Matter Intakes of Six Sheep given a Free Choice of Untreated and Treated Silages over a 7-day Period

		Dry Matter Consumption in Pounds																	
		Metabisulphite-Treated						Untreated						Total					
Sheep No.	Day of Trial	1	3	4	5	6	7	1	3	4	5	6	7	1	3	4	5	6	7
1		0.28	0.64	0.53	0.70	0.62	0.46	1.07	0.49	0.96	0.64	1.17	0.70	1.35	1.13	1.49	1.34	1.79	1.16
2		0.65	0.58	0.49	0.21	0.77	0.63	0.62	0.29	0.82	0.95	1.02	0.45	1.27	0.87	1.31	1.16	1.79	1.08
3		0.61	0.38	0.46	0.67	0.55	0.16	0.57	0.59	0.73	0.88	1.42	1.14	1.18	0.97	1.19	1.55	1.97	1.30
4		0.86	0.59	0.47	1.16	1.12	0.52	0.26	0.59	0.83	0.26	0.87	1.24	1.12	1.18	1.30	1.42	1.99	1.76
5		0.45	0.31	0.43	0.49	0.95	0.10	0.50	0.69	0.75	0.50	0.97	1.27	0.95	1.00	1.18	0.99	1.92	1.37
6		0.34	0.30	0.68	0.62	1.04	0.15	0.66	0.65	0.89	0.23	0.82	1.27	1.00	0.95	1.57	0.85	1.86	1.42
7		0.78	0.51	0.58	0.53	0.97	0.96	0.42	0.32	0.93	0.14	0.64	0.78	1.20	0.83	1.51	0.67	1.61	1.74
Total		3.97	3.31	3.64	4.38	6.02	2.98	4.10	3.62	5.19	3.60	6.91	6.85	8.07	6.93	9.55	7.98	12.93	9.93
Average		0.57	0.47	0.52	0.63	0.86	0.43	0.58	0.52	0.84	0.51	0.99	0.97	1.15	0.99	1.36	1.14	1.85	1.40

from the corresponding feed value. Individual day-to-day dry matter records of feeds and refuse were used to calculate the dry matter intakes of each sheep over the experimental period.

Dry Matter Consumption

The daily consumption of the two silages on a dry matter basis and the total dry matter consumed by each sheep over the experimental period are shown in Table XXIX. Throughout the trial each sheep consumed, on an average, 1.31 pounds of dry matter daily. Of the total, 0.58 pounds were derived from the treated silage and the remaining 0.73 pounds from untreated material. Through use of the statistical method previously described (see page 93), the mean daily dry matter intake difference of 0.15 ± 0.07 pounds in favour of the untreated silage, was found to be significant. Although individual data showed that sheep nos. 1, 3, 4, 6 and 7 consumed a greater amount of untreated silage on a dry matter basis, only in the case of sheep no. 7 was the preference for untreated silage significant.

The results of the trial, have, therefore, shown that, when dry matter intake was considered as an index of palatability, the sheep as a group showed a significantly slight preference for untreated silage. On an individual basis, however, only one animal preferred untreated material, the remainder exhibiting no significant preference.

Trial 3

General Observations

All three cows quickly became accustomed to stall feeding conditions and ate both silages readily. Day-to-day fluctuations in appetite were observed and, although the trend was similar for

individual cows, there was marked variation in the amounts of silage consumed.

Throughout the trial all animals exhibited two intensive feeding periods daily. During these periods of uninterrupted consumption, which followed each feeding time, the cows showed no marked desire to concentrate on any one silage, but consumed both alternatively. At the close of the trial all three cows were in normal health and good condition.

Feed Consumption

The daily intakes of untreated and treated silage and the total silage consumed by each cow throughout the experimental period are shown in Table XXX.

On an average, each cow consumed 81.24 pounds of fresh silage daily throughout the trial. This total comprised 42.31 pounds of treated silage and 38.93 pounds of untreated material, a mean daily difference of 3.38 pounds in favour of treated silage. When mean daily intake differences of fresh silage in favour of treated material, as recorded for each cow, were regarded as a random selection from a population of cows and days and a simple t-test (Snedecor 1955, p.62 et seq.) applied to the data, the overall mean daily intake difference of 3.38 ± 1.64 pounds in favour of the treated silage was found to be non-significant.

Table XXX shows that all three cows consumed a greater amount of treated silage. However, when each cow's preference was tested statistically by the above mentioned method, regarding daily intake differences in favour of treated silage as a random selection of possible days, exhibited individual preferences were all found to be non-significant.

The results of the trial have, therefore, shown that, when fresh silage intake was taken as an index of palatability, the cows,

Table XXV
Feed Intakes of Three Dry Cows given a Free Choice of Untreated and Treated Silages over a 7-day Period

Cow No. Day of Trial	Fresh Silage Consumption in Pounds								
	Metabisulphite-Treated			Untreated			Total		
	1	2	3	1	2	3	1	2	3
1	42.5	42.6	40.9	44.5	46.5	46.0	87.0	89.1	86.9
2	40.3	42.4	41.3	39.2	37.5	26.0	79.5	79.9	67.3
3	48.0	41.7	48.7	35.5	45.2	35.5	83.5	86.9	84.2
4	45.3	38.7	33.5	41.8	36.9	32.8	87.1	75.6	66.3
5	45.0	43.0	45.5	46.0	43.0	33.5	91.0	86.0	79.0
6	46.7	44.7	42.5	41.1	35.7	22.8	87.8	80.4	65.3
7	43.8	34.8	36.8	45.7	40.5	41.8	89.5	75.3	78.6
Total	311.6	287.9	289.2	293.8	285.3	238.4	605.4	573.2	527.6
Average	44.51	41.12	41.31	41.97	40.76	34.06	86.48	81.88	75.37

as a group and individually, showed no significant preference for either silage.

Dry Matter Content of Feeds and Refuse

Mean dry matter values for the two silages offered the experimental cows and the portion of each silage refused by them, are shown in Table XXXI. Daily records of the dry matter content of the feeds and refuse are lodged with the Dairy Husbandry Department of Massey Agricultural College.

Table XXXI

Mean Dry Matter Content of the Feeds and Refuse of
Three Dry Cows given a Free Choice of
Untreated and Treated Silages

(stated as percentage fresh silage - air dry basis)

Cow No.	1		2		3	
	Untreated	Metabi- sulphite- treated	Untreated	Metabi- sulphite- treated	Untreated	Metabi- sulphite- treated
Feed Analysis	18.18	19.44	18.18	19.44	18.18	19.44
Refuse Analysis	17.74	18.58	18.38	18.81	18.64	18.77

Treated silage had a higher content of dry matter compared with untreated material, but the difference of 1.26 per cent between silages was small. Mean dry matter values for the portion of each silage refused by the individual cows were, in general, little different from those of the corresponding feeds and similar between animals, an indication that animal selection within each silage was not practised.

Individual day-to-day dry matter values of the feeds and refuse were used to estimate the dry matter intakes of the cows over the experimental period.

Dry Matter Consumption

Individual daily dry matter intakes of treated and untreated silage and the total dry matter consumed by each cow over the experimental period are shown in Table XXXII.

Throughout the trial an average daily intake of 15.93 pounds of dry matter was recorded per cow, 8.55 pounds of the total being derived from treated silage and the remainder (7.38 pounds) from untreated material. The mean daily dry matter intake difference of 1.17 ± 0.41 pounds, in favour of the treated material, when subjected to statistical treatment, according to the method employed for fresh silage intakes (see page 97), was found to be highly significant.

Although an examination of individual dry matter intakes over the experimental period showed that all animals consumed more of the treated silage, individual preferences were all found to be non-significant.

Thus, on a dry matter basis, the three cows as a group showed a significant but slight preference for treated silage, while, on an individual basis, no significant preference for either silage could be demonstrated.

Table XXXII

Dry Matter Intakes of Three Dry Cows given a Free Choice of Untreated and Treated Silages over a 7-day Period

Cow No. Day of Trial	Dry Matter Consumption in Pounds								
	Metabisulphite-Treated			Untreated			Total		
	1	2	3	1	2	3	1	2	3
1	7.09	7.00	6.69	8.94	9.02	8.81	16.03	16.02	15.50
2	6.81	7.09	6.90	6.73	5.09	3.81	13.54	12.18	10.71
3	8.33	7.55	8.88	6.99	8.43	6.50	15.32	15.98	15.38
4	11.60	10.31	9.36	8.86	7.65	6.75	20.46	17.96	16.11
5	10.19	9.39	9.88	9.53	8.69	6.80	19.72	18.08	16.68
6	9.24	9.30	8.90	6.18	7.87	4.33	15.42	17.17	13.23
7	9.63	7.53	7.93	8.79	7.55	7.67	18.42	15.08	15.60
Total	62.89	58.17	58.54	56.02	54.30	44.67	118.91	112.47	103.21
Average	8.98	8.31	8.36	8.00	7.76	6.38	16.98	16.07	14.74

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C. THE DIGESTIBILITY OF THE SILAGES

Further data were obtained on the relative feeding values of the untreated and treated silages by determining the digestibility of the various conventional fractions in each and from these, by standard procedures, calculating the starch equivalent and total digestible nutrient content as a measure of the energy value, the content of digestible crude protein, and the nutritive ratio. The trial was conducted during the latter two periods of the first palatability trial, described in the previous section, and the experimental sheep used for palatability measurements simultaneously employed to determine the digestibility coefficients of the two silages.

Experimental Procedure

Application of Treatments

The coefficients of digestibility of each silage were determined in triplicate using sheep nos. 3, 5 and 7 for the untreated silage and sheep nos. 1, 4 and 6 for the treated material. The trial consisted of a preliminary period of 5 days followed by a collection period of 10 days, these periods being denoted the "second" preliminary period and experimental period in the palatability trial previously described (see page 77).

A full description of the experimental animals and silages, the feeding shed used, the level of feeding and the general conduct of the trial has already been furnished in the previous section dealing with the relative palatability of the silages (see pages 75 - 81).

Sampling of Feeds and Refuse

Each day, before the first feed was given, the two silages were thoroughly mixed and a representative 250 g. sample of each

taken for dry matter determination and subsequent chemical analysis.

Individual daily refusals, following collection and weighing, were also thoroughly mixed and a 250 g. sample of each taken for analysis. Samples were not taken from refused feeds weighing less than one pound, the average dry matter percentage from the other samples being used in all calculations.

Collection and Sampling of Faeces

The "conventional" method of determination of digestibility, involving total collection of the faeces, was employed. Faeces were collected in special canvas bags attached to the sheep by means of leather harness (fig. 9), as designed and described by Sears and Goodall (1942). The sheep were harnessed in the preliminary period of the trial and soon became accustomed to wearing the apparatus and to frequent handling associated with its use. Urine was allowed to run away as neither a nitrogen nor mineral balance of the animals was undertaken.

The collection bags were emptied four times daily, once prior to each feeding time, with a further collection at 10 p.m. Individual faeces were weighed after each collection, transferred to a plastic container and stored in a cool section of the feeding shed. The daily faecal output of each sheep during the collection period was thoroughly mixed and sampled by taking an aliquot part equal to one-twentieth of the total wet weight voided.

Chemical Determinations

Feed and refuse samples were prepared for analysis by drying in an electric oven of the forced draught type at a temperature of 150°F for eight hours. Faeces samples were dried at the same temperature for eleven hours, cracked and thereafter subjected

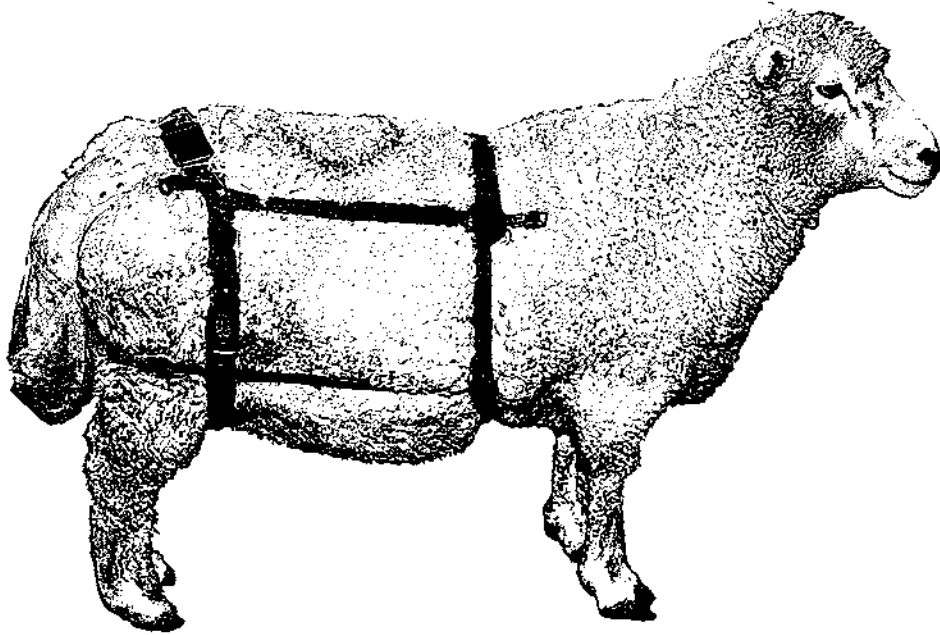


Figure 9

Sheep fitted with harness for the collection of faeces.

to a further drying period of twelve hours duration. After removal from the oven, all samples were allowed to come to constant-moisture content, weighed and finely ground in a laboratory mill. Dried ground samples were stored in sealed glass jars.

Composite samples of the two feeds and the individual refusals and faeces were made up over the collection period from the daily samples, giving a total of fourteen samples for chemical analysis. All analyses were done in duplicate on representative samples of the dried feeds, refusals and faeces, by the methods recommended by the Association of Official Agricultural Chemists (1952).

Weighing of Animals

All experimental sheep were weighed at the commencement and termination of the collection period, as previously described (see page 80).

Collection of Data

The following records were collected:

1. The weight of fresh silage offered to and refused by each sheep daily.
2. The daily faecal output of each sheep.
3. The dry matter content of the daily feeds, individual refusals and faecal output.
4. A complete feeding stuffs analysis of the two feeds, individual refusals and faeces voided over the collection period.
5. The change in liveweight of each sheep over the collection period.

Data collected were used to calculate the digestibility of the various conventional fractions in each silage.

Values for the starch equivalent of the silages were calculated according to the method of Kellner (1915), by adding the products of the digestible crude protein $\times 0.94$, the digestible ether extract $\times 1.91$, the digestible crude fibre plus the digestible nitrogen-free extract $\times 1.0$ and subtracting $0.58 \times$, the percentage of crude fibre in the food. In considering the value of the silages as sources of protein, the digestible crude protein content was used.

Values for the total digestible nutrient content of the silages were obtained by the method of Woodman (1952), by adding the percentages of digestible crude protein, nitrogen-free extract, crude fibre and ether extract $\times 2.25$.

The nutritive ratio of each silage was calculated by means of the following expression, given by Woodman (1952):

Nutritive ratio =

$$\frac{(\% \text{ dig. oil } \times 2.3) + \% \text{ dig. carbohydrate } + \% \text{ dig. fibre}}{\% \text{ dig. crude protein}}$$

Experimental Results

Composition of Feeds, Refuse and Faeces

The average chemical composition of the two feeds, the refusals of the individual animals and the total faeces voided by each sheep over the collection period are shown in Table XXIII.

The two silages fed were similar in chemical composition. Both had a low crude protein and high crude fibre content, a result arising from the mature stage of growth of the ensiled material. The higher total ash content of the treated silage may be partly explained by the presence of residual sulphite in the

Table XXXIII

Chemical Analysis of Feeds, Refuse and Faeces
(moisture-free basis)

(a) Feed Analyses

Silage	Percentage Composition of Feed						
	% Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
Untreated	18.01	12.09	2.26	9.58	33.31	42.76	90.42
Metabisulphite Treated	18.98	12.12	2.43	11.38	33.87	40.20	88.62

(b) Refuse Analyses

Silage	Sheep No.	Percentage Composition of Refuse						
		% Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
Untreated	3	18.40	10.94	1.75	10.58	35.67	41.06	89.42
	5	17.89	11.34	1.77	10.96	36.85	39.08	89.04
	7	18.52	11.42	1.78	11.40	36.73	38.67	88.60
Metabi-sulphite Treated	1	18.87	11.64	2.24	11.99	35.18	38.95	88.01
	4	19.35	11.97	2.14	11.56	35.41	38.92	88.44
	6	19.28	11.56	2.19	11.72	34.51	40.02	88.28

(c) Faeces Analyses

Silage	Sheep No.	Percentage Composition of Faeces						
		% Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
Untreated	3	36.63	15.98	2.65	13.25	29.25	38.87	86.75
	5	42.34	15.18	2.66	13.21	28.19	40.76	86.79
	7	37.41	14.77	2.63	12.90	28.91	40.71	87.10
Metabi-sulphite Treated	1	43.30	16.64	3.32	14.88	27.54	37.62	85.12
	4	37.97	16.35	3.36	15.56	26.02	38.71	84.44
	6	40.09	16.56	3.34	14.30	27.41	38.39	85.70

material, a factor which was not allowed for in the chemical analysis. Individual refusals had a slightly higher crude fibre content and lower protein value compared with the corresponding feed, but were similar in composition between animals, an indication that some selective feeding was practised by the sheep.

There was very little difference in composition of the constituents of the excreta of the sheep fed untreated and treated silage. Although the dry matter contents of the faeces of sheep nos. 3, 4 and 7 were slightly lower than those of the other animals, the condition did not affect the composition of the dry matter of the faeces nor the ability of the animals to digest nutrients.

Apparent Digestibilities of Nutrients

Detailed calculations of the digestibilities of the various nutrients in the two silages, as determined for the three sheep fed each silage, are given in Appendix III. The totals of the nutrients ingested, voided and digested by each sheep during the trial period were obtained from average chemical analyses data and the amount of dry matter offered, refused and excreted. In Table XXXIV are summarized the mean apparent digestibility coefficients of the constituents of the two silages.

There was little difference between the mean digestibility coefficients obtained for the dry matter and organic matter fractions of the two silages. Low digestibility values recorded for both treatments were a direct reflection on the inferior quality of the herbage ensiled. The main differences in digestibility between the silages were in the crude fibre and ether extract fractions. The former constituent was 6 per cent more digestible and the

Table XXXIV

Apparent Digestibility Coefficients of the Silages

Constituent	Untreated Silage	Metabisulphite-Treated Silage
Dry Matter	52.2	53.9
Organic Matter	54.6	55.9
Crude Protein	42.2	38.9
Ether Extract	49.7	42.6
Crude Fibre	55.6	61.7
Nitrogen-free Extract	54.3	57.1

latter 7 per cent less digestible in the treated silage.

Treated silage had a lower mean crude protein digestibility and a higher nitrogen-free extractive digestibility than untreated material. It is doubtful, however, if the treatment differences were real, as the individual coefficients determined for these constituents showed considerable variation (Appendix III). In both silages the crude protein fraction was of low digestibility. There was no indication from the appearance of the silages that excessive heating was responsible for the low values recorded. The mature nature of the material ensiled, and undesirable fermentations which occurred in both treatments, following the penetration of rain water, suggest themselves as more likely causes of low protein digestibility. The admission of rain water into the silages may also have some bearing on the overall low digestibility coefficients obtained for both treatments.

Changes in Body Weights

The changes in liveweight of the individual sheep over the collection period are given in Table XXXV.

Table XXXV

Average Weight of each Sheep at the Beginning and End of the 10-day Collection Period

Sheep No.	Silage Fed	Initial Weight	Final Weight	Gain (+) or Loss (-) in Weight
		pounds	pounds	pounds
1	Metabi-sulphite-Treated	122.5	119.0	-3.5
4		131.0	129.5	-1.5
6		141.5	139.0	-2.5
3	Untreated	127.5	122.5	-5.0
5		118.0	113.0	-5.0
7		120.0	115.0	-5.0

The individual liveweights of all sheep recorded at the termination of the collection period were lower than those recorded at its commencement. Individual differences between the initial and final weighings, however, were all of a low order. There was no apparent relationship between weight change and digestibility. Furthermore, the average daily faecal output of the individual sheep was in one case greater and in all other cases smaller in magnitude than the weight change during the collection period. It therefore seems safe to conclude that weight differences were due to variation in "gut fill" and for errors in weighing and were not actual weight losses.

Calculated Feed Values

The relative feeding value of the silages is shown in Table XXXVI.

The similar composition and digestibility of the silages resulted in their having very similar total digestible nutrient contents. Treated silage furnished about 51 pounds of total digestible nutrients in 100 pounds of dry matter and the untreated silage about 48 pounds. Treated silage, being superior

Table XXXVI

Mean Values for the Total Digestible Nutrient Content, the Starch Equivalent, Digestible Crude Protein Content and Nutritive Ratio of the Silages

Silage	Total Digestible Nutrients		Starch Equivalent		Digestible Crude Protein		Nutritive Ratio
	%	% Dry Matter	%	% Dry Matter	%	% Dry Matter	
Untreated	8.6	48.0	5.8	29.4	0.91	5.0	1 : 8.8
Metabi-sulphite Treated	9.6	50.8	6.3	33.0	0.89	4.7	1 : 9.9

to untreated material in crude fibre digestibility, had a slightly higher starch equivalent value. The starch equivalents of the dry matter were 33.0 and 29.4 for the treated and untreated silages respectively. Comparable values for the digestible crude protein fraction were 4.7 and 5.0 per cent, the difference between the treatments being small and insignificant.

The results of the digestibility trial, therefore, indicated that the energy values and digestible crude protein contents of the two silages were similar. Values recorded for both treatments were of a low order, a factor due primarily to the poor chemical composition of the products and the low digestibility of all nutrients in each. Since the ratio between the digestible crude protein and digestible non-protein fractions was wide in each silage, both could be considered as suited only for the provision of a maintenance ration for livestock.

D. DISCUSSION OF PRELIMINARY RESULTS

A comparison of analytical figures showed that the addition of sodium metabisulphite to herbage had little effect on the quality of the silage made. Treated silage was no better in appearance and smell than that made from similar material untreated with the salt, and both silages had a similar carotene content. These results do not conform with the findings of other workers. Gordon et al. (1953), Gowan et al. (1953), Sears (1955), Bratzler et al. (1956) and others have all commented on the greener colour and reduced odour of metabisulphite silage as against that of silage made from similar material without preservative addition, while the ability of metabisulphite treated herbage to yield silage of a higher carotene content than untreated material has been reported by various stations (Gordon et al. 1954; Allred et al. 1955; Bratzler et al. 1956).

Although metabisulphite treated silage was found to have a significantly higher dry matter content compared with the control silage, it was doubtful if this difference was real. In further analytical studies, conducted to determine the nutritive value of the silages, no marked difference in dry matter content could be detected between them.

No marked differences were shown to exist between the values recorded for the conventional feed fractions in the silages, a result in agreement with the findings of Little (1954) and Murdoch et al. (1956). Bratzler et al. (1956), however, found that metabisulphite silages, compared with untreated material, contained a higher percentage of nitrogen-free

extract. The authors attributed the difference to a reduction in loss of this constituent from treated material during storage. Allred et al. (1955), on the other hand, found metabisulphite silages to contain less nitrogen-free extract on a percentage basis than untreated silage. Values for the nitrogen-free extract fraction in silage must, however, be interpreted with caution. Nitrogen-free extract is obtained by a difference method and hence may be subject to considerable error.

Values of similar magnitude were recorded for the common fermentation products in the silages. It may, therefore, be concluded that both silages underwent a similar type of fermentation during storage. Each was characterised by a high pH value, moderate amounts of acetic and butyric acids, a trace of propionic acid and a low percentage of lactic acid, indicating that bacterial fermentation had occurred within the mass. The results also suggest that the acidity or hydrogen ion concentration developed within the silages was the agent responsible for their preservation, as is usual in silage made without additives. The degree of acidity attained in the silages, however, could not be regarded as satisfactory. Mean pH values were above the level of 4.0 and lactic acid concentration below the range of 1 - 2 per cent of the fresh material, considered by Watson (1939) and others as desirable for the successful preservation of silage.

The results obtained in the present study do not agree with the finding of Alderman et al. (1954) and others that treatment of ensiled herbage with metabisulphite resulted in a type of preservation different from that which normally occurs in herbage ensiled without treatment. Further data (Alderman et al. 1955) showed that the production of acetic and lactic acids by bacterial fermentation was limited in metabisulphite-treated silage, while

butyric acid production was almost eliminated, despite pH values well above the desired level of 4.0. The effectiveness of sodium metabisulphite in inhibiting fermentation in silage has been substantially confirmed by Archibald (1954), Sears (1955, 1956), Murdoch et al. (1956) and others, while Cowan et al. (1953) and Allred et al. (1955) have commented on the unorthodox behaviour of herbage preserved with metabisulphite with regard to the content of fermentation products in the resultant silage. Alderman et al. (1955) have suggested that metabisulphite silages are preserved primarily by the action of the bisulphite ion instead of the hydrogen ion as in other conventional types of silage.

Although two groups of sheep, fed either untreated or treated silage, showed no significant difference in fresh silage or dry matter intakes, the same animals when given a free choice of the silages did exhibit a significant preference for untreated material. Dry matter and fresh silage intakes in favour of the control silage were, however, slight and of little practical significance. Several workers have used sheep in digestion trials and found metabisulphite-treated silage to be palatable (Woolfolk et al. 1954; Wittwer et al. 1955; Bratzler et al. 1956), but no literature is available on the relative palatability of untreated and treated silages when fed to sheep.

That dairy cattle exhibited no marked feed preference when given a free choice of the silages, does not agree with the results obtained by Little (1954), Bratzler et al. (1955) and Bratzler et al. (1956). These workers reported the marked preference of dairy heifers for metabisulphite-treated silage over silage made from the same crop without preservative addition. In studies conducted by Wittwer et al. (1955), on the other hand, silage

treated with the salt apparently had a lower feed preference by dairy cows than untreated silage.

In view of the similarity of composition between the silages under discussion and the identical type of fermentation undergone by each, it is hardly surprising that no marked preference was shown by sheep and cattle for either silage. In the studies of Little (1954), Bratzler et al. (1955) and Bratzler et al. (1956), the use of sodium metabisulphite resulted in a different type of fermentation from that undergone by untreated herbage. In the studies of Bratzler et al. (1955), metabisulphite treatment limited bacterial fermentation within the mass, with a reduction in loss of the more digestible portion of the silage. This factor could account for the difference in consumption in favour of the treated silage. In trials, reported by Wittwer et al. (1955), metabisulphite treatment did not greatly inhibit fermentation, while dry matter losses of similar magnitude were recorded for untreated and treated silages. Low consumption of treated silage was attributed in part to the poor keeping quality of the material following removal from the silo, a factor not substantiated by the results of the present investigations.

Present research did support the view of Watson (1939), Monroe et al. (1946) and others, that the use of preservatives has little effect on the digestibility of dry matter in silages and their total digestible nutrient content, and the more recent finding of Gordon et al. (1954) and Wittwer et al. (1955) that metabisulphite treatment of herbage was ineffective in improving the digestibility of the dry matter in the resultant silage. Lancaster (1956) in one trial actually found metabisulphite silage to be slightly inferior to untreated material in dry matter digestibility. These results, however, disagree with the

finding of Pennsylvania workers (Cowan et al. 1953; Bratzler et al. 1956) that metabisulphite silage was superior to the corresponding no-preservative silage with regard to digestibility of the dry matter and total digestible nutrient content, and in some trials contained a higher content of digestible crude protein.

In the studies of Cowan and Bratzler metabisulphite treatment of the herbage caused diminished fermentation within the mass with a resultant reduction in loss of the digestible portions of the feed. Lowered nutrient losses from treated silage involved mainly the carbohydrate fraction and resulted in the production of a more nutritious fodder. Woolfolk et al. (1954), in feeding trials with sheep, has substantially confirmed the results of Pennsylvania workers.

In the present investigation, metabisulphite treatment proved to be ineffective in reducing fermentation within the mass, values of similar magnitude being recorded for the common fermentation products in the silages. These results are in agreement with those of Lancaster (1956), who, in addition, obtained no outstanding difference in the magnitude of dry matter loss from the untreated and treated silage. Although no records were kept of nutrient losses incurred during storage, chemical data relating to the conventional feed fractions and fermentation products would suggest that dry matter losses from the silages were of a similar order. Metabisulphite-treated silage could not, therefore, be expected to possess a higher nutritive value than the corresponding no-preservative silage.

That the addition of metabisulphite to herbage at ensiling time failed to produce a silage of superior quality to that made from similar material, untreated with the salt, may be attributed to one or all of several causes: the nature nature of the

herbage ensiled; the rate and method of application of the additive; and the penetration of rain water into the silages during storage.

Sodium metabisulphite is a powerful reducing agent when in solution and will oxidize to sodium bisulphate (Alderman et al. 1955). Therefore, any factor tending to increase the access of air or reducible material to the metabisulphite will correspondingly lower the residual sulphite in the silage. Alderman et al. (1955) have listed such factors as the dry matter content of the ensiled herbage, the rate of filling, type of silo, degree of consolidation, and type of seal used.

In the present investigation, herbage was ensiled at an advanced stage of maturity. American work (Cowan et al. 1953) emphasizes that the additive should not be used with material of this type, the salt having proved to be positive in action only when applied to immature material. Thus, Gordon et al. (1953), who used high dry matter herbage, found no difference in dry matter losses from untreated and treated silages, while the palatability and feeding value of the products were similar. Failure of the salt to produce a high quality silage was attributed to its oxidation by excess air remaining in the ensiled material. However, in the trials under discussion the herbage was chopped prior to ensiling, well consolidated and the pit rapidly filled, factors which should reduce the access of air to the metabisulphite. Furthermore, Murdoch et al. (1956) found metabisulphite to be effective in lowering fermentation activity and nutrient losses in silage when applied to chopped herbage of high dry matter content. Thus, the mature nature of the experimental herbage cannot in itself satisfactorily explain the failure of metabisulphite to produce a silage superior in

quality to that made from similar material ensiled without preservative addition.

That metabisulphite was applied to the swathe as a water spray at an application rate of 6 pounds per ton of ensiled herbage may have some bearing on the results obtained. Owing to the behaviour of the salt in the presence of excess air, it is reasonable to assume that much of the metabisulphite was oxidized prior to the entry of the herbage into the pit and thus became ineffective as a sterilising agent. The findings of Lancaster (1956), that metabisulphite applied to immature herbage as a water spray failed to improve the quality of the silage, supports this assumption. Although residual sulphite determinations conducted on the treated silage showed that a portion of the salt remained in a form capable of exhibiting bactericidal properties, there is reason to believe that the amount present was inadequate to ensure successful preservation of the silage. The results of recent American tests have shown that metabisulphite will not preserve silage effectively if the rate of application falls much below 8 pounds per ton of unwilted herbage (Bratzler *et al.* 1955).

The mechanical loss of metabisulphite in seepage from the pit cannot be overlooked as a possible factor in explanation of the results. The loss of any silage additive, when applied in solution, is well known (Murdoch *et al.* 1951; Dijkstra 1951). Where there is leaching of the silage by rain, as occurred in the present investigation, it seems probable that a readily soluble substance like sodium metabisulphite is liable to loss by seepage, the effect nullifying any advantage there might have been in using the additive. The fact that a significantly higher concentration of residual sulphite was found in the lower

layer of the silage compared with the upper region, supports the view that leaching occurred within the mass. In two trials reported by Murdoch et al. (1956) the failure of metabisulphite to produce a high quality silage was attributed in part to leaching of the salt following penetration of rain water into the mass. Gowan et al. (1956), in studies with trench silage, also found metabisulphite to be ineffective as a sterilizing agent when no seal was applied, a result attributed to leaching of the preservative.

It seems, therefore, that with chopped mature herbage, the application of metabisulphite as a water spray is of little value when compared with untreated silage. Although it is not possible to isolate any one factor from those discussed, which in itself could have affected the performance of the additive, the results of the investigation, supported by the findings of other workers, would suggest the rate and method of application of the additive as the major causal factor, with stage of maturity of the crop and possible leaching effects as minor accessories.

The poor quality of the untreated silage requires further explanation. According to Peterson (1925) and others, lactic acid fermentation normally occurs if the crop is harvested at a mature stage of growth with a decrease in pH to 4.0 or less. Furthermore, the herbage was chopped, a factor, which, according to Woodward and Shepherd (1938), Martin and Buysee (1953) and others, should further encourage a lactic fermentation. It seems probable that rain water which was admitted to the pit during storage of the crop, may have some bearing on the results. Barnett (1954) has stated that leaching of silage may result in the removal of lactic acid, with the subsequent attack of butyric acid producing organisms on both residual carbohydrate and

protein, while Archibald (1946) has shown that butyric acid formation may be high in excessively wet silage.

As the herbage used in the present investigation was cut at an advanced stage of maturity and not, therefore, typical of material which, when ensiled, invariably undergoes undesirable fermentation in the silo with the production of an undesirable type of silage, it could not be considered suitable for assessing the value of sodium metabisulphite as an additive. The value of the latter lies in its ability to prevent undesirable fermentation and/or encourage a desirable type of fermentation within the mass.

On these grounds it was considered desirable to further investigate the value of sodium metabisulphite as an additive in silage-making. Accordingly, further studies were undertaken the following season in which immature herbage, which better meets the requirements necessary for the full evaluation of an additive, was ensiled with and without the addition of metabisulphite. Mature material, untreated and treated with the salt, was also subjected to further test, a different rate and method of application of the additive being employed from that used in the present study.

E. SUMMARY OF PRELIMINARY RESULTS

1. Results are presented for the chemical composition, relative palatability and digestibility of silages made in an unlined pit from chopped mature herbage, untreated and treated with sodium metabisulphite.
2. Addition of metabisulphite had no effect on improving the quality of the resultant silage. Each silage was characterised by a high pH value, a low lactic acid and carotene content and a relatively high volatile acid content with no significant differences between them.
3. Treated silage contained a portion of the original metabisulphite added, the concentration of the residual salt showing a significant increase with depth in the pit.
4. Within each silage a significant decrease in pH value and a highly significant increase in dry matter content was observed with increasing depth in the pit, while a low lactic acid level was significantly correlated with a high pH value.
5. Similar digestibility coefficients were obtained for the dry matter, organic matter, crude protein and nitrogen-free extract fractions in the silages, while the crude fibre was slightly more digestible and the ether extract slightly less digestible in the treated silage. In consequence, treated silage had a higher mean starch equivalent value and total digestible nutrient content, but observed differences between treatments were small and of little practical significance.

The silages had a similar digestible crude protein content and wide nutritive ratio.

6. When sheep were fed either untreated or treated silage there was no significant difference between the treatments in fresh silage or dry matter intake. The same sheep, when given a free-choice of the silages, showed a significant but slight preference for untreated material.
7. Three dry cows, given a free-choice of the silages, showed no significant preference when fresh silage intake was used as an index of palatability. On a dry matter basis, the animals, as a group, showed a significant but slight preference for treated silage.
8. The failure of metabisulphite to reduce fermentation within the mass and produce a silage of superior quality to that made from similar material untreated with the salt, was attributed to the method and rate of application of the salt adopted, the possible leaching of the additive during storage of the silage, and the mature nature of the material ensiled.
9. Further studies are planned to investigate the value of metabisulphite as an additive when applied to immature and mature material, a higher rate and different method of application of the salt being adopted to that used in the present study.

CHAPTER IV

FURTHER STUDIES IN THE USE OF SODIUM METABISULPHITE AS AN ADDITIVE IN SILAGE-MAKING

In the present investigation, a grass-legume sward was cut at the leafy and early flowering stages of growth, chopped and ensiled in small experimental silos, with and without the addition of sodium metabisulphite. The objectives of the investigation were: to determine whether immature material needed to be treated with an additive to ensure successful preservation and if there was any advantage to be gained by applying the salt to mature material; whether and how metabisulphite reduces nutrient losses during storage and whether the additive influences the feeding value of the final product.

The results of the investigation are presented in two sections. The first section deals with the nutrient losses incurred by the silages during the storage period and their resultant chemical composition, while the second section is devoted to a study of their nutritive value, this being assessed in the present instance by determining the digestibility and relative palatability of the silages.

A. THE NUTRIENT LOSSES AND CHEMICAL COMPOSITION OF THE SILAGES

Estimates were obtained of the dry matter, organic matter, mineral matter and crude protein lost from each silage during the storage period. In addition, samples of the resultant silages were analysed to determine their pH value, carotene and volatile acid content and thereby gain information on the type

of fermentation undergone during storage. Carotene determinations were also made on the fresh herbage as ensiled.

Experimental Materials

Experimental Silos

A battery of four rectangular concrete silos, each of inner dimensions 5' x 4' x 5' and with a capacity of 2 - 3 tons, depending to a great extent on whether or not the herbage is chopped before ensiling, were used in the experiment (fig. 10).

Each silo had a cement base and a drain in the bottom (fig. 11), the latter being led by earthenware pipes, 4" in diameter, to a suitable container for the collection of exudate. Wooden oversilos, 3' in height, were fitted to the top of the silos, giving a total height of 8' and a capacity of approximately 4 tons of chopped herbage. A 6" layer of road metal was placed in the bottom of each silo to improve the efficiency of the drain.

Experimental Pasture

A 6-acre paddock, seeded in 1954 with a general purpose mixture of 20 pounds short rotation ryegrass, 5 pounds perennial ryegrass, 4 pounds broad red clover and 2 pounds white clover per acre, was selected for the experiment. The paddock was cut the same year for silage, oversown with 7 pounds of short rotation ryegrass per acre during April 1955 and closed for silage on the 9th September. Two blocks, each of 1 acre, were selected at random to provide the herbage requirements.

Experimental Methods

Botanical Composition of Herbage

The botanical composition of the two selected blocks was determined one day prior to the cutting of each, by use of the



Figure 10

The experimental silos.

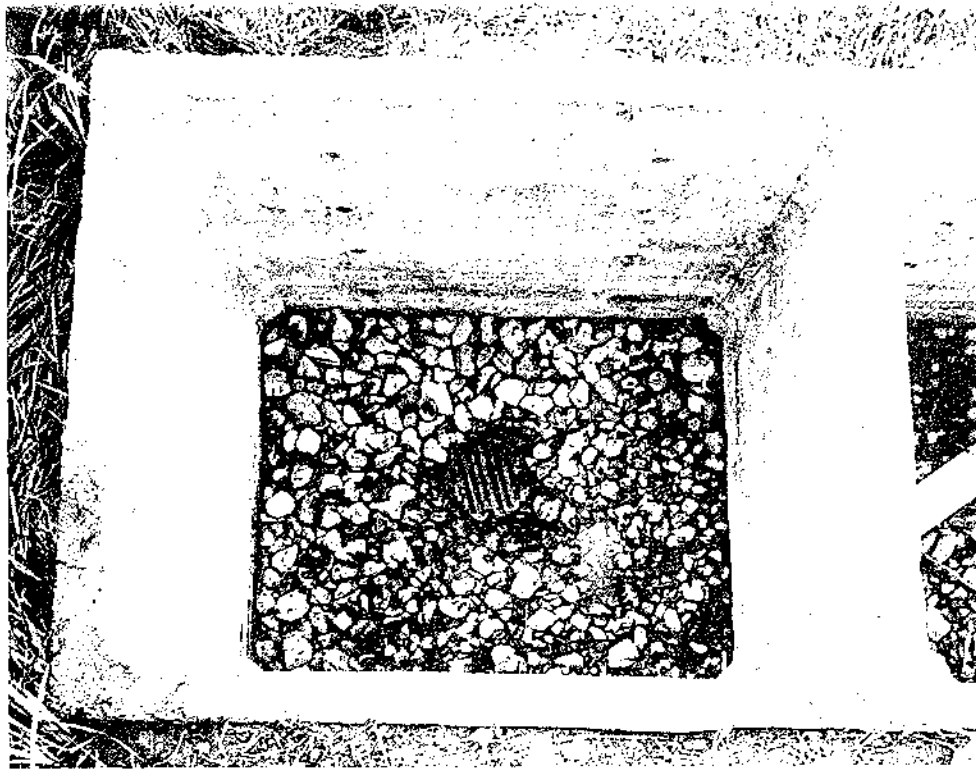


Figure 11

Interior view of experimental silo,
showing central drain.

Percentage Productivity Method (Brown 1954).

Ten 4" x 3" turf samples were taken per block. All samples were drawn from random throws of a frame over the whole area, care being taken to avoid edge effects. The vegetation from each turf sample was cut 3" from the base, placed in a plastic container and thereafter transferred to a deep freeze cabinet. Each sample was dissected out into the following species: ryegrasses, red clover, white clover, other grass species and other species. From green weight determinations made on the individual species, the mean percentage of each in the sward was estimated.

Individual species samples from each block were bulked, thoroughly mixed and two 50 g. sub-samples taken for dry matter determination. Drying was carried out in an oven of the forced draught type at 105°F for eight hours. From mean species dry weight figures, an estimate of the botanical composition of each block on a dry-weight basis was obtained.

Filling the Silos

Blocks 1 and 2 of the experimental paddock provided the herbage for the first and second cuts of silage respectively. All herbage was cut with a hay mower and immediately lifted by the forage harvester (fig. 12) with knives set to cut the material into 4 - 6" lengths. The resultant chopped material was blown into an accompanying truck and immediately transported to a concrete apron adjoining the experimental silos, thereby preventing wilting.

Immature material was ensiled on the 31st October and 1st November, at which times the pasture was 12 - 15" in height and



Figure 12

Field harvesting of the herbage.

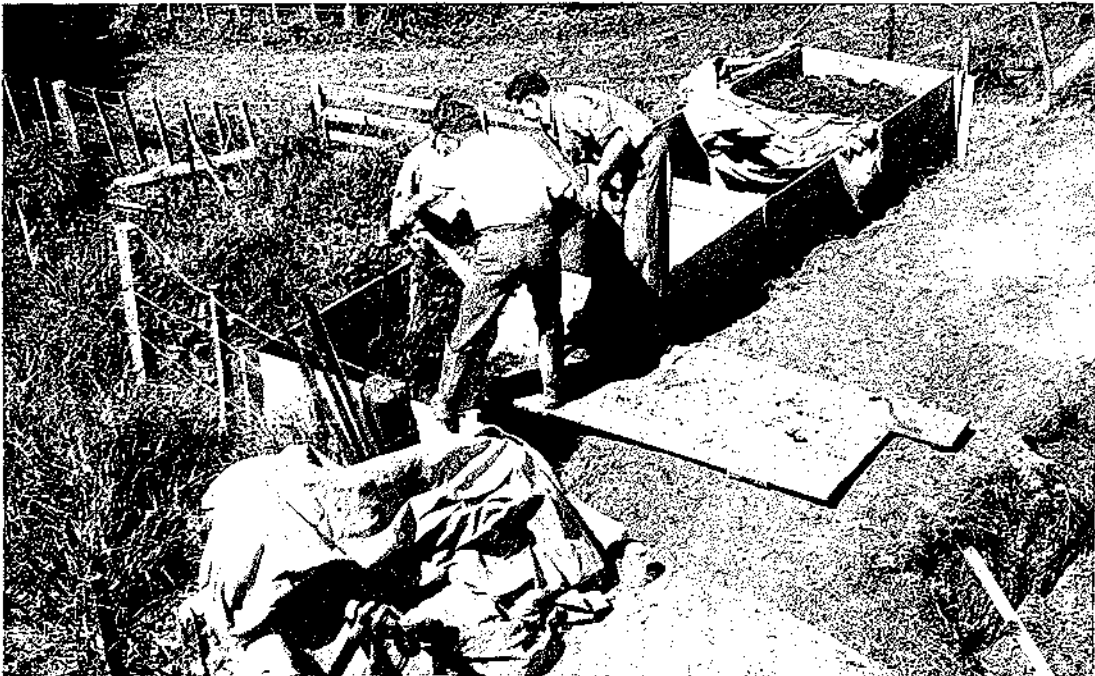


Figure 13

Filling the silos with immature herbage.

still making leafy growth. More-mature material was ensiled on the 25th November when the pasture was 18" in height and the ryegrasses were headed but in the pre-bloom stage. The four treatments were:

- Silo 1 - Untreated immature material.
- Silo 2 - Untreated more-mature material.
- Silo 3 - Metabisulphite-treated more-mature material.
- Silo 4 - Metabisulphite-treated immature material.

As the objective of the experiment was to compare silages made by the best possible techniques, untreated immature material was ensiled by the "low temperature" process as advocated and described by Watson and Ferguson (1937). Silo 4 was rapidly filled, a method which should prove satisfactory when a sterilizing agent is employed as an additive. The filling of silos 2 and 3 was rapid and continuous, a process advocated by all authorities for the ensilage of mature material (Watson 1939; Musgrave 1950; Barnett 1954.)

During the first day of operations silo 1 was filled to one-third of its capacity and the mass allowed to heat. As the desired temperature level of 80°F was reached the following day, ensiling was recommenced. Silos 1 and 4 were rapidly filled, loads being alternated between silos to ensure even distribution of the herbage (fig. 15). Each silo was topped up twice (2nd and 5th November) and thereafter sealed. Silos 2 and 3 were filled within three hours following the commencement of ensiling. Loads were again alternated between silos to ensure that each received similar material (fig. 14). Both silos were immediately sealed after filling. Sealing of all silos was effected by the use of a double layer of sisalkraft paper, on top of which was placed a layer of soil, approximately 10" thick in the middle of



Figure 14

Filling the silos with more-mature herbage.

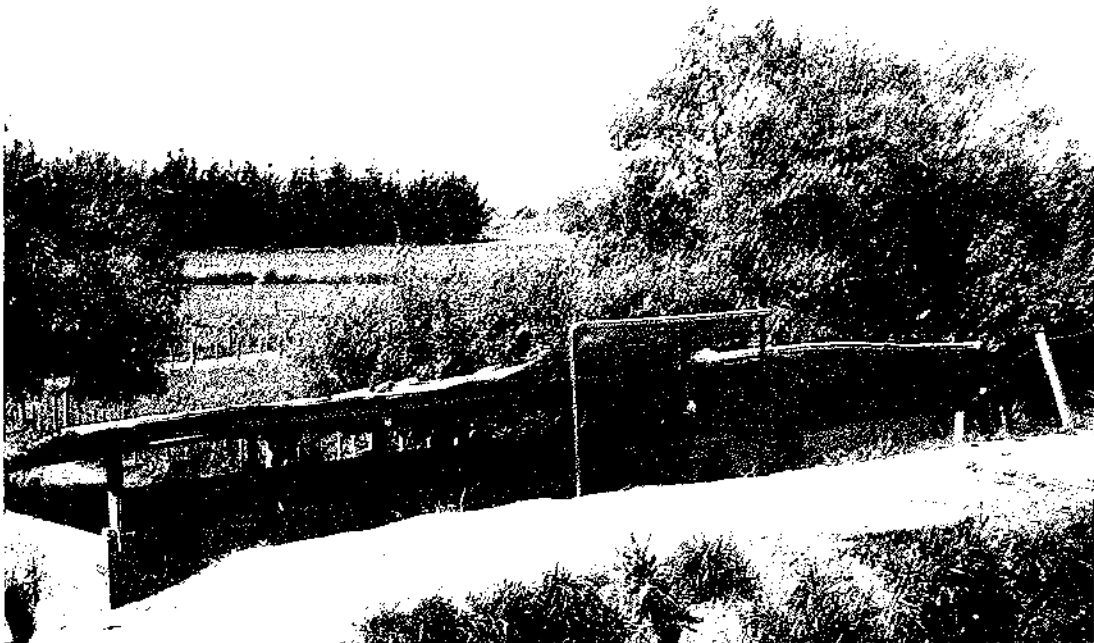


Figure 15

The experimental silos, roofed to prevent penetration of rain water.

the silo and 6" on the edges. This seal served the twofold purpose of excluding air and giving added consolidation to the mass. Thereafter, all four silos were roofed with corrugated iron covers to prevent penetration of rain water (fig. 15).

Weighing and Sampling of Herbage

All green material was weighed into the silos in lots of 50 pounds. Weights were recorded by use of a spring balance and tripod (fig. 16) and a set of platform scales (fig. 17). Light wooden boxes served as containers for the herbage. As each 50-pound lot of green material was weighed out, a sample of about 1 pound weight was taken and placed in a metal container. Samples were bulked and thoroughly mixed after each 1000 pounds of herbage had been ensiled and two sub-samples, each of 250 g., then taken for dry matter determination. Sub-samples were immediately transferred to the laboratory and dried in a forced draught electric oven at 150°P for 8 hours. After weighing, each pair of sub-samples was bulked, finely ground in a laboratory mill and stored in an airtight container. Crude protein, mineral matter and organic matter determinations were conducted in duplicate on laboratory samples drawn from each bulked sample of ground material, after thorough mixing of the latter.

All forty samples drawn from each 2000 pounds of ensiled herbage were thoroughly mixed and one representative sub-sample of approximately 100 g. weight taken for carotene determination. Each sub-sample was placed in a plastic container, immediately transported to a deep freeze cabinet and analysed at a later date.

The weights of dry matter, crude protein, mineral matter and organic matter ensiled were calculated by applying analytical values for these constituents to the weights of fresh forage ensiled.



Figure 16

Tripod and spring balance used to record the weights of ensiled herbage.

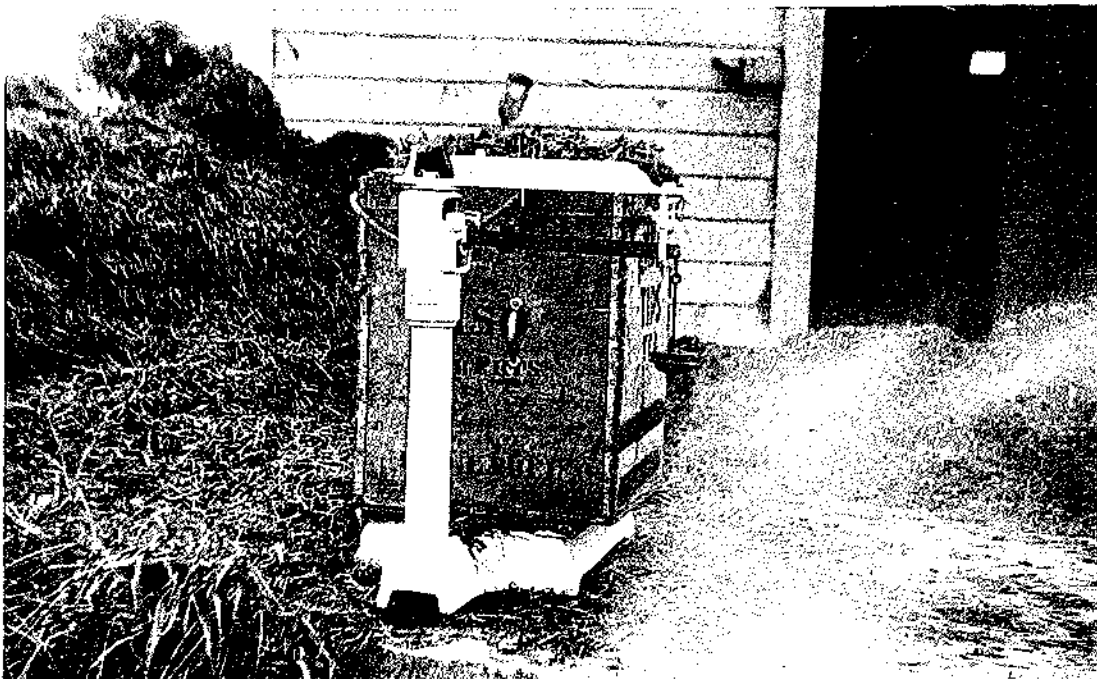


Figure 17

Platform scales used to record the weights of ensiled herbage.

Application of Sodium Metabisulphite

Sodium metabisulphite was applied as a powder at the rate of 10 pounds per ton of unwilted herbage. To ensure even distribution of the salt, previously weighed 200 g. portions were sprinkled uniformly over each 100 pound of fresh herbage as ensiled (fig. 18). A fresh load of herbage was immediately placed on top of the treated material to prevent possible loss of sulphur dioxide gas.

Collection and Treatment of Exudate

Exudate was collected by permitting each silo to drain into a 10-gallon metal can (fig. 19). During the first few 24-hour periods after completion of filling the volumes of exudate from the immature silages were measured at frequent intervals and from the average of the results, the flow for every 24-hour period was calculated. On cessation of the initial heavy flow, exudate was allowed to collect in the can over a 24-hour period and as flow further decreased, readings were taken at intervals of a few days. The estimated flow during these intervals was ascertained by interpolation of the results. Exudates from the more mature silages exhibited no initial heavy flow and were originally measured daily and thereafter at intervals throughout the period of flow.

Exudate volume was measured by means of a graduated container (fig. 19) and the results expressed on a gallonage basis. A 200 ml. sample was taken at each collection period. When flow was considerable samples were obtained directly from the inlet pipe. Thereafter, the contents of each can were thoroughly mixed and a representative sample withdrawn.

The pH value of each sample was recorded and chemical analyses made to determine the dry matter, crude protein, mineral matter and organic matter content. Each sample from treated silages was also



Figure 18

Application of sodium metabisulphite.

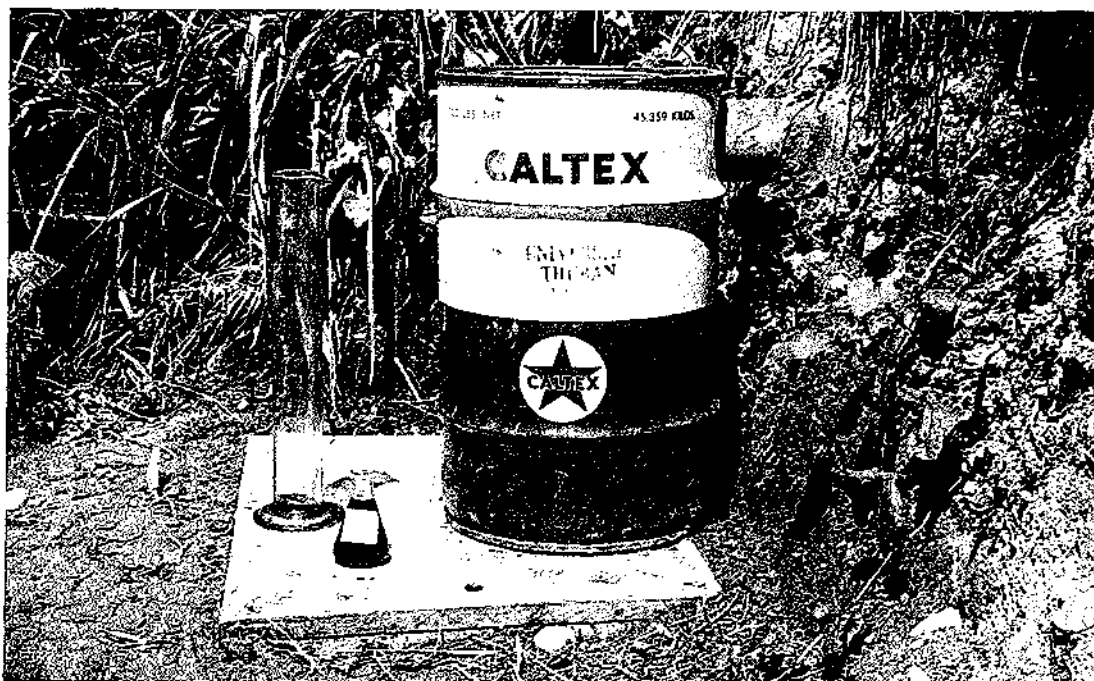


Figure 19

Collection of exudate from one of the experimental silos.

analysed to determine total residual sulphite. Specific gravity determinations were made on the first drawn samples from each silo. As values obtained were found to approximate closely to 1.00, the analysis was discontinued.

From chemical analysis data and total weights of exudate voided, the weights of dry matter, crude protein, mineral matter and organic matter lost in the exudate from each silo and the loss of metabisulphite from treated silages were calculated. The loss of each constituent was expressed as a percentage of that ensiled.

Temperature Recording

Thermocouples, constructed from copper-constantan wire, as described by Eggert (1946) and shown in fig. 20, were placed in the centre of each silo during the filling procedure, at depths of 2' and 4' from the base of silos 1, 2 and 3. Only one couple was placed at the former depth in silo 4. All couples were led up the inner wall of their respective silos to a central point to facilitate temperature recording.

Frequent recordings were taken daily following the filling of each silo until temperature reached a maximum. Thereafter, daily decline in temperature within each silo was recorded until values reached atmospheric level or remained at a constant value over a prolonged period of time. Recordings were made with a portable potentiometer and standardized by placing an ice bath in the circuit, to serve as a "cold junction" (fig. 21). Temperature readings were expressed in degrees Fahrenheit.

Removal of Silage

The two silos (1 and 4) containing untreated and treated immature herbage were opened 84 days after filling and the total contents of each weighed. The other two silos (2 and 3)

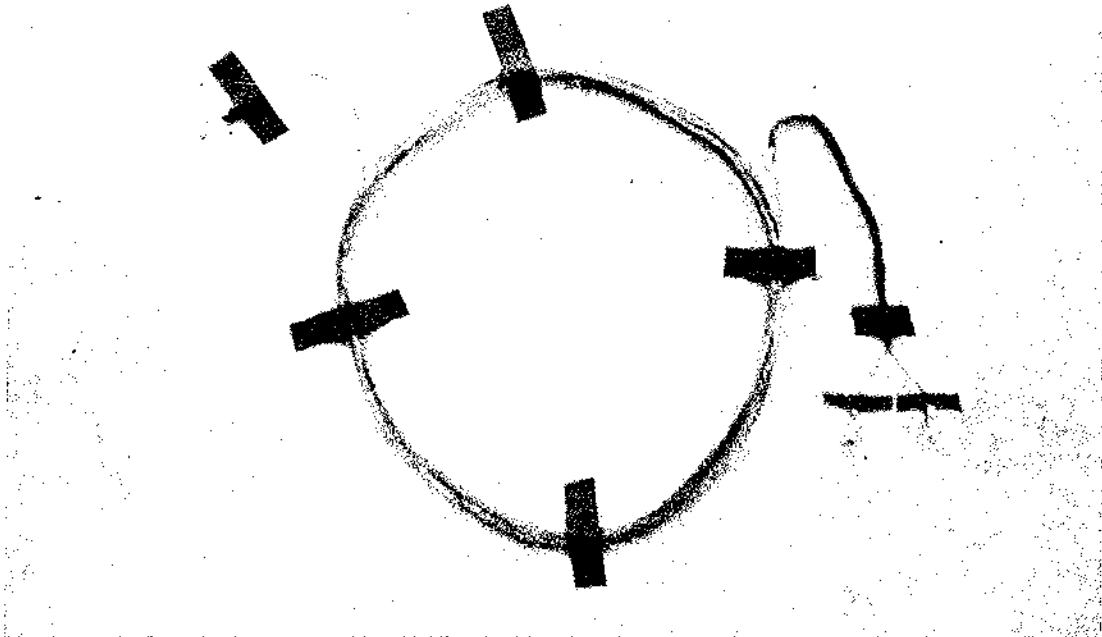


Figure 20

Close view of thermocouple lead.



Figure 21

Recording the temperatures in the silages.

containing the more-mature herbage were opened 73 days after filling and similarly treated. As trials were planned to determine the nutritive value of the silages, each silo was emptied over a 16-day period. Adoption of this procedure ensured that the experimental animals received a representative sample of each silage in their diet.

Material from each silo was cut out in sections daily throughout the 16-day period and pitched on to a canvas sheet (fig. 22). Silage which appeared inedible was separated out from edible material. The total weights of inedible and edible silage were recorded by means of a spring balance and tripod (fig. 23). All edible material was retained for feeding to sheep and dairy cows on digestibility and palatability trials respectively. Following the removal of daily silage requirements, the surface of each silo was covered with damp sacking to prevent drying out of the surface layers of silage and a wooden lid placed in position to prevent penetration of rain water.

A representative 250 g. sample of inedible and edible silage was taken daily from the material removed from each silo. Samples were dried in a forced draught electric oven at 150°C for 12 hours, weighed, finely ground in a laboratory mill and transferred to airtight containers. Dried samples of edible silage from each 1000 pounds of fresh silage were bulked. All dried samples of inedible silage from each silo were bulked. Crude protein, mineral matter and organic matter determinations were conducted in duplicate on representative laboratory samples drawn from each bulked sample of edible and inedible silage.

The weights of fresh edible and inedible silage removed and analytical values were used to calculate the total edible and inedible dry matter, crude protein, mineral matter and organic

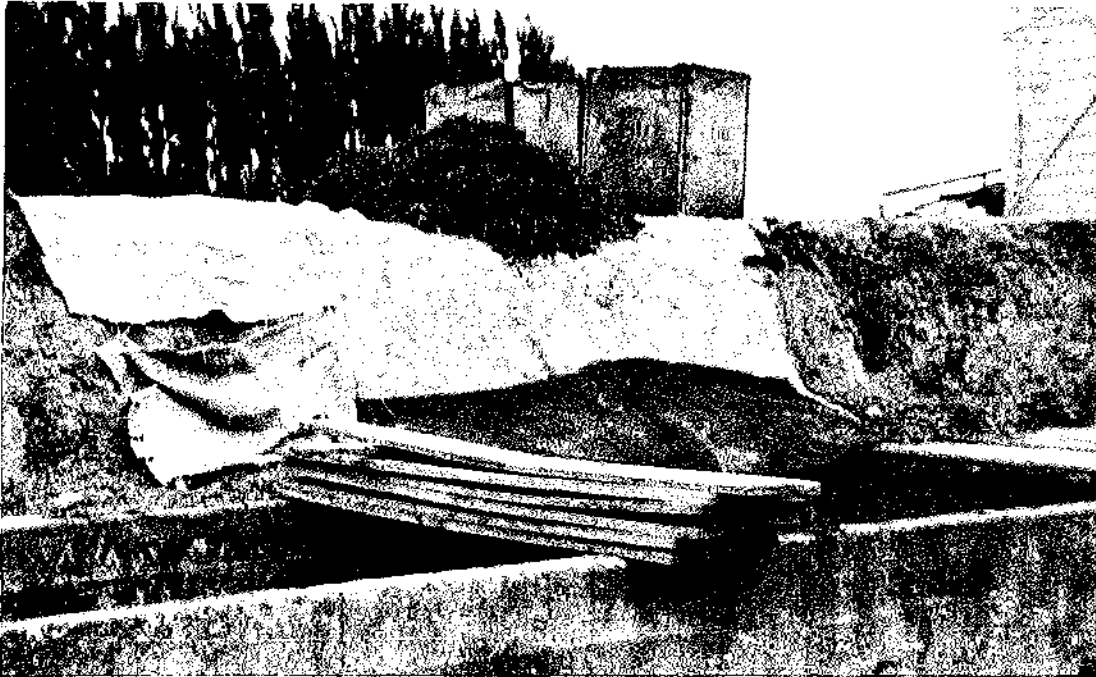


Figure 22

Removal of silage from experimental silo.

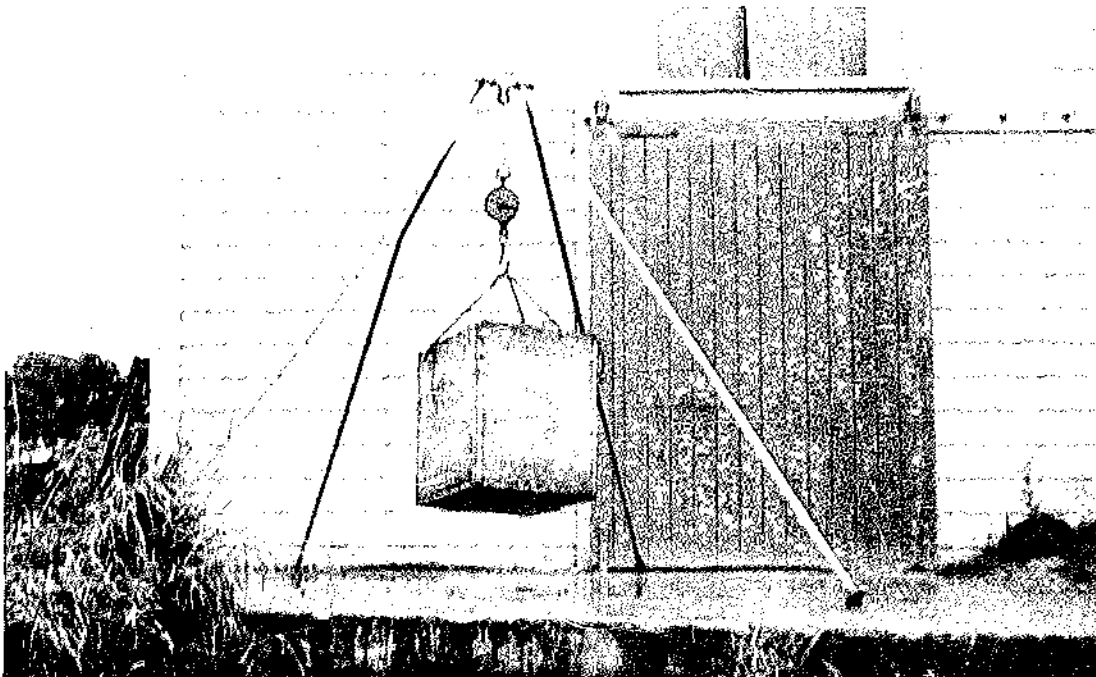


Figure 23

Tripod and spring balance used to record the weights of silage removed from the silos.

matter recovered from each silo.

Determination of Total, Spoilage and Fermentation Losses

Total Loss. The total loss of dry matter, crude protein, mineral matter and organic matter, incurred by each treatment during the storage period, was obtained by subtracting the amount of edible dry matter, crude protein, mineral matter and organic matter from the total amounts of each constituent ensiled.

Spoilage Loss. The losses of the above mentioned constituents as inedible silage were determined by subtracting the amount of each inedible constituent removed from the individual silos from the total amounts of each constituent ensiled.

Fermentation Loss. The fermentation loss of each constituent was calculated from the total loss data, by deducting the exudate and spoilage losses of each constituent from the total amount of each lost.

All losses of dry matter, crude protein, mineral matter and organic matter were expressed as percentages of the total ensiled.

Sampling Procedure

All silos were subdivided into two equal depths after removal of top spoilage. Within each silo four sample points were selected from a table of random numbers, such that two samples were located in the upper and two in the lower depth. Their position within the silo was marked by driving in metal rods to the appropriate randomly selected depths.

On reaching a sample point in the emptying process of the silo and 8" cube of silage was removed for analyses, the tip of the metal rod serving as the mid-point of the cube. Thereafter, each sample was thoroughly mixed and three representative

sub-samples withdrawn for carotene, pH and volatile organic acid determination respectively. pH determinations were made on sub-samples within two hours after their removal from the silo. Sub-samples for carotene and volatile acid estimations were stored in a deep freeze cabinet and analysed at a later date. All analytical values were subjected to the Analysis of Variance Test, according to Snedecor (1955, p.274 et seq.).

Analytical Methods

(a) Fresh Herbage and Silage.

Crude Protein, Mineral Matter and Organic Matter. All determinations were conducted in duplicate on representative laboratory samples of dried herbage and silage, according to methods recommended by the Association of Official Agricultural Chemists (1952).

pH Value. Silage samples were extracted in a press and determinations made in duplicate on the juice extract, by means of a Cambridge pH meter with a glass electrode.

Carotene Content. All determinations were made in duplicate on finely chopped 5 g. laboratory samples of fresh herbage and silage, according to the method of Worker (1957).

Volatile Organic Acids. The volatile fatty acid content of the silages, in terms of acetic, propionic and butyric acids, was determined on fresh laboratory samples, according to the method of James and Martin (1952).

(b) Exudate.

Dry Matter. The dry matter of the exudates was determined by evaporating 20 ml. samples to dryness on a water bath. After drying for three hours in an electric oven at 100°C, the product was weighed and the total dry matter lost in the exudate volume calculated.

Crude Protein. The crude protein content of exudate samples was determined by pipetting 20 ml. of the sample into a 300 ml. Kjeldahl flask, adding a few drops of concentrated sulphuric acid and evaporating nearly to dryness. To prevent bumping, a copper catalyst, in the form of a pellet, was added during the process of evaporation. The digestion was then conducted in the usual way.

Residual Sulphite. Total residual sulphite (free and combined), present in the exudate from treated material, was estimated as sulphur dioxide, according to the method described by Barnett (1951 b).

pH Value. All determinations were made in duplicate on 40 ml. samples of exudate, by means of a Cambridge pH meter with a glass electrode.

Mineral Matter and Organic Matter. Determinations were made on 20 ml. samples of exudate, according to methods recommended by the Association of Official Agricultural Chemists (1952).

Experimental Results

Botanical Composition of Herbage Ensiled

The botanical composition of the herbage actually ensiled, as determined one day prior to the cutting of each experimental block, is shown in Table XXXVII.

At the first cutting, the herbage was 55 per cent grass, 39 per cent legume and 6 per cent weeds on a dry-weight basis. At the second cutting, the grass component accounted for 66 per cent of the sward, legumes 33 per cent and weeds only 1 per cent. At both cuttings *Lolium* species (ryegrasses) were dominant, while *Trifolium pratense* (red clover) was the dominant legume.

TABLE XXXVIII

Country	1955		1956		Total
	Million Dollars	Percentage of Total	Million Dollars	Percentage of Total	
United States	10,000	45.0	12,000	48.0	22,000
United Kingdom	5,000	22.5	6,000	24.0	11,000
France	3,000	13.5	4,000	16.0	7,000
Germany	2,000	9.0	3,000	12.0	5,000
Canada	1,500	6.8	2,000	8.0	3,500
Japan	1,000	4.5	1,500	6.0	2,500
Other	1,500	6.8	2,000	8.0	3,500
Total	22,000	100.0	25,000	100.0	47,000

Table XXVIII

Mean Chemical Composition of Herbage Ensiled and the Resultant Silages

(moisture-free basis)

Treatment	Dry Matter Percentage		As Percentage of the Dry Matter									
			Crude Protein			Mineral Matter			Organic Matter			
	Herbage	Silage		Herbage	Silage		Herbage	Silage		Herbage	Silage	
		Edible	Inedible		Edible	Inedible		Edible	Inedible		Edible	Inedible
<u>1st Cut</u> (immature)												
Control	17.70	16.12	16.58	19.65	22.41	23.65	8.72	10.34	12.40	91.28	89.66	87.60
Metabisulphite-Treated	17.28	17.16	15.65	20.24	21.80	22.11	8.64	9.34	11.87	91.36	90.66	88.13
<u>2nd Cut</u> (more-mature)												
Control	21.11	19.24	16.30	15.03	18.35	20.00	6.87	8.58	8.40	93.13	91.42	91.60
Metabisulphite-Treated	20.73	19.05	16.25	14.60	17.92	19.80	7.26	8.98	11.89	92.72	91.02	88.11

Table XXXVII

Botanical Composition of the
Experimental Pasture

Species	Percentage Composition (dry-weight basis)	
	1st Cut (immature)	2nd Cut (more-mature)
Lolium species	53.0	64.0
Trifolium repens	13.0	5.0
Trifolium pratense	26.0	28.0
*Other Grasses	2.0	2.0
**Other Species	6.0	1.0
Total	100.0	100.0

*"Other Grasses" include *Holcus Lanatus*, *Poa trivialis*
and *Anthoxanthus odoratum*

**"Other Species" include *Rumex* spp. and *C. arvensis*.

Composition of the Herbage and Silage

Mean analytical values of the green material ensiled and the resultant silages are shown in Table XXXVIII. Complete details of all analyses are presented in Appendices IV to XI inclusive.

Immature herbage, as ensiled, showed little variation in dry matter content between silos. The more-mature herbage was much drier than the first cut but again the dry matter content of the ingoing material was similar for both silos. The dry matter content of the edible immature silages was almost identical with that of the herbage ensiled. Silages made from more-mature herbage, on the other hand, had a slightly lower dry matter content than the ingoing herbage. Addition of metabisulphite had little

effect on the dry matter content of the silages.

The crude protein content of the herbage showed a decline between the first and second cuts, but within the silages from each cut there was little variation. Silages consistently had a higher crude protein content than the fresh herbage. Compared with the composition of the herbage, all silages had a higher mineral matter and lower organic matter content. Treatment of the ensiled herbage with metabisulphite had little effect on the mineral matter and organic matter content of the resultant silages.

Exudate Losses

Rate of Exudate Flow. Exudate commenced flow from both immature silages within a few hours after completion of ensiling. The general trend of the flow was a rapid increase in the amount of exudate voided during the first two to three days, with a second but smaller peak flow a few days later, a result attributed to extra consolidation following "topping up" of the silos. Thereafter, flow from each silo showed a rapid decline to a low level, which in turn gradually decreased with time (fig. 24). Maximum daily flow for metabisulphite-treated silage occurred on the third day after ensiling, when 21.5 gallons of exudate were voided. Flow from the control silage did not reach as great a daily maximum, a figure of 8.5 gallons being recorded on the second day of flow. Although exudate flowed from both silos over the entire 84-day storage period, most of the seepage from treated silage occurred early; 79 per cent of the exudate was collected by the end of 14 days. A corresponding figure of 41 per cent was recorded for the control silage.

Both more-mature silages commenced flow on the fifth day after completion of ensiling. The general trend of flow was a

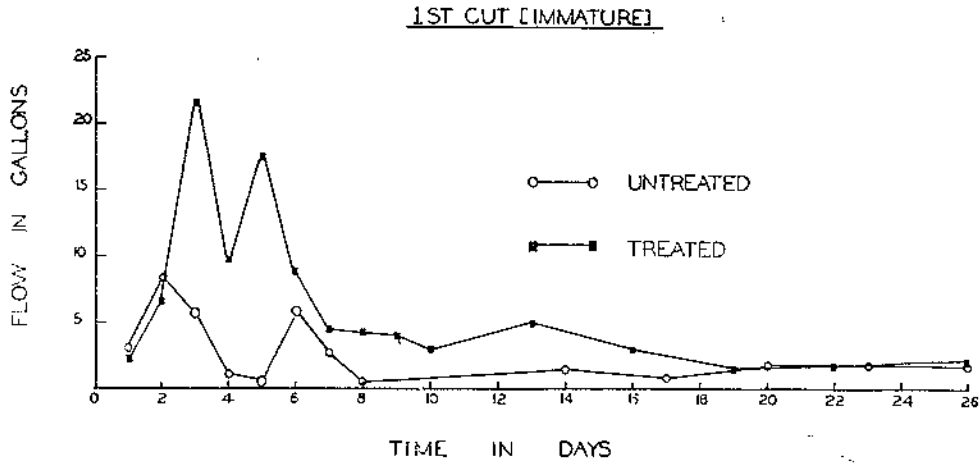


Figure 24

The flow of exudate from the immature silages during 26 days after completion of filling.

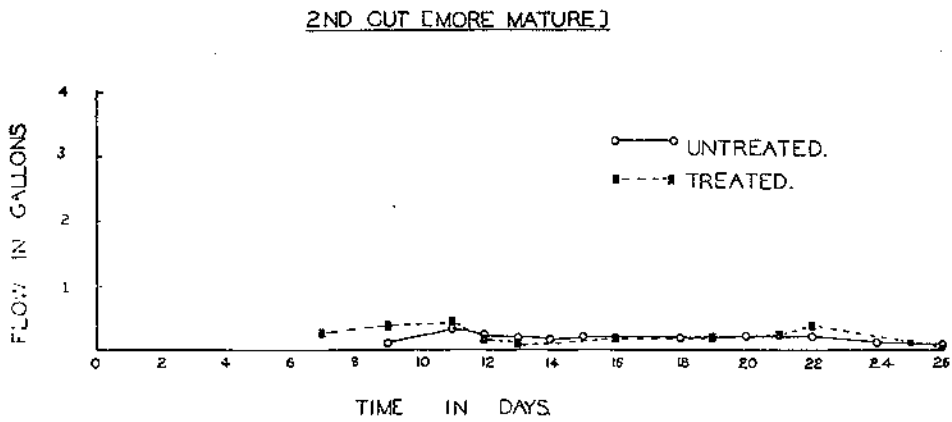


Figure 25

The flow of exudate from the more-mature silages during 26 days after completion of filling.

fairly uniform daily output of exudate over the first third of the 73-day storage period and thereafter a gradual decline (fig.25). Throughout the entire collection period daily exudate flow never exceeded 0.5 gallons from either silo.

Chemical Composition of Exudates. Mean analytical values for the pH, dry matter, crude protein, mineral matter and organic matter contents of the exudate from each silo are shown in Table XXXIX. Individual values for each constituent, as determined for exudate from untreated and treated immature and more-mature silages, are presented in Appendices XII to XV inclusive.

Table XXXIX
Mean Chemical Composition
of the Exudates

Treatment	Dry Matter %	pH	As Percentage Fresh Silage		
			Crude Protein	Mineral Matter	Organic Matter
<u>1st Cut</u> (immature)					
Control	5.74	4.96	1.44	1.45	4.29
Metabisulphite-Treated	6.42	5.57	1.78	1.69	4.72
<u>2nd Cut</u> (more-mature)					
Control	4.53	7.13	1.26	1.45	3.08
Metabisulphite-Treated	4.54	6.66	1.34	1.57	2.97

Exudate from metabisulphite-treated silages had a much darker colour and less odour than that from the corresponding control silages. The concentration of dry matter in the exudates from all silos varied throughout the collection period, but tended

to decrease with time. Extremes in dry matter concentration ranged from minimum values of 4.74 and 4.50 per cent to maximum values of 6.50 and 7.75 per cent for the control and treated immature silages. Corresponding dry matter values for the control and treated more-mature silages were 3.68 and 2.55 per cent (minimum) and 6.00 and 5.67 per cent (maximum) respectively.

The mean dry matter content of the exudate from untreated immature silage was less than that from the exudate of similar material treated with the salt. Both more-mature silages had a similar concentration of dry matter in the exudate, but values were lower than those recorded for immature silages. Exudate from treated immature silage had a higher concentration of crude protein, mineral matter and organic matter than that from the other silages. The latter had a similar mineral matter and crude protein concentrations in the exudate, but both more-mature silages were lower in organic matter content than untreated immature material.

Exudate from immature silages had lower mean pH values than that from mature material. In the former case, treated material had the higher pH value, while in the latter case the reverse occurred. Throughout the period of flow pH values of all exudates varied greatly (fig. 26). Although pH determinations of exudate were made at each collection no attempt has been made to speculate from them on the possible nature of the fermentation processes which occurred within the silos. The majority of exudate samples were obtained direct from the collection cans over a period of time. It seems probable that, under these conditions, the pH of the exudates may have altered somewhat from their original values on first entering the cans.

Total and Percentage Nutrient Losses in Exudates. Seepage losses, in terms of total exudate, dry matter, crude protein,

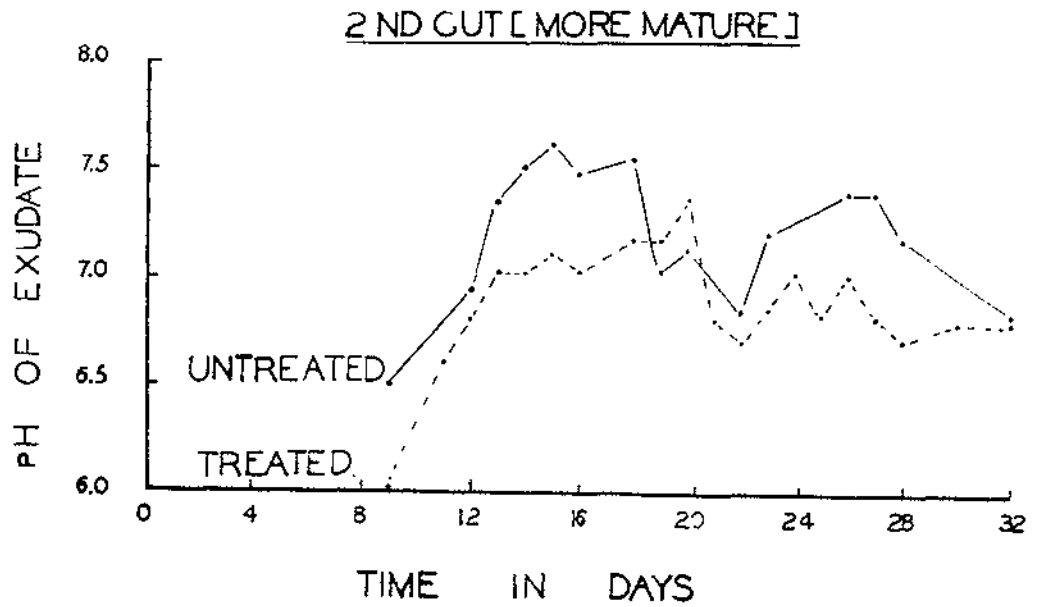
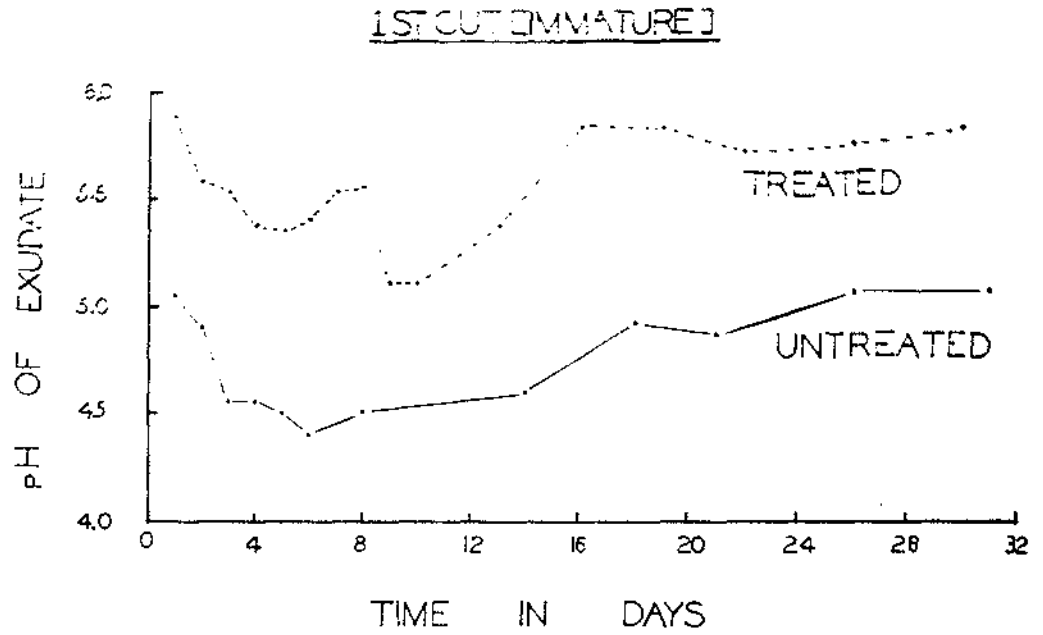


Figure 26

pH values of the exudate from the silages during 32 days after completion of filling.

mineral matter and organic matter lost from the different silages, are shown in Table XL. Details of all losses are presented in Appendices XII to XV inclusive.

Table XL

Weights of Fresh Material, Dry Matter, Crude Protein, Mineral Matter and Organic Matter Ensiled and Lost in Seepage from the Resultant Silages (all weights in pounds)

	1st Cut (immature)		2nd Cut (more-mature)	
	Control	Metabi-sulphite-Treated	Control	Metabi-sulphite-Treated
Green material ensiled	7,490	6,900	4,700	4,700
Exudate voided	721.5	1229.6	105.1	250.9
Percentage loss of ensiled wet weight in exudate	9.6	17.8	2.2	5.3
<u>Dry Matter</u> Ensiled	1326.5	1193.5	991.2	970.8
In Exudate	10.1	69.7	4.78	8.35
Percentage loss in exudate	3.0	5.8	0.5	0.9
<u>Crude Protein</u> Ensiled	260.0	242.2	148.9	141.6
In exudate	9.8	21.80	1.31	2.47
Percentage loss in exudate	3.8	8.9	0.9	1.7
<u>Mineral Matter</u> Ensiled	115.5	103.20	68.0	70.6
In exudate	10.70	17.60	1.56	3.05
Percentage loss in exudate	9.3	17.1	2.3	4.3
<u>Organic Matter</u> Ensiled	1211.0	1090.3	923.2	900.2
In exudate	29.4	52.1	3.22	5.30
Percentage loss in exudate	2.4	4.8	0.3	0.6

On a percentage basis metabisulphite-treated silages lost double the weight of exudate and crude protein in seepage compared with their corresponding controls and almost twice as much dry matter, mineral matter and organic matter. There was, however, a marked reduction in seepage losses from the more-mature silages over those made from immature material. Crude protein and mineral matter losses in the exudate from immature treated silage were unusually high, values being greater than those normally met with in the literature.

Higher nutrient losses in the exudate from treated silages compared with their corresponding controls are mainly due to differences in plant moisture squeezed out, there being only small differences in chemical composition between the exudates of treated and control silages (Table XXII). The greater flow of exudate from treated material is difficult to explain. A check kept on the rate of settling and final depth of silage within each silo failed to detect any marked difference between silages made from material within each cut.

Estimated Loss of Metabisulphite in Exudate. The concentration of metabisulphite in the exudate from immature treated material was high during the first few days of flow and then declined. The fall in concentration was rapid for several days and thereafter gradual (fig. 27). The concentration of the salt in the exudate from more-mature treated material showed greater daily variation compared with immature material, but tended to decrease with time (fig. 27). Extremes in concentration of metabisulphite ranged from minimum values of 0.02 and 0.04 g. per 100 ml. of exudate to maximum values of 0.20 and 0.09 g., for the immature and more-mature silages respectively. Mean concentration values of 0.08 and 0.05 g.

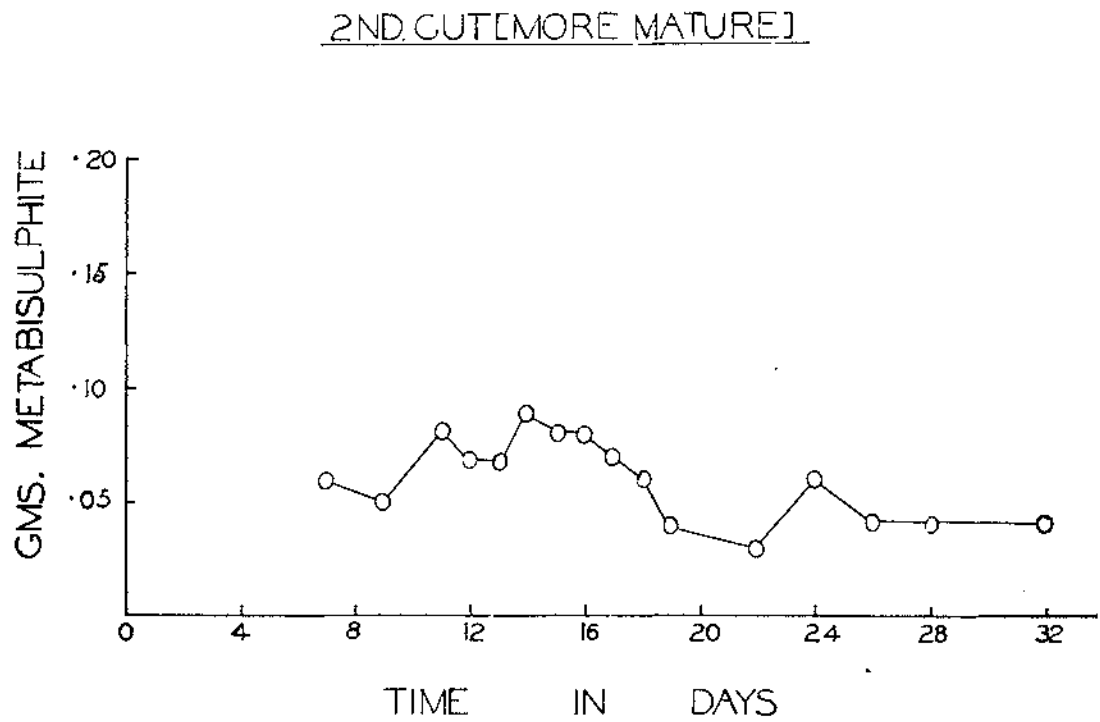
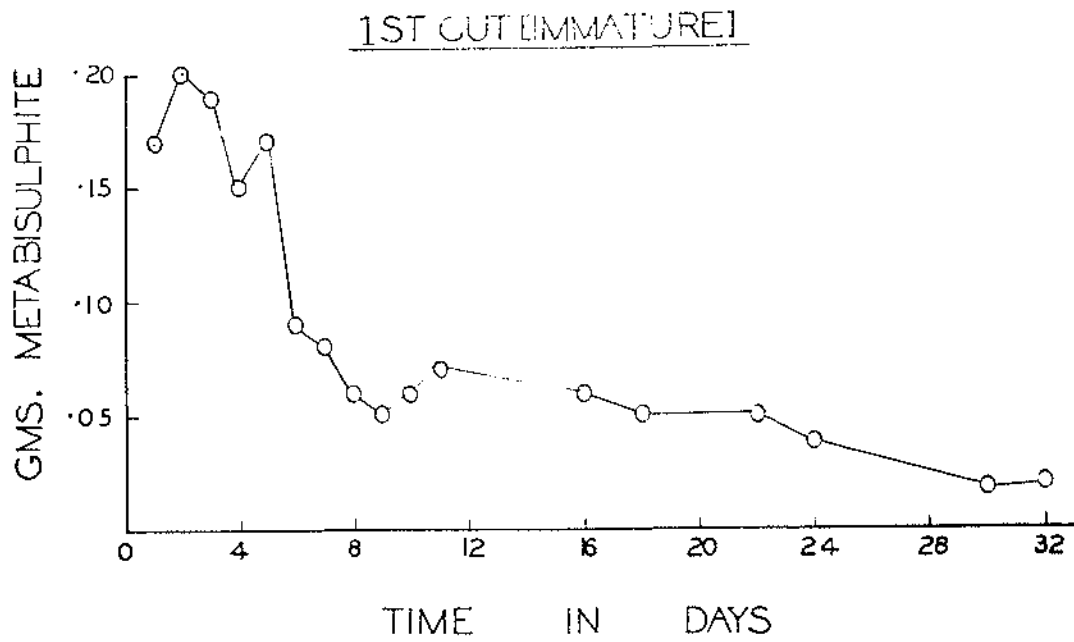


Figure 27

The loss of metabisulphite in the exudate from treated silages.

Table XII
Actual and Percentage Losses of Metabisulphite in
the Exudates from Treated Silages

Treatment	Weight of Green Material Ensiled (pounds)	Application Rate of Metabisulphite (gms/100 lb fresh silage)	Total Weight of Metabisulphite Applied (gms.)	Total Weight of Metabisulphite Lost in Exudate (gms.)	Percentage Loss of Metabisulphite
<u>1st Cut</u> (immature) Metabisulphite-Treated	6,900	200	13,800	651	4.7
<u>2nd Cut</u> (more-mature) Metabisulphite-Treated	4,700	200	9,400	57	0.6

metabisulphite were recorded for the treatments as listed. Percentage losses of metabisulphite in the exudate were 4.7 and 0.6 for the immature and more-mature silages respectively (Table XLI). The higher loss of the additive in seepage from immature material resulted mainly from the greater volume of exudate voided by this silage.

Spoilage Losses

Total and percentage nutrient losses from the silages as inedible material, resultant from spoilage, are shown in Table XLII. Full details of spoilage losses are presented in Appendices VIII to XI inclusive.

On a total weight and percentage basis, immature silages had less top and side spoilage than silages made from more-mature material. Depth of top spoilage was approximately 5" for all silages. Side spoilage was present in the upper half of all silos, more-mature silages possessing the greatest amounts. The bottom layer of silage was well preserved in all silos, a factor attributed mainly to the provision of adequate drainage facilities. At both stages of cutting, metabisulphite application had little effect on reducing the total amount of spoilage.

Treated immature silage showed lower percentage losses of dry matter, crude protein, mineral matter and organic matter as inedible silage, compared with the corresponding control material, but differences between the silages were small. Both more-mature silages, compared with immature material, showed higher percentage losses of the above mentioned constituents. Differences between untreated and treated more-mature silage in percentage losses were of little practical significance.

Table XLII

**Total and Percentage Losses of Dry Matter, Crude Protein,
Mineral Matter and Organic Matter from the Silages
as Inedible Material
(all weights in pounds)**

	1st Cut (immature)		2nd Cut (more-mature)	
	Control	Metabi- sulphite- Treated	Control	Metabi- sulphite- Treated
<u>Dry Matter</u>				
Ensiled	1326.5	1193.5	991.2	970.8
Removed as Inedible Silage	43.0	32.5	62.8	60.0
% Loss as Inedible Silage	3.2	2.7	6.3	6.2
<u>Crude Protein</u>				
Ensiled	260.0	242.2	148.9	141.6
Removed as Inedible Silage	10.16	7.2	12.6	11.9
% Loss as Inedible Silage	3.9	3.0	8.4	8.4
<u>Mineral Matter</u>				
Ensiled	115.5	103.2	68.0	70.6
Removed as Inedible silage	5.3	3.9	5.3	6.6
% Loss as Inedible Silage	4.6	3.8	7.8	9.3
<u>Organic Matter</u>				
Ensiled	1211.0	1090.3	923.2	900.2
Removed as Inedible Silage	37.7	28.6	57.5	53.4
% Loss as Inedible Silage	3.1	2.6	6.2	5.9

Fermentation Losses

Estimates of total and percentage nutrient losses, due to fermentation processes which occurred in the silages during storage, are presented in Table XLIII.

Table XLIII

**Total and Percentage Losses of Dry Matter, Crude Protein,
Mineral Matter and Organic Matter due to
Fermentation in the Silages
(all weights in pounds)**

	1st Cut (immature)		2nd Cut (more-mature)	
	Control	Metabi- sulphite- Treated	Control	Metabi- sulphite- Treated
<u>Dry Matter</u>				
Ensiled	1326.5	1193.5	994.2	970.8
Lost in Fermentation	379.1	233.8	250.8	232.1
Percentage Loss	28.6	19.6	25.3	23.6
<u>Crude Protein</u>				
Ensiled	260.0	242.2	148.9	141.6
Lost in Fermentation	46.5	26.9	11.2	7.3
Percentage Loss	17.9	11.3	7.5	5.2
<u>Mineral Matter</u>				
Ensiled	115.5	103.2	68.0	70.6
Lost in Fermentation	9.9	1.7	3.3	1.5
Percentage Loss	8.5	1.6	4.9	2.2
<u>Organic Matter</u>				
Ensiled	1211.0	1090.3	923.2	900.2
Lost in Fermentation	369.2	232.1	247.3	231.3
Percentage Loss	30.5	21.3	26.9	25.6

On a percentage basis, fermentation losses were highest in the silo containing immature material ensiled without metabisulphite treatment. Values recorded for the dry matter and organic matter losses in untreated silages were high but in agreement with figures

furnished by other workers for New Zealand silages (Sears and Goodall 1947).

The application of metabisulphite to immature material was effective in lowering nutrient losses due to fermentation. With more-mature material, on the other hand, metabisulphite treatment did not greatly reduce fermentation losses. Treatment of immature herbage reduced dry matter, crude protein, mineral matter and organic matter losses by 9, 6.6, 6.9 and 9.2 per cent respectively over those occurring in the control silage. With more-mature material the corresponding reductions in percentage fermentation losses through application of the salt were 1.7, 2.3, 2.7 and 1.3 per cent for the above listed constituents respectively.

Total Losses

Estimates of the actual and percentage total losses of dry matter, crude protein, mineral matter and organic matter which occurred during the storage period of the different silages are presented in Table XLIV. Complete details of all measurements made in determining these losses are given in Appendices IV to XI inclusive.

Untreated immature silage had the greatest percentage total losses of dry matter, organic matter and crude protein. Within the untreated silages lower losses of all constituents occurred in the silage of higher dry matter content, differences being most marked in the crude protein and mineral matter fractions. Total dry matter losses were high for both untreated silages, approximately one-third of the total dry matter ensiled being lost through seepage, spoilage and fermentation. In general, losses were lower than values reported in the literature for New Zealand silages made in concrete silos (Sill and Sears 1941; Sears and Goodall 1947).

Table XLVI

Actual and Percentage Total Losses of Dry Matter,
Crude Protein, Mineral Matter and Organic
Matter from the Silages
(all weights in pounds)

	1st Cut (immature)		2nd Cut (more-mature)	
	Control	Metabi- sulphite- Treated	Control	Metabi- sulphite- Treated
<u>Dry Matter</u>				
Ensiled	1326.5	1193.5	991.2	970.8
Removed as Edible Silage	864.3	857.5	673.0	670.3
Actual Loss	462.2	336.0	318.2	300.5
Percentage Loss	34.8	28.1	32.1	30.7
<u>Crude Protein</u>				
Ensiled	260.0	242.2	148.9	141.6
Removed as Edible Silage	193.5	186.3	123.8	119.9
Actual Loss	66.5	55.9	25.1	21.7
Percentage Loss	25.6	23.2	16.8	15.3
<u>Mineral Matter</u>				
Ensiled	115.5	103.2	68.0	70.6
Removed as Edible Silage	89.6	80.0	57.8	59.4
Actual Loss	25.9	23.2	10.2	11.2
Percentage Loss	22.4	22.5	15.0	15.8
<u>Organic Matter</u>				
Ensiled	1211.0	1090.3	923.2	900.2
Removed as Edible Silage	774.7	777.5	615.2	610.6
Actual Loss	436.3	312.8	308.0	289.6
Percentage Loss	36.0	28.7	33.4	32.1

Table XLV

Exudate, Spoilage, Fermentation and Total Losses of Dry Matter, Crude Protein,
Mineral Matter and Organic Matter from the Silages
(all values expressed as a % of total ensiled)

Treatment	Dry Matter				Crude Protein				Mineral Matter				Organic Matter			
	Exudate Loss	Spoilage Loss	Fermentation Loss	Total Loss	Exudate Loss	Spoilage Loss	Fermentation Loss	Total Loss	Exudate Loss	Spoilage Loss	Fermentation Loss	Total Loss	Exudate Loss	Spoilage Loss	Fermentation Loss	Total Loss
1st Cut (immature)																
Control	3.0	3.2	28.6	34.8	3.8	3.9	17.9	25.6	9.3	4.6	8.5	22.4	2.4	3.1	30.5	36.0
Metabisulphite-Treated	5.8	2.7	19.6	28.1	8.9	3.0	11.3	23.2	17.1	3.8	1.6	22.5	4.8	2.6	21.3	28.7
2nd Cut (more-mature)																
Control	0.5	6.3	25.3	32.1	0.9	8.4	7.5	16.8	2.3	7.8	4.9	15.0	0.3	6.2	26.9	33.4
Metabisulphite-Treated	0.9	6.2	23.6	30.7	1.7	8.4	5.2	15.3	4.3	9.3	2.2	15.8	0.6	5.9	25.6	32.1

Treatment of immature material with metabisulphite was effective in lowering the percentage losses of dry matter and organic matter but did not greatly reduce crude protein loss. Mineral matter losses were identical for both immature silages. Total losses, as recorded for immature treated silage, were 6.7, 2.0 and 7.3 per cent lower for the dry matter, crude protein and organic matter fractions than those occurring in similar material untreated with metabisulphite. Treatment of more-mature material with the additive, on the other hand, did not greatly reduce the percentage losses of any of the above mentioned constituents. Total losses of dry matter, crude protein and organic matter were 1.4, 1.5 and 1.3 per cent lower in treated material compared with those occurring in untreated silage. Both silages lost similar percentages of mineral matter.

For ease of direct comparison, estimates of the total loss of dry matter, crude protein, mineral matter and organic matter, incurred by each silage during storage, and the portion of that loss due to seepage, spoilage and fermentation, are set out in Table XLV. In the immature silages, fermentation processes accounted for the greatest portion of the total dry matter, crude protein and organic matter loss, while seepage accounted for the greater portion of mineral matter lost. With more-mature material, the highest percentage losses of dry matter and organic matter occurred as a result of fermentation, while spoilage accounted for the highest losses of the mineral matter and crude protein fractions. The reduction in total losses in all constituents following metabisulphite application, was effected mainly through a lowering of fermentation losses, the effect being more marked with immature material. Exudate losses of all constituents from treated silages were almost double those which occurred in the corresponding

untreated silage, an effect which tended to lower the margin of difference in percentage total losses of nutrients between untreated and treated silages.

Temperatures in the Silages

The major temperature changes which occurred in each silo during the storage period, are shown in Table XLVI. Day-to-day temperature changes, as recorded for each silage, are presented in fig. 28.

Table XLVI

Mean Temperatures in the Silages
(°F)

Days after Filling	1	2	3	4	10	25	31
<u>1st Cut</u> (immature)							
Control *	89	86	87	72	64	63	63
**	107	99	96	82	66	63	63
Metabisulphite-Treated *	75	75	75	72	72	65	64
<u>2nd Cut</u> (more-mature)							
Control *	76	77	76	75	71	67	65
**	88	92	94	94	89	77	74
Metabisulphite-Treated *	73	73	72	71	69	65	64
**	82	88	91	91	85	75	67

* 2' from base of silo.

** 4' from base of silo.

Temperatures in the upper layers of the silage were higher than those at lower levels. With the exception of the immature control

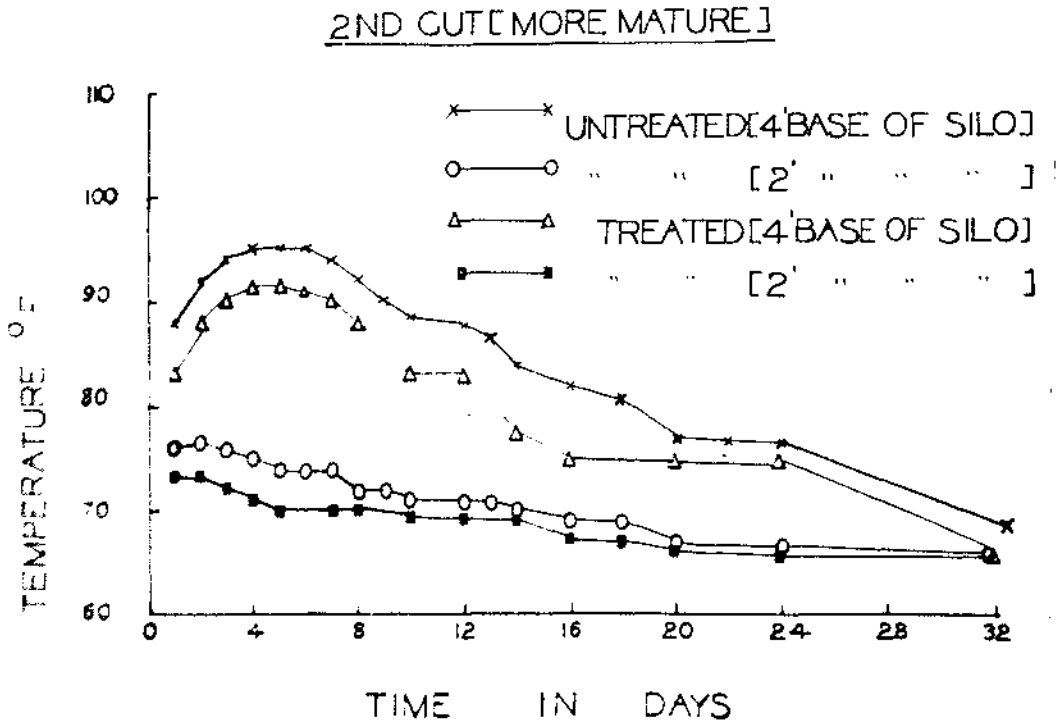
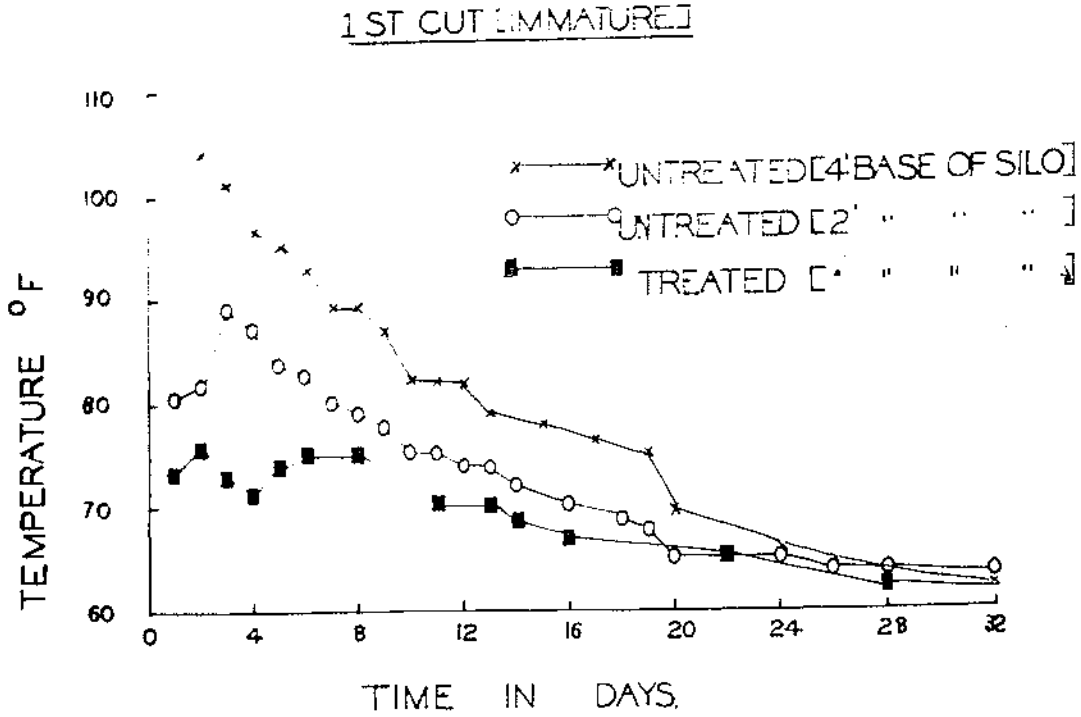


Figure 28

Daily temperature changes in the silages for 32 days after completion of filling.

silage, maximum temperatures recorded within the silos were low. Metabisulphite-treated silages showed a lower rise in temperature compared with their corresponding control silages. In the immature silages, the maximum temperature, at a depth of 2' from the base of the silo, was 14°F lower in the treated material. However, a direct comparison drawn between temperature differences in the immature silages cannot be considered as valid since temperature control was effected in the untreated material by the filling procedure adopted. If rapid filling of the silo had been practised in making the latter silage there is every reason to believe that the temperature difference between the untreated and treated silages would have been less marked.

Metabisulphite treatment of more-mature material had less effect on heat production compared with immature material. Maximum temperatures, as recorded at depths of 2' and 4' from the base of the silos, were 4° and 3°F lower in the treated silage.

Maximum temperature in immature silages was reached within 48 hours after completion of filling the silos, while in the case of more-mature material, temperature continued to rise in the region of the upper couple for a further 24-hour period. Sealing of the silos did not prevent temperature rising in the more-mature silages. With immature silages, maximum temperature was reached before the seal was applied. Temperature in the immature silages and lower depths of the more-mature silages reached atmospheric level within 30 days after completion of ensiling, but remained above atmospheric level in the upper layer of both more-mature silages throughout the storage period. When the silos were opened, there was no evidence that silage above the position of the upper thermocouple in each silo had been subjected to an undesirable temperature level.

Table XLVII

Mean Treatment and Depth Values of the pH, Volatile Organic Acid
and Carotene Content of the Silages

Constituent	Depth	1st Cut (immature)						2nd Cut (more-mature)					
		Control			Metabisulphite-Treated			Control			Metabisulphite-Treated		
		Upper	Lower	Both	Upper	Lower	Both	Upper	Lower	Both	Upper	Lower	Both
pH Value		4.36	4.17	4.26	4.31	4.70	4.50	4.27	3.84	4.05	4.37	4.36	4.36
Volatile Organic Acids (as % fresh silage)													
(a) Acetic Acid		0.71	0.81	0.76	0.47	0.59	0.53	0.67	0.46	0.56	0.56	0.78	0.67
(b) Butyric Acid		0.23	0.10	0.16	0.26	0.00	0.13	0.16	0.03	0.08	0.06	0.09	0.07
(c) Propionic Acid		0.11	0.11	0.11	0.03	0.00	0.01	0.04	0.03	0.03	0.03	0.03	0.03
Carotene (mg./100 g. fresh silage)		1.10	1.90	1.50	2.70	2.31	2.50	0.53	0.75	0.64	2.21	2.43	2.32
				*(5.94)			*(5.81)			*(5.16)			*(3.91)

*Mean carotene values for herbage as ensiled (mg./100 g. fresh herbage).

General Description of Silages

On the basis of visual analysis, all four silages were considered to be well preserved. There was no evidence of excessive breakdown of plant tissue, mould or proteolysis in any of the silages except for small amounts of top and side spoilage. Metabisulphite-treated silages, on the basis of colour and smell, could be distinguished from untreated material. Both untreated silages were darker in colour than the original herbage. The colour of immature material was greenish-yellow (fig. 29) while that of the more-mature material was yellowish-brown (fig. 31). Both silages had a strong and sweet acid smell.

Metabisulphite silages retained more of the original green colour of the freshly ensiled herbage compared with the control material. This effect was more marked in the immature silage (figs. 30 and 32). Both silages possessed a faint but pleasant acid smell.

pH Values, Volatile Organic Acid and Carotene Content of the Silages

Mean treatment and depth values for the pH, volatile organic acid and carotene content of the silages are presented in Table XLVII. Individual determinations, made on all four samples, selected at random within each silage, are shown in Appendix XVI. Differences between mean values were tested by Analysis of Variance (Snedecor 1955 p.214 et seq.) and the results given in Table XLVIII. Values for the mean carotene content of the herbage, as ensiled, are also presented in Table XLVII, while figures for individual herbage carotene determinations are listed in Appendix XVII.

Mean pH values of 4.26 and 4.05, as recorded for the untreated immature and more-mature silages respectively, were lower than

Table XLVIII

Analysis of Variance of Mean pH, Volatile Organic Acid and Carotene Values of the Silages

(a) Immature Silages

Source of Variation	Degrees of Freedom	pH Value			Carotene Content			Acetic Acid			Butyric Acid			Propionic Acid		
		Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result
Silages	1	0.11	1.15	N.S.	2.54	21.20	**	0.10	6.67	N.S.	0.028	< 1	N.S.	0.0171	6.57	N.S.
Depths within Silages	2	0.095	9.5	*	0.14	1.67	N.S.	0.015	7.5	*	0.0412	< 1	N.S.	0.0006	< 1	N.S.
Samples within Sub-classes	4	0.01			0.12			0.002			0.0500			0.0026		

** Highly Significant (p < 0.01)

* Significant (p < 0.05 > 0.01)

N.S. Not Significant (p > 0.05)

(b) More-mature Silages

Source of Variation	Degrees of Freedom	pH Value			Carotene Content			Acetic Acid			Butyric Acid			Propionic Acid		
		Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result	Mean Square	F	Result
Silages	1	0.19	1.42	N.S.	5.66	29.78	**	0.02	2.50	N.S.	0.0006	< 1	N.S.	0.0005	< 1	N.S.
Depths within Silages	2	0.09	< 1	N.S.	0.05	< 1	N.S.	0.046	5.12	N.S.	0.0087	9.66	*	0.00012	1.2	N.S.
Samples within Sub-classes	4	0.13			0.19			0.008			0.0009			0.0001		

** Highly Significant (p < 0.01)

* Significant (p < 0.05 > 0.01)

N.S. Not Significant (p > 0.05)

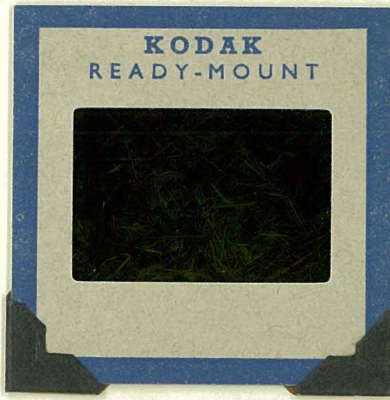


Figure 29

Sample of untreated immature grass silage.



Figure 30

Sample of metabisulphite-treated immature

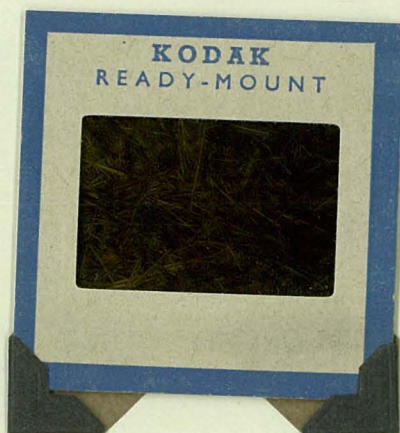


Figure 31

Sample of untreated more-mature grass silage.

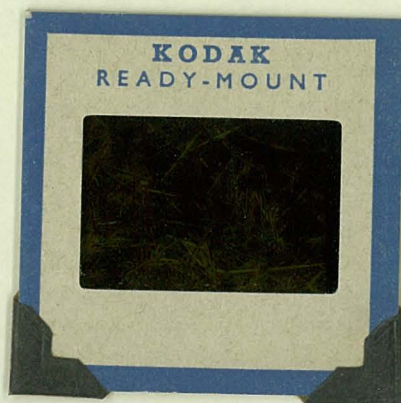


Figure 32

Sample of metabisulphite-treated more-mature
grass silage.

values attained in the corresponding treated silages (4.50 and 4.36). Differences between untreated and treated silages, however, were not statistically significant at the 5 per cent level (Table XLVIII). The pH of untreated immature material showed a significant decrease with increasing depth in the silo, while the reverse was true in the corresponding treated silage. No significant difference in pH value with increasing depth could be demonstrated for the untreated and treated silages made from more-mature material.

The mean pH of untreated more-mature silage approached a level of 4.0, the accepted value for good quality silage, while the pH of the corresponding immature material was only slightly higher. Treated silages had lower mean pH values than was expected with use of a sterilizing agent as an additive. The pH values clearly indicated that a reasonable amount of fermentation had occurred within all silages.

Moderate amounts of volatile organic acids were found in all silages. Analysis of the fatty-acid mixtures in terms of acetic, butyric and proprionic acids, showed that acetic acid was always present in the greatest amounts, but within the normal range for well preserved silage made by other techniques (Watson 1939). No significant difference could be detected between the mean acetic acid values for untreated and treated material within each cutting. Immature silages showed a significant but small increase in acetic acid content with increasing depth in the silo.

All silages contained traces of proprionic acid. Metabisulphite treatment did not significantly reduce the amount of this acid present in either the immature or more-mature material, while no significant increase or decrease in the amount of proprionic acid with increasing depth in the silages could be demonstrated.

Small amounts of butyric acid were present in the silages. Mean treatment values for the acid were slightly higher in immature compare with more-mature material. Treatment of the herbage with metabisulphite at both stages of cutting, however, did not significantly reduce the mean butyric acid content of the resultant silages. The content of the acid in untreated more-mature material showed a significant but small increase with increasing depth in the silo, while the reverse occurred in the untreated material.

Although metabisulphite-treated silages had mean pH values above the critical level for butyric acid formation, only small amounts of the latter acid were produced. Furthermore, individual data (Appendix XVI) showed that three samples of immature treated silage, with pH values of 4.44, 4.74 and 4.66 respectively, were entirely free from butyric and proprionic acids. Thus, it would appear that the pH level is of little use in judging the value of metabisulphite-treated silage.

Mean carotene values for the herbage as ensiled were similar between the first and second cuttings, with the exception of the metabisulphite treatment of the latter cutting, which had a lower mean carotene content. Individual herbage samples within each cutting, however, showed considerable variation in carotene content (Appendix XVII). All silages had a much lower mean carotene content than the fresh herbage, differences being most marked with the untreated mature material. Treatment of the herbage with metabisulphite at both stages of growth resulted in a silage of significantly higher mean carotene content than the corresponding untreated material.

Untreated more-mature silage, which contained an average of 0.64 milligrams of carotene per 100 grams of fresh silage, had the

lowest carotene value of the four silages. This level is equivalent to 290 milligrams per 100 pounds of fresh silage. At this rate, 28 pounds of the fresh silage was capable of meeting the daily nutrient allowance of carotene for a 1400-pound lactating non-pregnant dairy cow, as outlined by the National Research Council (1945). On this basis, therefore, more than enough carotene was present in each of the silages to supply the needs of dairy cows.

B. THE NUTRITIVE VALUE OF THE SILAGES

The relative feeding value of the four silages was assessed by determining the digestibility of the various conventional fractions in each silage and from these, by standard procedures, calculating their starch equivalent and total digestible nutrient content, as a measure of energy value, digestible crude protein content and nutritive ratio. In further trials, designed to assess the relative palatability of the silages, dairy cows were given a free choice of treated and untreated silages and their preference recorded.

(a) Digestibility of the Silages

Experimental Procedure

Two digestibility trials were conducted and the effect of metabisulphite on the material ensiled at the immature and more-mature stages of growth evaluated separately. The "conventional" method of determination of digestibility was employed. Each trial consisted of a 5-day preliminary period and a 10-day collection period, throughout which three sheep were fed each silage as a sole feed, at a plane of nutrition slightly above maintenance level. The same sheep were used in both trials and housed in individual pens in a wooden feeding shed, a full description of which has been given in an earlier section (see page 76).

To overcome differences in the silages due to variations in fermentation at different depths and thus ensure the experimental sheep received a representative sample of each silage during the trial, the silos containing immature material were emptied over a 16-day period and a portion of the total silage, removed daily, fed

Table XLIX

Chemical Analyses of Feeds, Refuse and Faeces
(moisture-free basis)

(a) Feed Analysis

Silage	Percentage Composition of Feed						
	Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
<u>1st Cut (immature)</u>							
Control	16.73	21.64	4.29	9.42	28.16	36.49	90.58
Metabisulphite-Treated	16.98	21.45	4.14	10.99	27.50	35.92	89.01
<u>2nd Cut (more-mature)</u>							
Control	19.54	18.66	3.05	10.59	29.72	38.00	89.41
Metabisulphite-Treated	19.42	18.90	2.90	11.45	29.58	37.17	88.55

(b) Refuse Analysis

Silage	Sheep No.	Percentage Composition of Refuse						
		Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
<u>1st Cut (immature)</u>								
Control	2	17.40	19.49	4.73	16.15	29.36	35.27	88.85
	4	16.18	18.70	4.78	15.47	29.89	31.16	84.53
	5	16.00	18.98	3.98	12.34	29.50	35.20	87.66
Metabisulphite-Treated	1	17.58	19.40	4.08	13.86	29.25	33.41	86.14
	3	16.65	19.42	3.81	16.13	29.14	31.50	83.87
	6	17.26	19.46	3.67	12.68	29.12	35.07	87.32
<u>2nd Cut (more-mature)</u>								
Control	2	21.52	16.60	1.67	15.06	32.93	33.74	84.94
	4	21.50	16.08	2.18	14.94	32.97	33.83	85.06
	5	20.76	16.85	1.77	13.62	32.83	34.93	86.38
Metabisulphite-Treated	1	20.75	16.10	1.94	14.51	32.78	34.67	85.49
	3	21.63	17.22	1.68	15.51	32.87	32.72	84.49
	6	21.30	16.00	1.71	13.63	32.87	35.79	86.37

(c) Faeces Analysis

Silage	Sheep No.	Percentage Composition of Faeces						
		Dry Matter	Crude Protein	Ether Extract	Total Ash	Crude Fibre	Nitrogen-free Extract	Organic Matter
<u>1st Cut (immature)</u>								
Control	2	37.61	21.20	4.17	14.62	28.20	31.81	85.38
	4	27.64	20.30	4.23	14.54	27.60	33.33	85.46
	5	38.83	20.79	4.63	14.67	27.65	32.26	85.33
Metabisulphite-Treated	1	31.83	18.59	4.20	14.04	27.59	35.56	85.96
	3	32.19	18.60	4.80	14.05	27.97	34.58	85.95
	6	31.58	19.57	4.87	14.54	27.70	33.32	85.46
<u>2nd Cut (more-mature)</u>								
Control	2	29.64	16.65	3.15	17.28	28.75	34.17	82.72
	4	43.26	17.01	3.33	17.61	27.17	34.88	82.39
	5	32.64	16.85	3.11	16.88	27.82	35.34	83.72
Metabisulphite-Treated	1	33.66	15.88	3.71	16.24	28.53	35.64	83.76
	3	33.40	15.91	3.34	15.28	28.49	36.98	84.72
	6	32.05	15.81	3.30	16.85	28.86	35.18	83.15

to the experimental sheep. More-mature silages, used in the second trial, were subjected to similar treatment.

Methods employed in the collection of faeces, sampling of feeds, refuse and faeces, chemical determinations and weighing of experimental animals, along with a list of the data collected in each trial and description of the standard procedures used to calculate the digestibility coefficients and feeding value of each silage, have been outlined previously (see pages 102 - 105).

Experimental Results

Chemical Composition of Feeds, Refuse and Faeces

The average chemical composition of the four feeds, individual refusals and total faeces voided by each sheep over the collection period of each trial is presented in Table XLIX.

Within each cutting, the silages as fed were similar in chemical composition. Silages made from the first cut had a higher crude protein and lower nitrogen-free extract and crude fibre content compared with those from the second cut. Analytical values obtained for the dry matter, crude protein, mineral matter and organic matter fractions are in fairly close agreement with values recorded for these constituents in the determination of nutrient losses (Table XXXVIII).

Individual refusals of the sheep fed any one silage were similar in chemical composition. All refusals, compared with the original feed, were lower in crude protein and higher in crude fibre and total ash, an indication that a certain amount of selective feeding took place. This was apparent from observation, the refuse consisting mainly of excessively stalky material.

The average faeces analyses of sheep fed any one silage showed a variation in dry matter content, the effect being more

marked in animals fed control silages. This factor, however, did not affect the composition of the dry matter of the faeces, which was remarkably similar for animals fed the same silage. When sheep were changed over from immature to more-mature silage, a decline was observed in the crude protein and ether extract fractions of the faeces with a corresponding rise in the total ash and nitrogen-free extract fractions.

Apparent Digestibilities of Nutrients

Detailed calculations of the digestibilities of the conventional fractions in each silage are given in Appendix XVIII. The totals of the nutrients ingested, voided and digested by each sheep during the collection period were obtained from average chemical analyses data (Table XLIX) and the total weights of dry matter offered, refused and excreted. The mean apparent digestibility coefficients of the various constituents in each silage are summarized in Table I.

Table I.

Mean Apparent Digestibility Coefficients
of the Silages

Constituent	1st Cutting		2nd Cutting	
	Control	Metabi- sulphite- Treated	Control	Metabi- sulphite- Treated
Dry Matter	65.2	68.4	55.7	60.7
Organic Matter	67.5	70.0	60.0	63.6
Crude Protein	67.5	72.8	62.5	69.5
Ether Extract	64.4	65.4	61.2	62.2
Crude Fibre	65.5	67.8	53.1	59.3
Nitrogen-free Extract	69.4	70.5	64.9	63.6

Considering the stage of maturity of the herbage ensiled at each cutting, the average apparent digestibility coefficients of the resultant control silages are all fairly high and agree favourably with values recorded by other workers for New Zealand silages (Sears and Sill 1949). As shown in Table L, there was a diminution in the digestibility of all constituents between cuttings, a result arising from the more mature nature of the second cut of herbage.

Both metabisulphite-treated silages were superior to their corresponding control silages in digestibility. Differences in digestibility of the various constituents in treated and untreated material showed a similar trend within each cutting.

The mean digestibility of the dry matter was 3 and 5 per cent higher in treated immature and more-mature silage respectively, compared with their corresponding control silages, while the organic matter fraction was about 3 per cent more digestible. The main differences in digestibility were in the crude protein fraction, values for this constituent, in treated immature and more-mature material, being 5 and 7 per cent higher than those of their corresponding no-preservative silage.

The digestibility of the crude fibre fraction was much higher (59.3) in the treated more-mature silage compared with the control material (53.1), but within the immature silages this difference was less marked, digestibility values of 65.5 and 67.8 per cent being recorded for untreated and treated material respectively.

The ether extract fraction was more digestible in the treated silages, but differences between untreated and treated material, within each cutting, were small and of little practical significance. Similar digestibility coefficients were obtained

for the nitrogen-free extract fraction in untreated and treated silages within each cutting.

The results of the digestibility trials, therefore, suggested that application of sodium metabisulphite to immature and more-mature herbage, prior to ensiling, had a slight beneficial effect on the digestibility of the resultant silages, the crude protein and crude fibre fractions being mainly affected.

Changes in Body Weights of Experimental Sheep

The changes in liveweight of the individual sheep over the collection period of each trial are presented in Table LI.

The individual liveweights of all sheep, recorded at the termination of each trial, were identical or slightly higher than those recorded at the commencement of the period. During the first trial, average weight gains of 3.3 and 2.8 pounds were recorded for the sheep fed treated and untreated immature silage respectively, while corresponding average weight gains of 1.0 and 0.3 pounds were recorded for the same animals fed more-mature silages in the second trial. The lower average weight gain in the latter trial can be partly attributed to the lower leaf : stem ratio of the silages fed compared with those fed in the first trial. This factor led to a lowered intake of fresh silage, since by feeding the silages at a level slightly above maintenance, excessive selection was not permitted. Other factors, which include errors in weighing and reduction in digestibility of all nutrients between cuttings, must also be considered.

Calculated Feed Values

Data on the relative feeding value of the silages are presented in Table LII.

Table LI

Average Weight of Each Sheep at the Beginning and End of the 10-day Collection Period

Treatment	Sheep No.	Initial Weight pounds	Final Weight pounds	Gain (+) or Loss (-) in Weight pounds
<u>1st Cut</u> (immature)				
Control	2	142	143	+ 1
	4	145	151	+ 6
	5	134	135	+ 1
Metabisulphite-Treated	1	146	146	-
	3	141	146	+ 5
	6	137	142	+ 5
<u>2nd Cut</u> (more-mature)				
Control	2	143	143	-
	4	151	152	+ 1
	5	136	136	-
Metabisulphite-Treated	1	149	149	-
	3	146	148	+ 2
	6	144	145	+ 1

Values for the total digestible nutrient content of the silages were lower than figures of 79 and 65 per cent, as reported in the literature for New Zealand silages, made from immature and more-mature herbage respectively (Sears and Sill 1941; Sears *et al.* 1942), but compared favourably with American data (Schneider 1947). Although silages within each cutting were similar in chemical composition, the slightly higher digestibility of treated material (Table L) resulted in the latter having a higher content of total digestible nutrients. Within each cutting, however, differences between treated and untreated silage in total digestible nutrient content per 100 pounds of dry matter were small and of little practical significance.

Table LII

Mean Values for the Total Digestible Nutrient Content, Starch Equivalent, Digestible Crude Protein Content and Nutritive Ratio of the Silages

Treatment	Total Digestible Nutrients		Starch Equivalent		Digestible Crude Protein		Nutritive Ratio
	%	% Dry Matter	%	% Dry Matter	%	% Dry Matter	
<u>1st Cut</u> (immature)							
Control	10.22	61.09	7.76	46.4	2.44	14.78	1 : 3.4
Metabisulphite-Treated	10.58	62.31	8.13	47.9	2.65	15.61	1 : 3.2
<u>2nd Cut</u> (more-mature)							
Control	10.44	53.43	7.36	37.69	2.18	11.16	1 : 4
Metabisulphite-Treated	10.68	54.99	7.73	39.81	2.33	11.92	1 : 4

Calculated starch equivalents for the silages were lower than values of 54 and 42, as reported in the literature for immature and more-mature New Zealand silages respectively (Sears and Sill 1942), but compared favourably with British figures, where a starch equivalent value of 48 - 50 for pasture silage is considered extremely high and normal values for mature silages are within the range of 38 to 40 (Report 1952).

At both stages of cutting, treated silages, being superior to non-treated material in digestibility of the crude protein and crude fibre fractions, had slightly higher starch equivalent values, but differences between untreated and treated material within each cutting were of a low order.

The superior digestibility of the crude protein fraction in metabisulphite silages, resulted in the latter having a higher content of digestible crude protein compared with their corresponding no-preservative silages, but differences were not great.

In each silage the ratio between the digestible crude protein and digestible non-protein fractions was narrow and of similar magnitude between untreated and treated material within each cutting, a direct reflection on the high digestible crude protein content of the silages.

Results of the digestibility trials, therefore, suggested that the application of metabisulphite to immature and more-mature herbage, prior to ensiling, produced a slight improvement in the feeding value of the resultant silages, compared with no addition. All silages, however, were of high feeding value and could provide a valuable production ration.

(b) Relative Palatability of the Silages

Experimental Procedure

Two free choice palatability trials were conducted to determine the preference of lactating dairy cows for silage, untreated and treated with sodium metabisulphite. The immature silages were compared in the first trial and the more-mature silages in the second. Each trial was conducted over a 15-day experimental period, which coincided with the emptying of the silos.

Throughout the emptying period of the silos, a representative portion of the total silage removed daily from each silo was set aside for the palatability test and covered with damp sacking to prevent drying out of the surface layers.

Five metal feeding bins, each subdivided into two equal compartments, were spaced at intervals in a concrete yard adjoining the milking shed of The Dairy Research Institute (N.Z.) experimental farm (fig. 33), to serve as containers for the experimental silages.

The Dairy Research Institute milking herd, comprising sixteen sets of lactating monozygous twins of the Ayrshire, Friesian and Jersey breeds, served as the experimental animals in both trials. Although the animals were on an "all-herbage" diet they were accustomed to silage.

Daily throughout the experimental period of each trial, approximately ten pounds of the untreated and treated silages were placed in separate compartments of each feeding bin prior to the evening milking of the experimental herd. Five cows were selected at random to receive the silages, the selected animals being admitted to the yard after milking (fig. 34), and their preference of the silages recorded. The experimental cows had free access



Figure 33

Layout of feeding bins in concrete
yard for palatability tests.

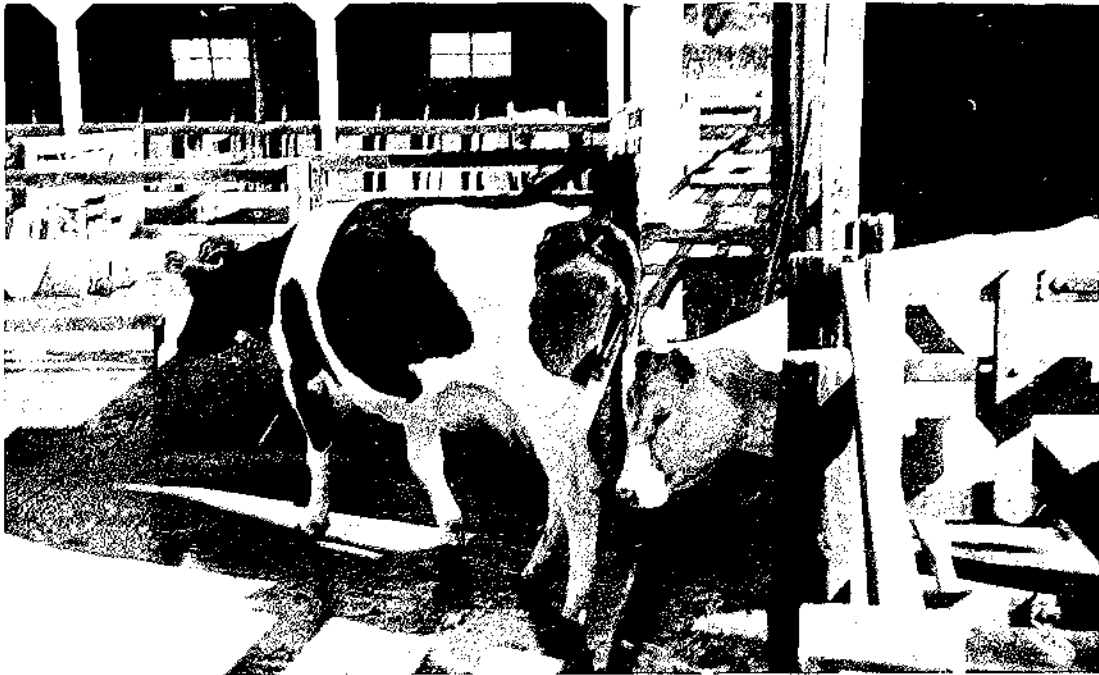


Figure 34

The admission of the cows to the yard to test their preference of the silages.



Figure 35

The experimental cows on the palatability test.

to all feeding bins (fig. 35). No quantitative measurements of silage consumption were made. Preference was determined according to which silage the experimental cows settled down to consume and not necessarily the first selected.

Owing to unfavourable weather conditions, it was not possible to conduct the trials each day throughout their respective fifteen day periods. Furthermore, the small size of the experimental herd restricted selection, with the result that more than one observation was made on several cows, while all cows in the herd were not subjected to test. In all 53 and 40 observations, involving 27 and 20 individual cows, were made in the first (immature silages) and second (more-mature silages) trials respectively. Results were subjected to the Chi-squared test, as outlined by Snedecor (1955 p. 16 et seq.).

Experimental Results

Of the 27 dairy cows given a free choice of immature silages untreated and treated with metabisulphite, 5 cows refused either silage, 16 animals showed a preference for treated material and the remaining 6 cows favoured the untreated silage (Table LIII).

With the more-mature silages, 2 cows out of a total of 20 in the trial refused either silage, 4 animals favoured untreated material and the remaining 14 cows showed a distinct preference for treated silage (Table LIII).

On applying the Chi-squared test to the data, the overall preference for treated silage over the corresponding untreated silage, as shown by the cows which consumed silage, was statistically significant at the 5 per cent level of probability (Table LIII). Untreated silages, however, when fed alone, were readily consumed by all animals in the herd.

Table LIII

Preference of Dairy Cows for Silage made from Immature and More-mature Herbage, Untreated and Treated with Sodium Metabisulphite

(a) Immature Silages

	Silage Preference		
	Control	Metabisulphite-Treated	Total
Number of Individuals	6	16	22

$\chi^2 = 4.54$. For $n = 1$, $P = .05$, $\chi^2 = 3.84$

(b) More-mature Silages

	Silage Preference		
	Control	Metabisulphite-Treated	Total
Number of Individuals	4	14	18

$\chi^2 = 5.55$. For $n = 1$, $P = .05$, $\chi^2 = 3.84$

Visual observation seemed to suggest that the overall preference shown by dairy cows for treated silages, could be ascribed primarily to the animals' sense of taste. All animals were observed to nose the silages about in the feeding bin and to taste both before making their final choice. Sense of smell, however, cannot be overlooked as a controlling factor in the choice of silages, since metabisulphite silages had less odour than their corresponding control silages.

As the experimental cows employed in each trial were selected at random from one small population, many animals were

subjected to test more than once throughout the period of each trial, while several animals received both the immature and more-mature silages. It is, therefore, of interest to compare the choice of individual cows when offered untreated and treated silages more than once in each trial and the choice of the same animals when given more-mature material in place of immature material.

In the first trial (immature silages), the preference of 15 cows for the silages was recorded on two occasions and that of 3 cows on three occasions, while 1 cow appeared in the trial four times throughout the experimental period. With one exception, all animals exhibited the same preference each time they were subjected to test. The exception was one animal which refused either silage the third time on test, having previously shown a preference for treated silage.

In the second trial (more-mature silages), 3 cows were subjected to two observations, 4 cows to three observations and 3 cows to four observations. With two exceptions, a similar preference was recorded for the individual cows at each observation. The exceptions were two cows which refused either silage the third and fourth times on test respectively. Both animals had shown a preference for treated silage on previous occasions.

Of a total of 14 cows which appeared in both trials, 10 animals preferred treated material in each trial, 3 animals switched their preference from treated to untreated material, when transferred from immature to more-mature material, and one animal refused to consume either silage in both trials.

The results, therefore, suggested that individual cows tended to show a similar preference each time they were given a free choice

of untreated and metabisulphite-treated silages, irrespective of whether the silages were made from immature or more-mature material.

C. DISCUSSION OF RESULTS

(a) Chemical Composition of the Silages

Present research substantiated the finding of Cowan et al. (1953) and others, that the application of metabisulphite to ensiled herbage, as compared with no addition, improved the colour and odour of the final product and resulted in a higher retention of carotene. All silages, however, had low carotene values compared with those of the herbage as ensiled, although maximum temperatures recorded within the silos suggested that efficient packing and exclusion of air were adequately controlled for carotene preservation.

That metabisulphite was ineffective in significantly reducing volatile acid formation in the silages did not agree with the results of Bratzler et al. (1953), Sears (1955), Murdoch et al. (1956) and Cowan et al. (1956). However, the untreated silages of the above workers were characterised by pH values above the level of 4.0, as considered desirable for the successful preservation of untreated material (Watson 1939). In the present study, both untreated silages were well preserved as judged by the mean pH values and quantities of fermentation products formed. If the untreated silages had been less carefully made and unchopped herbage had been ensiled the advantage of using metabisulphite might, therefore, have been greater. Nevertheless, Alderman et al. (1954, 1955) found metabisulphite silages to contain lactic, acetic and butyric acid contents of approximately one-half the values reported by Archibald (1954) and others for well preserved silages made by various other techniques. In the treated silages under discussion, mean acetic and butyric acid values were of similar

magnitude to those reported by Archibald (1954). Present results did not, therefore, support the claim of Alderman et al. (1955) and others that metabisulphite partly inhibits acid production by bacteria in silage. Owing to the limited number of fermentation products investigated in the present study and the extreme variation within the data presented, however, it would be unwise to conclude that metabisulphite was ineffective in reducing fermentation. It is probable that a more detailed experiment, involving a large number of samples and their subsequent analysis for all common fermentation products, would have detected any possible differences which might have existed between the treatments in this respect.

That no marked differences in the values obtained for the conventional feed fractions in the silages were discovered as a result of preservation with metabisulphite, agreed with the results of Little (1954) and others.

(b) Nutrient Losses Attendant on Ensilage

Present research supported the finding of Gowan et al. (1953) and others that the application of metabisulphite to chopped immature herbage reduced fermentation losses in the silage and resulted in a saving of dry matter, but that the salt had little effect in reducing nutrient losses, when applied to more mature herbage. However, the 7 per cent reduction in dry matter loss recorded in favour of metabisulphite-treated immature silage in the present study was, in general, lower than that reported by other workers who used the additive in similar trials (Bratzler et al. 1955, 1956).

That metabisulphite had but a slight beneficial effect upon crude protein loss and did not serve to reduce mineral matter

loss from the immature silage, suggested that the saving in nutrients mainly affected the carbohydrate fraction of the silage. Bratzler et al. (1956) did find that metabisulphite lowered carbohydrate fermentation in immature silage and reduced the loss of this constituent. Unfortunately, sampling was inadequate in the present study to detect any possible differences in the degree of carbohydrate fermentation which might have occurred between the treated and untreated silages.

The finding that appreciably more dry matter was lost in the exudate from immature metabisulphite silage, compared with the control material, does not agree with the results of other workers. Allred et al. (1956) found that exudate flow reached a maximum earlier in metabisulphite silage, due to the rapid killing of plant tissue and early release of excess moisture by sulphur dioxide liberated from the metabisulphite, but total exudate flow was of similar magnitude for the untreated and treated silages. A similar finding has been reported by Sears (1956).

The less favourable results obtained when metabisulphite was applied to more mature herbage, compared with immature material, require further explanation. It has been shown that mechanical loss of sulphite may occur in seepage from ensiled material and thus nullify any advantage possible through use of the additive (Cowan et al. 1956; Murdoch et al. 1956). In the present study, however, loss of metabisulphite through leaching was found to be of a low order in both treated silages.

Alderman et al. (1955) have reported that metabisulphite is a powerful reducing agent when in solution and will oxidize to sodium bisulphate and thus become useless for the preservation of silage. The amount of air entrapped in the ensiled crop is,

therefore, a major factor influencing the performance of the additive. Immature herbage, once ensiled, packs firmly in the silo, thereby excluding free oxygen (Watson 1939). The main requirement for the positive action of metabisulphite as a bactericide is thus satisfied. On the other hand, immature herbage, ensiled without preservatives, invariably undergoes an undesirable type of fermentation (Masgrave 1950). Conditions prevailing in immature silage are, therefore, in favour of metabisulphite treatment. With more-mature material undesirable fermentations should not occur and nutrient losses during storage should not be high, provided the crop is handled according to recommended procedures (Watson 1939). However, the complete exclusion of free oxygen from mature silage is difficult to achieve, owing to the fibrous nature of the material. Thus conditions are less favourable for the action of metabisulphite when a mature crop is ensiled.

In the present study, it is probable that a portion of the metabisulphite added to the more-mature herbage was oxidised - the amount of residual sulphite within the mass being insufficient to prevent or reduce fermentation. The finding that the final depth of silage within all silos was similar, although over 2,000 pounds less of the more-mature herbage was ensiled, would suggest that consolidation of the mass and thus exclusion of air was less efficient in the more-mature silages. As no residual sulphite determinations were made on the treated silages, however, this explanation can be considered as tentative only.

That the addition of metabisulphite to immature herbage did not produce such a marked saving of nutrients, as reported by Pennsylvanian workers (Bratzler *et al.* 1956), who used the additive in similar trials, cannot be satisfactorily explained.

Silage can be a very variable product under the influence of many factors which differ widely between and within the studies of individual investigators. Because of this, reasons postulated for differences obtained by workers who used metabisulphite in silage studies can only be suggestive in nature.

It may be that the type of immature material ensiled is an important factor in determining the efficacy of metabisulphite as an additive. New Zealand silages, made from dominantly ryegrass-clover mixtures, cut at an immature stage of growth and carefully ensiled without treatment, appear to be characterised by higher fermentation losses than normally occur in American and European silages (Sears and Goodall 1947; Barnett 1954), where different mixtures of grasses and legumes are ensiled.

In American studies (Bratzler et al. 1956) the greatest saving in nutrients resulted when metabisulphite was added to medium bloom red clover - the reduction in nutrient losses through application of the salt to grass mixtures being less marked. In this connection it is worthwhile noting the results of other New Zealand workers who used metabisulphite. Sears (1956), who compared treated and untreated silages, made from an immature ryegrass-clover mixture, recorded a percentage reduction in dry matter loss in favour of metabisulphite treatment of similar magnitude to that obtained in the present study. In trials, conducted by Lancaster (1956), metabisulphite treatment of protein-rich herbage resulted in a slightly higher saving of dry matter. In the studies of both workers, metabisulphite silages lost approximately one-fourth of the dry matter ensiled - a result little different from that recorded in the present instance. These losses, although lower than those recorded for similar material untreated with the salt, are still of a high

order and would suggest that metabisulphite is not the complete answer to the problem.

(c) The Nutritive Value of the Silages

With regard to the feeding value of the silages, data presented showed no outstanding differences, although both no-preservative silages were slightly lower than their corresponding metabisulphite silage in digestibility of the dry matter, total digestible nutrients, starch equivalent value and digestible crude protein content. Similar findings have been reported by Pennsylvanian workers (Bratzler et al. 1956) but other stations have found metabisulphite to be ineffective in significantly increasing the digestibility of the dry matter in silage, compared with no treatment (Gordon et al. 1954; Wittwer et al. 1955).

In view of the finding of Monroe et al. (1946) and others that no wide variation exists in dry matter digestibility between well made untreated silage and the fresh herbage, the slight gain in dry matter digestibility through the use of metabisulphite was not unexpected. Although the lowered loss of dry matter from immature treated silage, compared with the corresponding no-preservative silage, may account for the improvement in dry matter digestibility of the former, this factor cannot fully explain the higher digestibility of the dry matter fraction in metabisulphite-treated more-mature silage, compared with no treatment, as almost identical dry matter losses were recorded for both silages.

That metabisulphite treatment of the herbage increased the digestibility of the crude protein fraction in the silages, agreed with the results of Pennsylvanian workers (Cowan et al. 1953). Murdoch et al. (1956) have shown that the use of

metabisulphite reduced true protein losses from silage - a factor which could account for the improved crude protein digestibility of the treated silages under discussion. The finding of Alderman et al. (1955) that metabisulphite markedly reduced protein breakdown, in comparison with other types of silage, may also have some bearing on the results obtained.

Bratzler et al. (1956) found the digestibility of the crude fibre fraction in metabisulphite silage to be of a higher order than that recorded for similar material ensiled without preservative addition. This result was attributed to a decreased loss of crude fibre from treated material during storage, through a lowering of fermentation within the mass. It may be that a similar action occurred in the more-mature silages under discussion, as crude fibre losses were not determined and chemical analyses data were inadequate to draw final conclusions. This, however, does not satisfactorily explain the less marked difference between the immature silages in crude fibre digestibility, as results showed that metabisulphite was, in other respects, more effective as an additive with immature herbage.

On the basis of these results it would appear that the use of metabisulphite has little effect on improving the feeding value of silage made from immature and more-mature herbage, provided good silage-making methods are followed.

That dairy cows given a free choice of metabisulphite-treated and untreated silages showed a distinct preference for the former, agreed with the findings of Little (1954), Bratzler et al. (1956) and others. However, the same cows when given only untreated silage readily consumed it and although no quantitative measurements were made, there is every reason to believe that fresh silage intakes would have been little different for the

untreated and treated silages within each cutting.

It must be borne in mind that the essential criterion of a food is its contribution to efficient animal production. In view of the fact that the use of metabisulphite had but a slight beneficial effect on the feeding value of the silages under discussion, and both were readily consumed when fed alone, it would appear that the observed preference for treated silages in the free choice trials, was of little economic importance.

In general, the results of present research indicated that free choice palatability trials may create a false impression if not followed up by further experimentation, in which each food under test is fed separately to the same animals. Thus Bratzler *et al.* (1956) and others, who reported the preference of cattle for metabisulphite silage over similar material made without addition, did not subject the animals to further test, although the control silages were stated to be of good quality and readily consumed by other livestock. As mentioned previously (see review, page 59), Wittwer *et al.* (1955), who reported the preference of dairy cows for molassed silage over metabisulphite-treated material, found that when the latter silage was fed alone to the same animals, overall intake was not significantly different from that recorded for the molassed silage in the free choice test.

Present research has proved to be of value, however, since it has shown that the use of metabisulphite did not adversely affect the palatability of the silage, relative to that made from similar material by good silage-making methods and without preservative addition.

(d) Economic Considerations

The true test of efficiency of any process for adoption on the farm is the relation between cost of production and relative

cash value. In giving a relative cash value for the untreated and treated silages under discussion, the nutrient content must form the basis of calculation.

Data obtained from the metabolism trials and estimates of nutrient losses incurred by the silages during storage, made it possible to calculate the amount of digestible organic matter (D.O.M.) removed from each silo per 100 pounds of organic matter (O.M.) ensiled.

Results showed that approximately 43 and 49 pounds of D.O.M. per 100 pounds of O.M. ensiled were obtained from the silos containing untreated and metabisulphite-treated immature silages - a difference of 6 pounds D.O.M. in favour of metabisulphite treatment. Corresponding values of 40 and 43 pounds D.O.M. were recorded for the untreated and treated more-mature silages -- a difference of 3 pounds D.O.M. in favour of treatment with the salt.

The cost of metabisulphite was 10 shillings per ton of fresh herbage ensiled, this value being equivalent to 36 and 30 pence per 100 pounds of O.M. ensiled at the immature and more-mature stages of growth respectively. Other silage-making costs for the untreated and treated silages within each cutting were considered to be of equal magnitude, after excluding the time involved in application of the preservative. Thus, the extra 6 and 3 pounds of D.O.M., present in the treated immature and more-mature silages, per 100 pounds of O.M. ensiled were obtained at a cost of 36 and 30 pence respectively.

By means of a prediction equation, formulated by Wallace (1956) for the D.O.M. consumption of grazing Jersey cows, $[D.O.M. = 0.35 \text{ lbs (FOM)} + 0.08 (LW^{0.73}) + 3(LWG)]$ and assuming that the extra silage D.O.M. was used solely for the function of milk production and its quality was equivalent to that of herbage

D.O.M., it was calculated that 6 pounds of D.O.M. would produce approximately 0.7 pounds of butterfat. This latter figure, at current market values, is equivalent to a cash value of 23 pence - a figure below that of the cost of the preservative per 100 pounds of O.M. ensiled. Thus, the use of metabisulphite in the present investigation proved to be an uneconomic proposition.

D. SUMMARY OF RESULTS

1. The effect of adding sodium metabisulphite on the quality, composition, nutrient losses and relative feeding value of silages made from chopped immature and more-mature herbage is discussed.
2. Metabisulphite silages retained more of the original green colour of the freshly ensiled herbage and had less odour than their corresponding controls.
3. All silages were characterised by low mean butyric and proprionic acid values, acetic acid contents within the range for well preserved silage and mean pH values slightly above the level of 4.0, with no significant differences between the untreated and treated silages within each cutting.
4. Treated silages had a significantly higher carotene content than their corresponding no-preservative silages.
5. The application of the salt to immature herbage resulted in a greater saving of dry matter and organic matter but did not serve to reduce crude protein and mineral matter losses, compared with the control silage.
6. With more-mature material, metabisulphite proved to be an ineffective means of reducing loss of nutrients during the storage period of the silages.
7. Metabisulphite silages were superior to their controls in digestibility, the crude protein and crude fibre fractions being mainly affected by the treatment. In consequence, they had a higher mean starch equivalent value and a greater

quantity of total digestible nutrients and digestible crude protein. Differences in favour of metabisulphite treatment, however, were of a low order and of little practical significance.

8. Dairy cows, when given a free choice of metabisulphite and untreated silages, showed a significant preference for the treated material, irrespective of the stage of maturity of the ensiled herbage. Untreated silages, nevertheless, when fed alone, were readily consumed by the same animals.
9. It was concluded that the small saving in digestible nutrients which resulted from the use of metabisulphite with immature herbage, did not justify the high net cost of the additive and that no advantage was to be gained through application of the salt to mature material.

CHAPTER V

FINAL SUMMARY AND CONCLUSIONS

This manuscript presents a study of the problems associated with the production of high quality silage from grass-legume mixtures and the role of additives in their solution.

A brief outline of the process has shown that bacteria are the principal agents in the preservation of herbage as silage, but all too frequently undesirable types predominate when immature herbage is ensiled. Their prolonged action within the mass gives rise to inefficient chemical reactions with an accompanying loss of nutrients. A detailed review has indicated that these losses are of a high order in all grassland countries - a factor which limits widespread adoption of the process as a method of conserving surplus growth when the feeding value is highest. The use of additives, as a means of reducing these losses, has received considerable attention. A review of the many materials subjected to test has shown, however, that no one additive has proved capable of adoption by the farming community as a whole. In view of the recent finding of American workers that the treatment of immature herbage at ensiling time with sodium metabisulphite decreased storage losses and improved the quality of the silage, a study was undertaken to assess the value of the additive in silage-making under New Zealand conditions.

In a preliminary trial chopped mature herbage was ensiled in an unlined pit, untreated and treated with metabisulphite. Addition of the salt to the swathe in a water solution, at an

application rate of 6 pounds per ton of herbage, failed to improve the quality and feeding value of the resultant silage. Both silages were considered to be of inferior quality, as judged by the quantities of fermentation products formed. The inability of metabisulphite to effect an improvement in the silage was attributed to one or all of several factors, which could not be isolated on the basis of the data collected: oxidation of metabisulphite prior to entering the pit; leaching of the salt during the storage period; and, insufficient addition of the preservative.

In a second trial with slightly less mature herbage, the use of metabisulphite, at a higher rate of application and in powder form, did not serve to significantly reduce nutrient losses during storage or improve the quality and feeding value of the resultant silage. Both silages, on the basis of chemical data, were considered to be well preserved. Oxidation of the metabisulphite, by free oxygen entrapped in the mass, was considered to be the major reason for the failure of the salt to exhibit its bactericidal properties. These results, coupled with the findings of other workers that metabisulphite was ineffective as a sterilizing agent when applied as a water solution to immature herbage, would suggest that the method of applying metabisulphite in the preliminary trial was unsatisfactory. However, had the salt been applied as a powder, conditions prevailing within the pit would still have nullified any possible advantage to be gained through its use. If the herbage had been ensiled unchopped, conditions would have been still less favourable for the action of the additive.

In general, these studies have confirmed the finding of overseas workers that no advantage is to be gained by applying

metabisulphite as a water spray or in powder form to mature herbage, when the crop is ensiled by the use of recommended procedures for the making of good silage. Furthermore, the use of metabisulphite cannot be considered as an "insurance" against poor ensiling techniques - factors such as inadequate consolidation and improper sealing of the container, being detrimental to the efficacy of the additive.

In a further trial chopped immature herbage was ensiled with and without the addition of metabisulphite in powder form. Silage treated with the salt retained more of the original dry matter ensiled and was of higher feeding value than untreated silage. The saving in dry matter appeared to involve mainly the carbohydrate fraction, the additive having little effect on reducing crude protein and mineral matter losses. Metabisulphite silage had a higher carotene content than the control material and although fermentation had occurred within the mass, the silage was well preserved. Nevertheless, satisfactory silage was obtained when the herbage was ensiled without metabisulphite treatment.

The decrease in storage losses and improvement in feeding value in favour of the metabisulphite silage were, however, of a lower order than those reported by Pennsylvanian workers, who used the additive with immature herbage, and not sufficient to offset the purchase cost of metabisulphite. On the basis of this study, one could not recommend the use of metabisulphite as a preservative for chopped immature herbage.

As silage can be a highly variable product, conclusions drawn from the above trial, as to the value of metabisulphite for general use with immature herbage, must be interpreted with caution. It must also be borne in mind that chopped herbage was used. Several workers claim that chopping alone can produce a

good quality silage from immature herbage. Hence it may well be that, using unchopped herbage, metabisulphite would have shown up more favourably in reducing nutrient losses and improving the feeding value of the final product. Data presented, however, would suggest that if conditions on the farm are such that a well preserved silage cannot be made from immature crops by good ensiling techniques, metabisulphite would probably improve this condition and be economically practical. Nevertheless, since it is not advisable to make silage from immature crops without some form of treatment comparison with other methods of silage-making will be necessary before the full value of metabisulphite can be assessed for practical use in New Zealand.

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APPENDIX I

THE CHEMICAL COMPOSITION OF GRASS SILAGE ENSILED WITHOUT
PRESERVATIVE ADDITION (1954)

Block No.	Sample No.	Dry matter Percentage (Air dry)	pH	Lactic acid (% fresh silage)	Volatile acids (% fresh silage)			Carotene (mg./100g. fresh silage)
					Acetic acid	Butyric acid	Propionic acid	
1	I	13.60	4.8	-	-	-	-	2.20
	II	15.40	4.6	0.52	0.27	0.12	0.08	-
	III	16.60	5.0	-	-	-	-	1.70
	IV	14.80	5.4	0.31	0.19	0.17	0.08	-
2	I	12.00	5.6	-	-	-	-	2.05
	II	17.20	4.8	-	-	-	-	-
	III	18.72	4.0	-	-	-	-	1.55
	IV	14.40	4.5	-	-	-	-	-
3	I	16.20	5.3	0.29	0.47	0.20	0.05	1.90
	II	16.40	4.1	-	-	-	-	-
	III	16.28	4.5	-	-	-	-	3.40
	IV	18.84	3.9	-	-	-	-	-
4	I	13.20	5.3	-	-	-	-	2.25
	II	15.52	5.3	-	-	-	-	-
	III	14.88	3.9	-	-	-	-	2.35
	IV	22.80	4.1	1.00	0.53	0.04	0.02	-
5	I	15.00	4.6	-	-	-	-	3.10
	II	18.40	5.0	-	-	-	-	-
	III	18.40	5.0	-	-	-	-	3.68
	IV	16.24	4.8	-	-	-	-	-
6	I	18.00	5.6	-	-	-	-	1.03
	II	14.80	5.0	0.30	0.33	0.24	0.08	-
	III	21.52	4.8	0.34	0.28	0.35	0.12	2.13
	IV	20.64	4.0	-	-	-	-	-

APPENDIX II

THE CHEMICAL COMPOSITION OF GRASS SILAGE ENRICHED WITH ADDITION OF SODIUM METABISULFITE (1957)

Block No.	Sample No.	Dry Matter Percentage (Air dry)	pH	Lactic Acid (% fresh silage)	Volatile Acids (% fresh silage)			Carotene (µg/100g. fresh silage)	Residual Sulphite (p.p.m. fresh silage)
					Acetic Acid	Butyric Acid	Propionic Acid		
1	I	13.24	4.5	-	-	-	-	1.80	-
	II	20.64	4.1	-	-	-	-	-	-
	III	19.80	4.3	-	-	-	-	1.95	-
	IV	18.40	4.0	-	-	-	-	-	-
2	I	16.20	5.3	0.20	0.36	0.26	0.07	1.28	360
	II	19.40	3.8	-	-	-	-	-	362
	III	19.40	3.6	-	-	-	-	1.55	410
	IV	19.04	4.3	0.48	0.48	0.14	0.05	-	670
3	I	21.36	4.8	0.38	0.23	0.07	0.02	1.95	530
	II	19.60	3.7	-	-	-	-	-	-
	III	21.16	4.1	0.91	0.53	0.12	0.00	2.40	378
	IV	18.00	3.7	-	-	-	-	-	-
4	I	17.80	4.5	-	-	-	-	1.28	330
	II	20.00	3.8	-	-	-	-	-	-
	III	21.92	3.6	-	-	-	-	2.15	740
	IV	17.20	4.2	-	-	-	-	-	-
5	I	17.24	4.0	-	-	-	-	2.85	440
	II	18.20	3.9	-	-	-	-	-	-
	III	17.08	4.8	-	-	-	-	2.88	680
	IV	22.00	3.9	-	-	-	-	-	-
6	I	14.80	5.1	0.37	0.46	0.17	0.11	1.50	300
	II	15.12	5.3	-	-	-	-	-	-
	III	19.86	4.7	0.50	0.48	0.21	0.16	2.15	860
	IV	17.60	4.6	-	-	-	-	-	-

APPENDIX III

CALCULATED DIMENSIVILITIES OF HERBERIES IN GRASS
SILAGES, UNTREATED & TREATED WITH
SODIUM METASULPHITE (1954)

(a) Digestibility of Dry Matter

Silage	Sheep No.	Gms. of Dry Matter Offered	Gms. of Dry Matter Refused	Gms. of Dry Matter Consumed	Gms. of Dry Matter Excreted	Gms. of Dry Matter Retained	Percentage Digestibility of Dry Matter
Metabi- sulphite- treated silage	1	12255.40	6422.75	5832.65	2584.84	3247.81	55.52
	4	12255.40	7200.01	5055.39	2415.72	2639.67	52.01
	6	12255.40	4599.21	7656.19	3506.87	4149.32	54.06
Untreat- ed silage	3	11801.85	3824.09	7977.76	3488.55	4489.21	55.15
	5	11801.85	4888.64	6913.21	3180.50	3732.71	52.65
	7	11801.85	5444.15	6357.70	3156.20	3201.50	48.75

(b) Digestibility of Organic Matter

Silage	Sheep No.	Gms. of Organic Matter Offered	Gms. of Organic Matter Refused	Gms. of Organic Matter Consumed	Gms. of Organic Matter Excreted	Gms. of Organic Matter Retained	Percentage Digestibility of Organic Matter
Metabi- sulphite- treated silage	1	10841.24	5652.66	5188.58	2200.22	2988.36	57.59
	4	10841.24	6367.69	4473.55	2039.85	2433.70	54.40
	6	10841.24	4069.18	6772.06	3005.39	3766.67	55.68
Untreat- ed silage	3	10480.57	3419.50	7061.07	3026.32	4034.75	57.14
	5	10480.57	4352.85	6127.72	2760.18	3367.54	55.05
	7	10480.57	4825.52	5655.05	2749.05	2906.00	51.49

(c) Digestibility of Crude Protein

Silage	Sheep No.	Gms. of Crude Protein Offered	Gms. of Crude Protein Refused	Gms. of Crude Protein Consumed	Gms. of Crude Protein Excreted	Gms. of Crude Protein Retained	Percentage Digestibility of Crude Protein
Metabi- sulphite- treated silage	1	1482.69	747.61	735.08	450.18	304.90	41.49
	4	1482.69	861.84	620.85	394.97	225.88	36.38
	6	1482.69	581.67	901.02	569.74	331.28	39.94
Untreat- ed silage	3	1402.66	418.36	984.30	557.47	426.83	45.36
	5	1402.66	554.37	848.29	482.77	365.52	43.09
	7	1402.66	621.72	780.94	466.17	314.77	40.31

APPENDIX III - (Contd.)

(a) Digestibility of Ether Extract

Silage	Sheep No.	Gms. of Ether Extract Offered	Gms. of Ether Extract Refused	Gms. of Ether Extract Consumed	Gms. of Ether Extract Secreted	Gms. of Ether Extract Retained	Percentage Digestibility of Ether Extract
Metabi-sulphite-treated silage	1	297.27	143.55	153.41	85.81	67.00	44.15
	4	297.27	154.08	143.19	81.18	82.05	43.32
	6	297.27	130.72	166.55	117.12	79.43	40.41
Untreated silage	3	262.20	66.92	195.29	92.45	92.85	47.54
	5	262.20	66.55	175.67	94.60	91.07	51.64
	7	262.20	96.91	165.29	83.01	92.08	49.78

(b) Digestibility of Crude Fibre

Silage	Sheep No.	Gms. of Crude Fibre Offered	Gms. of Crude Fibre Refused	Gms. of Crude Fibre Consumed	Gms. of Crude Fibre Secreted	Gms. of Crude Fibre Retained	Percentage Digestibility of Crude Fibre
Metabi-sulphite-treated silage	1	4143.45	2259.52	1883.93	711.86	1172.07	62.21
	4	4143.45	2549.52	1593.93	626.57	965.36	60.56
	6	4143.45	1587.19	2556.26	961.25	1594.75	62.59
Untreated silage	3	3864.57	1364.05	2500.52	1020.40	1480.12	59.19
	5	3864.57	1801.46	2063.11	866.52	1166.59	53.55
	7	3864.57	1992.64	1864.93	912.45	952.48	51.07

(c) Digestibility of Nitrogen-free Extract

Silage	Sheep No.	Gms. of N.F.E. Offered	Gms. of N.F.E. Refused	Gms. of N.F.E. Consumed	Gms. of N.F.E. Secreted	Gms. of N.F.E. Retained	Percentage Digestibility of N.F.E.
Metabi-sulphite-treated silage	1	4917.83	2501.06	2416.17	972.42	1443.75	59.75
	4	4917.83	2902.24	2115.59	935.13	1180.46	55.80
	6	4917.83	1840.00	3077.25	1353.92	1713.41	55.69
Untreated silage	3	4960.94	1570.17	3390.77	1705.83	1684.94	49.69
	5	4960.94	1910.48	3050.46	1295.29	1754.17	57.50
	7	4960.94	2105.25	2855.69	1267.24	1587.85	55.60

APPENDIX IV

WEIGHTS OF GREEN MATERIAL, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER & ORGANIC MATTER, CUT FROM A GRASS-LEGUME SWARD AT AN INTERMEDIATE STAGE OF GROWTH & DRIED WITHOUT PRESERVATIVE ADDITION (1955)

Load No.	Weight of Green Material Dried lb.	Percentage Dry Matter (moisture-free basis)	Weight of Dry Matter Dried lb.	Percentage Crude Protein (as % D.M.)	Weight of Crude Protein Dried lb.	Percentage Mineral Matter (as % D.M.)	Weight of Mineral Matter Dried lb.	Percentage Organic Matter (as % D.M.)	Weight of Organic Matter Dried lb.
1	930	16.66	154.9	19.98	30.9	8.75	13.5	91.25	141.4
2	920	16.81	154.6		30.9	8.64	13.4	91.36	141.2
3	1282	18.84	241.5	19.23	46.5	8.18	19.8	91.82	221.7
4	990	18.51	183.2		35.2	8.66	15.9	91.34	167.3
5	1000	18.38	183.8	19.45	35.7	8.81	16.2	91.19	167.6
6	1042	18.25	190.2		37.0	8.90	16.9	91.10	173.3
7	1326	16.46	218.3	20.05	43.8	9.09	19.8	90.91	198.5
Total	7490	---	1326.5	---	260.0	---	115.5	---	1211.0

APPENDIX V

WEIGHTS OF GREEN MATERIAL, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER, MINERAL MATTER & ORGANIC MATTER CUT FROM A GRASS-LARGE BARD AT A TRAYING STAGE OF GROWTH & ENILED WITH ADDITION OF SODIUM METABISULFITE (1955.)

Load No.	Weight of Green Material Enailed lb.	Percentage Dry Matter (moisture-free basis)	Weight of Dry Matter Enailed lb.	Percentage Crude Protein (as % D.M.)	Weight of Crude Protein Enailed lb.	Percentage Mineral Matter (as % D.M.)	Weight of Mineral Matter Enailed lb.	Percentage Organic Matter (as % D.M.)	Weight of Organic Matter Enailed lb.
1	1,000	16.76	167.6	20.50	38.50	8.73	16.4	91.27	171.4
2	1,000	17.34	173.4	20.27	36.8	9.08	16.3	90.92	163.1
3	1,000	17.23	172.3	20.23	34.9	8.40	14.4	91.60	157.8
4	1,000	17.04	170.4	19.96	34.5	8.60	14.7	91.40	155.7
5	1,000	17.13	171.3		34.7	8.32	14.3	91.68	157.1
6	1,000	16.56	165.6		33.5	8.50	14.1	91.50	151.5
7	900	16.30	146.7		29.3	8.85	13.0	91.15	133.7
Total	6,900		1193.5		242.2		103.20		1090.3

APPENDIX VI

WEIGHTS OF GREEN MATERIAL, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER
& ORGANIC MATTER CUT FROM A GRASS-LAMINA STAND AT A MORE MATURE
STAGE OF GROWTH & HAYED WITHOUT PRESERVATIVE ADDITION (1953)

Load No.	Weight of Green Material Hayed lb.	Percentage Dry Matter (mixture-free basis)	Weight of Dry Matter Hayed lb.	Percentage Crude Protein (as % D.M.)	Weight of Crude Protein Hayed lb.	Percentage Mineral Matter (as % D.M.)	Weight of Mineral Matter Hayed lb.	Percentage Organic Matter (as % D.M.)	Weight of Organic Matter Hayed lb.
1	1,000	20.32	203.2	14.67	30.3	7.04	14.3	92.99	188.9
2	1,000	20.01	200.1	14.40	28.8	6.84	13.7	93.16	186.5
3	1,000	22.29	222.9	15.13	33.7	6.70	14.9	93.30	207.9
4	1,000	21.53	215.3	15.43	33.2	6.84	14.7	93.16	200.6
5	700	21.38	149.7	15.31	22.9	6.98	10.4	93.02	138.3
Total	4,700	---	991.2	---	148.9	---	68.0	---	923.2

APPENDIX VII

WEIGHTS OF GREEN MATERIAL, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER & ORGANIC MATTER OBTAINED FROM A GRASS-LAMOURE SHARD AT A MORE ADVANCED STAGE OF GROWTH & ENDED WITH ADDITION OF SODIUM METABISULPHITE (1955)

Load No.	Weight of Green Material Ensilaged lb.	Percentage Dry Matter (moisture-free basis)	Weight of Dry Matter Ensilaged lb.	Percentage Crude Protein (as % D.M.)	Weight of Crude Protein Ensilaged lb.	Percentage Mineral Matter (as % D.M.)	Weight of Mineral Matter Ensilaged lb.	Percentage Organic Matter (as % D.M.)	Weight of Organic Matter Ensilaged lb.
1	1,000	19.62	196.2	14.19	27.8	7.40	14.6	92.60	181.7
2	1,000	20.04	200.4	14.31	28.7	6.92	13.9	93.08	186.6
3	1,000	20.24	202.4	14.89	31.2	7.30	15.3	92.70	194.1
4	1,000	21.20	212.0	14.66	31.1	7.48	15.7	92.52	196.1
5	700	21.83	152.8	14.95	22.8	7.28	11.1	92.72	141.7
Total	4,700	---	970.8	---	141.6	---	70.6	---	900.2

APPENDIX VIII

TOTAL WEIGHTS OF FRESH SILAGE, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER & ORGANIC MATTER REMOVED FROM SILO CONTAINING IMMATURE MATERIAL ENSILED WITHOUT PRESERVATIVE ADDITION (1956)

Load No.	Wet Weight of Silage Removed lbs.		Dry Matter Percentage (moisture-free basis)		Weight of Dry Matter Removed lbs.		Crude Protein Percentage (as % D.M.)		Weight of Crude Protein Removed lbs.		Mineral Matter Percentage (as % D.M.)		Weight of Mineral Matter Removed lbs.		Organic Matter Percentage (as % D.M.)		Weight of Organic Matter Removed lbs.			
	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.	Ed.	Ined.		
1	-	52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
2	265.0	31	14.91	16.58	157.9	43.0	22.68	23.63	35.8	10.16	11.62	18.3	5.3	88.38	139.5	88.38	139.5	139.5	37.7	
3	230.5	41.5																		
4	269.0	26.0																		
5	234.0	29.0																		
6	415.0	25.0	15.39	16.58	239.5	43.0	22.40	23.63	53.6	10.16	10.77	25.8	5.3	89.23	213.7	89.23	213.7	213.7	37.7	
7	134.0	-																		
8	307.0	20.0																		
9	431.0	28.0																		
10	91.0	-																		
	178.0	4.0																		
11	115.0	-	16.58	16.58	106.3	43.0	22.36	23.63	23.8	10.16	9.82	10.4	5.3	90.18	95.8	90.18	95.8	95.8	37.7	
12	111.0	3.0																		
	259.0	-																		
13	156.0	-																		
	103.0	-																		
	469.0	-																		
	187.0	-																		
	78.0	-																		
14	389.8	-	16.75	16.75	104.2	43.0	22.40	23.63	23.4	10.16	9.78	10.2	5.3	90.22	94.2	90.22	94.2	94.2	37.7	
	288.8	-																		
	163.8	-																		
	252.0	-																		
Total	5390.5	259.5	-	-	864.3	43.0	-	-	193.5	10.16	-	-	89.6	5.3	-	-	-	-	774.7	37.7

APPENDIX IX

TOTAL WEIGHTS OF FRESH SILAGE, DRY MATTER, CRUDE PROTEIN, MINERAL MATTER & ORGANIC MATTER REMOVED FROM SILES CONTAINING FEATHER MATERIAL
ENGLAND WITH ADDITION OF SOLUBLE PHOSPHORUS (1956)

Load No.	Net Weight of Silage Removed lbs.		Dry Matter Percentage (moisture-free basis)	Weight of Dry Matter Removed lbs.	Crude Protein Percentage (as % D.M.)	Weight of Crude Protein Removed lbs.	Mineral Matter Percentage (as % D.M.)	Weight of Mineral Matter Removed lbs.	Organic Matter Percentage (as % D.M.)	Weight of Organic Matter Removed lbs.
	Ed.	Ined.								
1	49.0	100.0								
2	228.0	5.0								
3	242.5	29.5	16.08	176.2	20.82	37.1	9.2	16.4	90.8	161.8
4	232.0	30.0								
5	305.0	10.0								
6	272.0	17.0								
7	54.0	-	15.80	166.5	22.30	37.1	9.2	15.3	90.8	151.2
8	267.0	7.0								
9	202.0	3.0	15.65	32.5	22.11	7.2	11.87	3.9	85.13	26.6
10	219.0	1.0								
11	137.0	-								
12	182.0	5.0								
13	304.0	-	18.02	210.6	22.06	46.5	9.6	20.2	90.4	190.4
14	177.0	-								
15	369.0	-								
16	96.0	-								
17	400.0	-								
18	87.0	-	18.31	223.6	21.52	48.1	9.2	20.6	90.8	202.9
19	390.0	-								
20	128.0	-								
21	118.0	-								
22	319.0	-	16.77	78.6	22.23	17.5	9.50	7.5	90.5	71.2
23	150.0	-								
Total	4,968.5	207.5		857.5		186.3		80.0		777.5

APPENDIX I

TOTAL WEIGHTS OF FEED STUFFS, DRY MATTER, CRUDE PROTEIN,
MINERAL MATTER & ORGANIC MATTER REMOVED FROM SILAGE CONTAINING
NORME NATURES MATERIAL, FEEDING WITHOUT PRESERVATIVE ADDITION (1956)

Load No.	Net Weight of Silage Removed lbs.	Dry Matter Percentage (mixture-free basis)	Weight of Dry Matter Removed lbs.	Crude Protein Percentage (as % D.M.)	Weight of Crude Protein Removed lbs.	Mineral Matter Percentage (as % D.M.)	Weight of Mineral Matter Removed lbs.	Organic Matter Percentage (as % D.M.)	Weight of Organic Matter Removed lbs.
1	Ed. 115.0		Ed. Ined.	Ed. Ined.	Ed. Ined.	Ed. Ined.	Ed. Ined.	Ed. Ined.	Ed. Ined.
2	126.0		153.6	18.34	28.2	8.65	13.3	91.25	140.3
3	131.0	19.34							
4	235.0		216.9	18.70	40.6	8.60	18.7	91.40	198.3
5	107.0			20.00					
	197.0	16.30	62.8		12.6	8.40	5.3	91.60	57.5
6	103.0								
7	183.0								
8	103.0								
9	240.0								
10	102.0								
	78.0								
	303.0								
11	95.0								
	209.0								
12	81.0	19.12	154.9	16.13	28.1	6.61	13.3	91.39	144.5
	82.0								
	83.0								
13	262.0								
14	89.0								
15	240.0	16.98	147.6	18.23	26.9	6.47	12.5	91.53	135.1
	141.0								
16	234.0								
	74.0								
	349.0		673.0		123.8		57.8		615.2
	385.0		62.8		12.6		5.3		57.5

APPENDIX XI

TOTAL WEIGHTS OF FRESH SILAGE, DRY MATTER, CRUDE PROTEIN,
MINERAL MATTER & ORGANIC MATTER REMOVED FROM SILO CONTAINER
MORE NATURE MATERIAL MIXED WITH ADDITION OF SODIUM METABISULFITE (1956)

Load No.	Ed.	Ined.	Dry Matter Percentage (moisture-free basis)	Ed.	Ined.	Weight of Dry Matter Removed lbs.	Ed.	Ined.	Crude Protein Percentage (as % D.M.)	Ed.	Ined.	Weight of Crude Protein Removed lbs.	Ed.	Ined.	Mineral Matter Percentage (as % D.M.)	Ed.	Ined.	Weight of Mineral Matter Removed lbs.	Ed.	Ined.	Organic Matter Percentage (as % D.M.)	Ed.	Ined.	Weight of Organic Matter Removed lbs.	
1	-	110.0																							
2	133.0	37.0																							
3	132.0	36.0																							
4	228.0	52.0	18.63			147.6			17.98			26.5			9.0			13.2			91.0			134.4	
5	115.0	17.0																							
6	126.0	8.0																							
7	207.0	40.0																							
8	95.0	-	18.95			200.7			17.62			35.3			8.98			18.0			91.02			182.8	
9	104.0	13.0																							
10	131.0	-																							
11	396.0	10.0																							
12	92.0	-	16.25			60.0			19.80			11.9			11.00			6.6			89.00			53.4	
13	168.0	-																							
14	75.0	-																							
15	84.0	-	19.61			163.4			18.01			29.4			6.34			14.4			91.16			148.9	
16	88.0	-																							
17	326.0	-																							
18	87.0	-																							
19	285.0	-	19.02			158.6			18.08			28.7			8.76			13.8			91.24			144.8	
20	139.0	-																							
21	136.0	-																							
22	188.0	-																							
Total	3519.0	369.0				670.3	60.0					119.9						59.4	6.6					610.6	53.4

APPENDIX XII

QUANTITY, CHEMICAL ANALYSIS & ACTUAL LOSS OF URICATE FROM
SILCO CONTAINING IMPURIFIED IMPURIFIED MATERIAL (1955-56)

Day after Filling	Volume of Urinate voided		Dry Matter %	Specific Gravity	Actual Loss Dry Matter gms.	Crude Protein %	Actual Loss Crude Protein gms.	Mineral Matter %	Actual Loss Mineral Matter gms.	Organic Matter %	Actual Loss Organic Matter gms.	pH of Urinate
	m l.	Walls.										
1	13,000	2.86	5.51	1.00	716.3	1.23	159.9	1.26	163.8	4.25	552.5	5.14
2	38,500	6.35	5.57	"	2144.45		473.6	1.39	535.2	4.18	1609.25	4.98
3	26,000	5.72	6.10	"	1586.00	1.46	379.6	1.52	395.2	4.58	1190.80	4.63
4	5,500	1.21	6.18	"	339.00		80.3	1.46	80.3	4.72	259.60	4.62
5	3,000	0.66	6.41	"	192.33	1.63	48.9	1.58	47.4	4.85	144.90	4.58
6	26,500	5.83	6.23	"	1650.95		432.0	1.57	416.05	4.66	1234.90	4.36
7	12,000	2.64	6.16	"	739.20	1.61	193.2	1.49	178.8	4.67	560.40	4.33
8	3,000	0.66	6.23	"	186.90		48.3	1.60	48.3	4.63	136.90	4.52
14	7,000	1.54	5.81	"	406.70	1.66	116.2	1.48	103.6	4.33	303.10	4.72
17	4,000	0.80	6.50	"	260.00		66.4	1.65	66.0	4.85	194.00	4.86
20	9,000	1.98	6.21	"	558.90	1.75	157.5	1.75	137.7	4.68	421.20	4.62
23	8,500	1.87	6.16	"	523.60		148.8	1.75	130.9	4.62	392.70	4.72
27	10,500	2.30	6.10	"	640.50	1.50	157.5	1.50	168.0	4.50	472.50	4.67
31	8,500	1.87	5.70	"	424.50		127.5	1.50	147.05	3.97	337.45	5.14
35	6,700	1.91	5.28	"	459.36	1.16	100.92	1.16	129.63	3.79	329.73	5.14
39	18,000	3.96	5.30	"	954.00		208.8	1.16	266.40	3.82	687.60	5.24
45	26,000	5.78	4.88	"	1268.00	1.12	291.2	1.12	361.40	3.49	907.40	5.30
52	2 6,000	5.72	5.00	"	1300.00		291.2	1.12	377.00	3.55	923.00	5.67
62	27,100	5.96	5.08	"	1376.68	1.56	427.8	1.56	401.08	3.60	975.60	5.68
72	23,500	5.17	4.74	"	1113.90		366.6	1.56	314.90	3.40	799.00	5.66
82	24,000	5.28	5.34	"	1281.60	1.20	288.0	1.20	366.40	3.73	895.20	5.70
Total		72.45			18184.7		4449.2		4855.14		13329.80	
Total (pounds)					40.10		9.8		10.70		29.40	

APPENDIX VIII

QUANTITY, CHEMICAL ANALYSIS & ACTUAL LOSS OF EXUDATE FROM SLO CONTAINING DEWARRE MATERIAL TREATED WITH SODIUM BICARBONATE (1955-56)

Day after Filling	Vol. of Exudate voided ml.	Day Matter %	Specific Gravity	Actual Loss Dry Matter gms.	Crude Protein %	Actual Loss Crude Protein gms.	Mineral Matter %	Actual Loss Mineral Matter gms.	Organic Matter %	Actual Loss Organic Matter gms.	pH of Exudate	Actual Loss Metabilsulphite gms.
1	10,500	6.75	1.00	708.75	1.67	175.4	1.67	175.35	5.08	533.4	5.75	18.37
2	30,100	7.70	"	2317.7		501.0	1.93	580.95	5.77	1736.77	5.57	60.20
3	98,000	7.75	"	7595.0	1.79	1754.2	1.87	1832.60	5.88	5762.40	5.51	186.20
4	42,000	7.48	"	3141.6	1.74	751.8	1.75	735.00	5.73	2406.60	5.46	63.00
5	79,500	7.22	"	5739.9		1383.3	1.75	1391.25	5.44	4348.65	5.40	135.20
6	40,000	6.55	"	2620.0	1.69	696.0	1.76	704.00	4.79	1916.00	5.44	36.00
7	21,000	6.70	"	1407.0	1.65	354.9	1.75	367.50	4.95	1039.50	5.52	16.80
8	20,000	6.41	"	1282.0	1.72	338.0	1.68	336.00	4.73	946.00	5.54	12.00
9	18,000	6.41	"	1153.8	1.79	297.0	1.71	307.80	4.70	846.00	5.12	9.00
10	14,500	5.93	"	859.8	1.83	239.25	1.27	184.20	4.66	675.60	5.12	8.70
13	23,000	4.50	"	1035.0	1.77	395.60	1.04	239.20	3.46	795.80	5.30	16.10
16	14,000	5.93	"	830.2	1.83	240.80	1.72	240.00	4.21	589.40	5.84	8.40
19	6,500	6.23	"	404.9	1.79	116.35	1.80	117.00	4.43	287.95	5.83	3.25
22	8,500	6.63	"	563.55	1.83	152.15	1.83	155.55	4.80	408.00	5.76	4.25
26	10,500	6.90	"	724.50	1.83	192.15	1.89	198.45	5.01	526.05	5.40	4.20
30	8,500	6.61	"	561.85	1.77	155.55	1.88	159.80	4.73	402.05	5.51	1.70
34	7,000	5.06	"	354.2	1.72	123.90	1.32	92.40	3.74	261.80	5.58	2.1
38	12,000	6.03	"	723.6	1.72	212.40	1.84	220.80	4.19	502.80	5.60	6.0
45	18,800	5.48	"	1030.24	1.96	323.40	1.20	225.60	4.28	804.64	5.92	13.16
51	14,000	6.00	"	840.0	1.96	240.80	1.68	235.20	4.32	604.80	8.97	7.0
61	20,100	6.30	"	1266.3	1.98	394.00	1.78	357.78	4.52	908.52	5.80	13.55
71	18,600	6.02	"	1119.72	1.98	364.60	1.72	319.92	4.30	799.80	5.78	13.83
81	24,000	6.91	"	1658.4	1.98	475.20	2.00	480.00	4.91	1178.40	5.30	12.00
Total	122.96	---	---	37938.1	---	9877.4	---	---	---	2828.11	---	651.01
Total (no units)	---	---	---	69.7	---	21.80	---	17.6	---	52.1	---	1.43

APPENDIX XIV

QUANTITY, CHEMICAL ANALYSIS & ACTUAL LOSS OF EXUDATE FROM SILLO
CONTAINING UNWEATED MORE MATURE MATERIAL (1955-56)

Day after Filling	Vol use of Exudate Voided ml.	Dry Matter %	Specific Gravity	Actual Loss Dry Matter gms.	Crude Protein %	Actual Loss Crude Protein gms.	Mineral Matter %	Actual Loss Mineral Matter gms.	Organic Matter %	Actual Loss Organic Matter gms.	pH of Exudate
9	500	5.73	1.00	28.65	1.55	7.75	1.67	8.40	4.06	20.30	6.50
11	2,600	4.58	"	119.08		40.30	1.04	27.00	3.54	92.04	6.94
12	1,000	4.88	"	53.65	1.60	17.60	1.42	15.62	3.46	36.06	7.34
13	950	5.27	"	50.07		15.20	1.66	17.77	3.61	34.30	7.58
14	900	5.24	"	47.16	1.64	14.76	1.65	14.85	3.59	35.31	7.62
15	1,000	5.06	"	50.60		16.40	1.50	15.00	3.56	35.60	7.25
16	900	4.75	"	42.75	1.12	8.96	1.44	12.96	3.31	29.79	7.48
17	1,000	4.72	"	47.20		11.20	1.43	14.30	3.29	32.90	7.54
18	1,000	4.51	"	45.10	1.14	11.40	1.44	14.40	3.07	30.70	7.02
19	900	4.36	"	39.24		10.26	1.43	12.87	2.93	26.37	7.11
20	1,100	4.24	"	46.64	1.09	11.99	1.38	15.18	2.86	31.46	7.18
21	1,000	3.68	"	36.80		10.90	0.96	9.60	2.72	27.20	7.10
22	1,000	3.80	"	36.00	1.20	12.00	1.30	13.00	2.50	25.00	6.84
23	800	4.04	"	32.32		9.60	1.41	11.28	2.63	21.04	7.20
24	900	4.19	"	37.71	1.10	9.90	1.38	12.42	2.81	25.29	7.33
25	700	4.26	"	29.82		7.70	1.37	9.59	2.89	20.23	7.40
26	750	4.28	"	32.10	1.20	9.00	1.51	11.33	2.77	20.77	7.33
27	700	4.52	"	31.64		8.40	1.64	11.48	2.88	20.16	7.40
28	600	4.21	"	25.26	1.00	6.00	1.52	9.12	2.69	16.14	7.10
32	2,600	4.20	"	109.20		26.00	1.50	39.00	2.70	70.20	6.90
37	2,800	4.02	"	112.56	1.37	38.36	1.44	40.32	2.58	72.24	6.82
47	6,600	6.00	"	396.00		90.42	1.98	130.68	4.02	265.32	6.67
64	10,000	4.10	"	410.00	1.12	112.00	1.40	140.00	2.70	270.0	7.01
73	7,500	4.10	"	307.00		90.00	1.40	105.00	2.70	202.5	6.68
total	--	--	--	2168.55	--	596.1	--	709.17	--	1459.38	--
total (pounds)	--	--	--	4.76	--	1.31	--	1.56	--	3.22	--

APPENDIX XV

QUANTITY, CHEMICAL ANALYSIS & ACTUAL LOSS OF EXUDATE FROM SILO CONTAINING MORE MATURE MATERIAL TREATED WITH SODIUM METABISULPHITE (1955-56)

Day after filling	Volume of Exudate Voided ml.	Volume of Exudate Cells.	Dry Matter %	Specific Gravity	Actual Loss Dry Matter gms.	Crude Protein %	Actual Loss Crude Protein gms.	Mineral Matter %	Actual Loss Mineral Matter gms.	Organic Matter %	Actual Loss Organic Matter gms.	pH of Exudate	Actual Loss Metabisulphite gms.
7	1,200	0.25	5.67	1.00	68.04	1.62	19.44	1.60	19.20	4.07	48.84	5.18	0.72
9	1,400	0.31	5.50	"	77.00		22.68	1.76	24.64	3.74	52.36	5.80	0.70
11	1,600	0.35	5.46	"	87.36	1.60	25.60	1.70	27.20	3.76	60.16	6.60	1.28
12	860	0.19	4.43	"	38.10		13.76	1.42	12.24	3.04	25.89	6.84	0.60
13	700	0.15	5.24	"	36.68	1.68	11.76	1.80	12.60	3.44	24.08	7.02	0.50
14	750	0.16	5.27	"	39.53	1.30	12.60	1.75	13.13	3.52	26.40	7.08	0.68
15	1,000	0.22	5.35	"	53.50		13.00	1.79	17.90	3.56	35.60	7.11	0.80
16	800	0.18	4.94	"	39.52	1.24	10.40	1.67	13.36	3.27	26.16	7.03	0.64
17	750	0.16	4.70	"	35.25		9.30	1.66	12.45	3.04	22.80	7.62	0.53
18	850	0.18	4.26	"	36.21	1.25	10.54	1.65	14.03	2.61	22.18	7.18	0.51
19	800	0.18	4.32	"	34.56		9.92	1.72	13.76	2.60	20.80	7.18	0.32
20	800	0.18	4.30	"	34.40	1.30	10.00	1.73	13.84	2.57	20.56	7.38	0.32
21	1,200	0.26	3.90	"	46.80		15.00	1.22	14.64	2.68	32.16	6.76	0.72
22	1,500	0.33	3.88	"	58.20	1.40	19.50	0.94	14.10	2.94	44.10	6.70	0.45
23	700	0.15	4.20	"	29.40		9.10	1.66	11.62	2.54	17.78	6.88	0.35
24	700	0.15	4.50	"	31.50	1.44	9.80	1.68	11.76	2.82	19.74	7.07	0.42
25	600	0.13	4.62	"	27.72		8.40	1.60	9.60	3.02	18.12	6.85	0.30
26	500	0.11	4.66	"	23.30	1.48	7.01	1.68	8.40	2.98	14.90	7.02	0.20
27	600	0.13	4.60	"	27.60		8.46	1.70	10.20	2.90	17.40	6.84	0.24
28	600	0.13	4.53	"	27.18	0.86	8.88	1.60	9.60	2.93	17.58	6.78	0.24
32	2,200	0.46	4.95	"	108.90		32.56	1.72	37.84	3.23	71.06	6.82	1.10
37	2,600	0.48	4.81	"	125.06	0.90	24.08	1.68	43.68	3.13	81.38	6.69	1.04
47	38,500	8.47	2.35	"	904.75		326.80	0.91	350.35	1.44	554.4	5.01	23.10
64	37,500	8.25	3.00	"	1125.00		337.50	1.10	412.50	1.90	712.5	5.68	15.00
75	16,000	3.52	4.20	"	672.00		144.00	1.60	256.00	2.60	416.0	5.26	6.40
Total		25.09			3787.56		1120.11		1384.61		2402.95		57.14
Total	(pounds)				8.35		2.47		3.05		5.30		

APPENDIX XVI

THE pH VALUE, VOLATILE ORGANIC ACID & CAROTENE
CONTENT OF SILAGE MADE FROM IMMATURE & MATURE HARVEST
CROPPAGE WITHOUT & WITH ADDITION OF SPECIAL METABOLITES (1959)

(a) Immature Silage

Treatment	Depth	Sample No.	pH	Volatile Acids (as % fresh silage)			Carotene μ g./100g fresh silage
				Acetic Acid	Butyric Acid	Propionic Acid	
1st Cut (immature) Control	Upper	I	4.54	0.79	0.06	0.05	2.55
		II	4.53	0.69	0.40	0.17	0.86
	Lower	I	4.18	0.82	0.05	0.15	1.52
		II	4.16	0.80	0.15	0.09	2.28
Metabiol- phite-treat- ed.	Upper	I	4.19	0.48	0.52	0.07	2.65
		II	4.44	0.47	0.00	0.00	2.58
	Lower	I	4.74	0.59	0.00	0.00	2.46
		II	4.66	0.60	0.00	0.00	2.17

(b) Mature Silage

Treatment	Depth	Sample	pH	Volatile Acids (as % fresh silage)			Carotene μ g./100g fresh silage
				Acetic Acid	Butyric Acid	Propionic Acid	
2nd Cut (more mature) Control	Upper	I	4.02	0.60	0.18	0.05	0.69
		II	4.52	0.75	0.14	0.03	0.44
	Lower	I	3.84	0.46	0.04	0.05	0.84
		II	3.84	0.47	0.02	0.05	0.68
Metabiol- phite-treat- ed.	Upper	I	4.46	0.60	0.10	0.05	2.27
		II	4.29	0.52	0.06	0.05	2.16
	Lower	I	4.33	0.87	0.09	0.05	1.85
		II	4.39	0.69	0.09	0.06	3.04

APPENDIX XVII

CARCINOME CONTENT OF HERBAGE AS INITIATED
IN 3-TON EXPERIMENTAL SILOS AT AN INTERMEDIATE
& MORE MATURE STAGE OF GROWTH, WITH & WITHOUT
ADDITION OF SODIUM METABISULPHITE (1955)

(expressed as ngn./100g. fresh material)

Treatment	Depth in Silo			
	Lower	Middle	Upper	All
1st Cut (immature)				
Control	4.87	7.08	5.88	5.94
Metabisulphite-treated	5.71	5.52	6.19	5.81
2nd Cut (more mature)				
Control	4.80	5.64	5.04	5.16
Metabisulphite-treated	3.55	3.74	4.44	3.91

APPENDIX VIII

CALCULATED DIGESTIBILITIES OF NUTRIENTS IN GRASS
SILAGES MADE FROM IMMATURE & MORE MATURE MATERIAL,
RUSTED WITH & WITHOUT THE ADDITION OF SODIUM METABISULFITE (1958)

(moisture-free basis)

(a) Digestibility of Dry Matter

Treatment	Sheep No.	Gms. of Dry Matter Offered	Gms. of Dry Matter Refused	Gms. of Dry Matter Consumed	Gms. of Dry Matter Excreted	Gms. of Dry Matter Retained	Percentage Digestibility of Dry Matter
1st Cut (immature) Control	2	15452.05	4222.05	9170.02	5321.06	6119.04	66.7
	4	"	1054.19	15507.60	4524.78	7745.03	62.6
	5	"	2257.11	11174.94	3749.75	7425.13	66.4
Metabisulphite-treated	1	13632.77	5321.10	10251.67	3565.50	6325.17	67.2
	3	"	1027.13	12605.64	3721.54	6393.60	70.4
	6	"	1521.50	12061.27	5007.35	6143.32	67.6
2nd Cut (more mature) Control	2	17723.63	5124.77	12601.92	5826.69	7055.25	55.8
	4	"	7330.09	10316.80	4124.45	6062.15	59.1
	5	"	5839.04	11737.65	5804.54	6155.11	52.2
Metabisulphite-treated	1	17617.82	7331.01	9756.31	3675.27	6061.54	62.5
	3	"	5415.87	12201.96	4936.65	7215.30	59.1
	6	"	6579.59	11055.23	4513.67	6721.56	60.9

(b) Digestibility of Organic Matter

Treatment	Sheep No.	Gms. of Organic Matter Offered	Gms. of Organic Matter Refused	Gms. of Organic Matter Consumed	Gms. of Organic Matter Excreted	Gms. of Organic Matter Retained	Percentage Digestibility of Organic Matter
1st Cut (immature) Control	2	12166.75	3736.81	8379.94	2605.75	5774.19	68.9
	4	"	699.59	11237.13	3952.36	7314.25	64.9
	5	"	1976.56	10186.17	3193.67	6963.50	68.6
Metabisulphite-treated	1	12134.53	3012.43	9222.05	2823.28	6398.07	68.6
	3	"	301.45	11275.06	5196.92	9074.13	71.6
	6	"	1380.97	10753.56	3254.27	7499.29	69.7
2nd Cut (more mature) Control	2	15652.93	4352.93	11500.00	4604.75	6895.24	60.0
	4	"	6362.56	9490.42	3647.57	6042.35	63.7
	5	"	5175.35	10679.65	4658.43	6021.16	56.4
Metabisulphite-treated	1	15600.53	6720.33	8680.20	3078.41	5601.79	63.5
	3	"	4375.37	11024.71	4224.60	6300.02	61.7
	6	"	5682.79	9917.79	5566.82	6330.97	63.8

APPENDIX XVIII (Contd.)

(c) Digestibility of Crude Protein

Treatment	Sheep No.	Gms. of Crude Protein Offered	Gms. of Crude Protein Refused	Gms. of Crude Protein Consumed	Gms. of Crude Protein Excreted	Gms. of Crude Protein Retained	Percentage Digestibility of Crude Protein
<u>1st Cut</u> (immature) Control	2	2906.7	830.67	2076.03	647.02	1429.01	68.8
	4	"	199.00	2707.70	938.85	1768.87	65.5
	5	"	428.40	2473.30	779.58	1693.72	68.5
Metabisulphite-treated	1	2934.25	655.93	2278.30	625.64	1652.66	72.4
	5	"	199.47	2734.78	692.26	2042.50	74.5
	6	"	307.78	2626.47	745.22	1881.25	71.5
<u>2nd Cut</u> (more mature) Control	2	3307.60	859.71	2447.89	926.85	1521.04	62.5
	4	"	1202.60	2105.00	711.77	1393.23	66.2
	5	"	1009.15	2298.45	944.56	1353.89	68.9
Metabisulphite-treated	1	3329.77	1265.62	2064.15	585.63	1478.52	71.7
	5	"	932.61	2397.16	795.33	1601.83	66.9
	6	"	1052.75	2277.04	681.99	1595.05	70.0

(d) Digestibility of Ether Extract

Treatment	Sheep No.	Gms. of Ether Extract Offered	Gms. of Ether Extract Refused	Gms. of Ether Extract Consumed	Gms. of Ether Extract Excreted	Gms. of Ether Extract Retained	Percentage Digestibility of Ether Extract
<u>1st Cut</u> (immature) Control	2	576.25	201.59	374.66	127.27	247.37	66.0
	4	"	50.87	525.38	195.62	329.74	62.8
	5	"	89.85	486.40	173.61	312.79	64.5
Metabisulphite-treated	1	564.40	137.94	426.46	141.35	285.11	66.9
	5	"	89.19	525.27	178.64	346.63	66.0
	6	"	58.04	506.36	185.44	320.92	65.4
<u>2nd Cut</u> (more mature) Control	2	557.12	85.58	471.54	175.35	296.19	61.2
	4	"	165.06	374.06	159.54	214.52	62.7
	5	"	106.01	431.11	174.30	256.81	59.6
Metabisulphite-treated	1	510.92	152.50	358.42	136.35	222.07	61.9
	5	"	90.99	419.93	166.55	253.38	60.5
	6	"	112.51	398.41	142.35	256.06	64.5

APPENDIX XVIII (Contd.)

(e) Digestibility of Crude Fibre

Treatment	Sheep No.	Gms. of Crude Fibre Offered	Gms. of Crude Fibre Refused	Gms. of Crude Fibre Consumed	Gms. of Crude Fibre Excreted	Gms. of Crude Fibre Retained	Percentage Digestibility of Crude Fibre
<u>1st Cut</u> (immature) Control	3	3782.46	1251.55	2531.35	842.04	1689.09	66.7
	4	"	512.00	3464.37	1276.44	2187.95	63.2
	5	"	665.84	5116.82	1056.80	3079.82	66.7
Metabisulphite-treated	1	3749.01	933.97	2780.04	949.07	1810.97	65.6
	3	"	299.30	3449.71	1040.99	2408.72	69.8
	6	"	430.55	5239.43	1054.80	2255.63	67.9
<u>2nd Cut</u> (more mature) Control	2	5263.37	1037.59	3690.73	1600.42	1980.56	55.3
	4	"	2466.12	2302.19	1569.15	1453.04	51.2
	5	"	1966.20	3302.17	1559.13	1742.99	52.8
Metabisulphite-treated	1	5211.55	2576.84	3034.51	1043.55	1985.96	60.2
	3	"	1780.20	3431.15	1420.70	2010.45	58.6
	6	"	2102.71	3043.64	1244.93	1803.71	59.2

(f) Digestibility of Nitrogen-free Extract (N.F.E.)

Treatment	Sheep No.	Gms. of N.F.E. Offered	Gms. of N.F.E. Refused	Gms. of N.F.E. Consumed	Gms. of N.F.E. Excreted	Gms. of N.F.E. Retained	Percentage Digestibility of N.F.E.
<u>1st Cut</u> (immature) Control	2	4901.56	1505.22	3393.14	975.25	2417.89	71.5
	4	"	331.60	4569.76	1541.44	3028.32	66.3
	5	"	794.50	4105.86	1309.67	2797.19	70.5
Metabisulphite-treated	1	4896.89	1296.25	3600.64	1196.77	2403.87	66.7
	3	"	323.55	4573.34	1397.01	3176.33	71.8
	6	"	554.63	4342.23	1233.81	3108.45	73.1
<u>2nd Cut</u> (more mature) Control	2	6736.14	2729.10	5007.04	1902.14	3104.90	62.0
	4	"	2530.51	4205.63	1459.54	2746.09	65.3
	5	"	1966.20	4769.94	1559.13	3210.76	67.5
Metabisulphite-treated	1	6549.54	2725.41	3825.13	1309.87	2515.26	65.7
	3	"	1772.07	4776.47	1344.06	3432.41	61.4
	6	"	2354.84	4193.70	1517.55	2676.15	63.8