NUTRITIVE EVALUATION OF LOW-QUALITY FORAGES
SUPPLEMENTED WITH DIFFERENT NITROGEN SOURCES
IN RUMINANT FEEDS

by

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ABSTRACT

The utilization of low-quality forages in the feeds of ruminant animals takes on special importance because of the abundance of these materials and their potential value if supplemented with protein. The effect of the use of three different nitrogen sources, urea, biuret and poultry wastes, to replace a portion of soybean meal nitrogen in high roughage rations of sheep was investigated using in vivo and in vitro techniques.

The chemical composition of poultry waste was determined to study the feasibility of using it as a nitrogen source. There was a considerable variation in the chemical composition of poultry litter (bedding material plus droppings) as compared with the cage droppings. The litter contained 21.5 to 30.4% protein equivalent, approximately one-third of which was in form of uric acid nitrogen. The cage droppings contained 26.3 to 35.4% protein equivalent and about two-fifths of this was in the form of uric acid nitrogen.

Before feeding trials were undertaken, attempts were made to reduce the number of pathogenic bacteria that might be present in the poultry wastes by heat treatment. Though autoclaving or steaming had no significant effect on the total nitrogen or uric acid nitrogen, these heat treatments however, were sufficient to destroy all the microflora in the wastes.
No significant differences were observed in the digestibility coefficients of dry matter, crude protein, crude fiber or gross energy when approximately 50% of the soybean meal (SBM) nitrogen of the control ration was replaced by urea, biuret or poultry droppings in the rations of fattening lambs fed in the unpelleted form. However, similar replacement of 50% of the SBM nitrogen of the control ration by poultry litter, resulted in significantly lower nutrient digestibility coefficients of this ration when compared with the control. It might therefore be concluded that the presence of bedding material in the poultry litter hampered the availability of nitrogen from this source when fed to lambs.

However, when the rations were offered in the pelleted form, the differences in nutrient digestibility coefficients, particularly between the control and the litter supplemented rations, were no longer significant. Pelleting was found to increase the voluntary intake of the rations regardless of the source of nitrogen supplementation.

Although all animals were in positive nitrogen balance, those fed the urea and poultry litter supplemented rations had significantly lower nitrogen retention than those fed the soybean, biuret and poultry droppings supplemented rations. This observation was also reflected in the lower body weight gains and feed efficiency of the animals fed the urea and litter containing diets.
In experiments designed to determine the maximum level of poultry droppings that could be safely incorporated as an NPN source in high roughage rations, it was found that at levels of 18.7, 50.2 and 64.2% of the total nitrogen in the rations, there was no significant difference in the voluntary intake. This indicated that as a source of NPN, poultry droppings had an equally effective replacement value at all the three levels studied.

*In vitro* tests were employed to determine the effect of alkali treatment on the nutritive value of low-quality forages. Treatment with NaOH or NH$_4$OH significantly increased cellulose digestibility. The type of nitrogen source (urea, biuret or uric acid) used in the basal medium did affect the cellulose digestibility. There appeared to be a positive relationship between the solubility of the nitrogen source and cellulose digestibility *in vitro.*
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Dedicated to my son, Adebowale Adeleke Adetola.
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I

INTRODUCTION

It is difficult to anticipate the steps which will be taken during the next few decades to cope with the problem of providing adequate food for the ever-increasing world population. Curbs on population growth brought about by war and by contraception may play a part in eking out the world resources but the extent of this contribution is impossible to predict. In any event, the nutritionist is not concerned with this aspect but only with ensuring that the best use is made of the available foodstuffs.

Most writers on the subject of the world's food supplies confine themselves to calculating man's total caloric requirements and the capability of agriculture to meet these demands. This appears to be an oversimplification of the problem of food shortage, if one considers the fact that, despite the impressive scientific and technical progress we have made, mankind has failed in its efforts to feed the billions of people now living on earth in terms of a balanced diet containing adequate energy, protein, minerals and vitamins. Although opinions vary about the extent of malnutrition and
of actual hunger, there is general recognition that there is food shortage and that the most serious problem is lack of protein.

Many suggestions have been put forward as to how the world's resources can be better utilized to produce more protein. Such possibilities include synthesis of protein from bacteria subsisting on petroleum by-products; production of edible algae; better exploitation of the animal resources of the sea; and in addition, the increasing of land productivity by clearing, drainage and irrigation. But, perhaps one of the most important sources of food energy and thus potential animal protein is that contained in the world's grasslands. The importance of forage-producing lands is emphasized because of their abundance and because their crops can form a major portion of the ration of many of man's food-producing animals.

The ruminant species are predominant among the world's food producing animals. Ruminants have evolved through many millions of years into the domesticated species which today constitute one of the most important components of animal agriculture. Their specialization as forage consumers is dependent on the capacious nature of a portion of their digestive tract: (rumen), and the microorganisms living in a symbiotic relationship within this organ. It is these
microflora and microfauna which are the actual converters of the cellulose forage components into nutrients which can be absorbed and utilized by the host animal. These are among the characteristics which have enabled these species to play a dominant role in the production of human food from pasture material which would otherwise be of little nutritional value as a direct food for humans.

Modern-day commercialization of animal husbandry has resulted in an intensive effort to increase the efficiency of meat, milk and wool production, an important manifestation of which is the feeding of rations which most economically can result in high levels of production. Although ruminants may not be as efficient as other classes of livestock in terms of units of feed needed to produce a given unit of product, they compare more favourably when rations used to feed the various classes of livestock are examined qualitatively. For while species such as swine and poultry require high energy concentrate feeds to maintain levels of efficient production, ruminants have the ability to utilize relatively low-energy and low-cost fibrous feeds. These capacities are not being fully exploited when, as at present, half the world's grain crop is being fed to both ruminants and non-ruminants and a large part of the potential arable land in many parts of the world is devoted to the production of fodder.
In those parts of the world, particularly in the tropical regions, where the climatic conditions are conducive to rapid plant growth and subsequent overmaturity, an abundance of matured and highly lignified forages is available. These forages are often of such poor quality that the ruminant animal is unable to consume the forages in amounts that would meet its maintenance energy requirements. However, the utilization of such low-quality forages takes on special importance because of the abundance of these forages and because of their potential value if supplemented with proteins, minerals and vitamins.
A. Importance of forages in livestock production

In most countries in Africa where cattle and other herbivorous animals are raised, forages constitute the major portion of, and in some cases, the entire diet for these animals. In North America as well as most temperate regions, forage in one form or another constitutes some 65% of the feed of beef cattle, 55% of dairy cattle and about 90% of sheep (Crampton et al., 1960). In developing countries, forage is even more important in regions where grain-growing is uneconomic or the grain which is produced is used for human consumption, and cattle production is becoming increasingly dependent on grassland farming.

A fundamental material in the structure of plant cell walls is cellulose. Notwithstanding its abundant distribution in nature, only the herbivorous animals among the higher animals can utilize it as their primary source of energy. It has long been known that the digested portion of crude fiber consists mainly of cellulose (Armsby, 1896), which has the same nutritive value as starch once digested. The site
of cellulose degradation is the rumen, and this degradation (fermentation) is brought about by microorganisms present in this organ. The actual significance of cellulose breakdown to volatile fatty acids was not fully appreciated until reports dealing with volatile fatty acid (VFA) metabolism were published. Among the first of these was that of Phillipson (1947) who estimated that VFAs are produced in the rumen in quantities that could supply up to 40% of the fasting energy requirements of the animal. Thus, apart from the supply of other nutrients by the forage the cellulose component makes a significant contribution to the energy requirements of the animals.

B. Nutritive evaluation of forages

The search for a meaningful quantitative description of the "over-all" nutritive value of feeds has resulted in intensive biological and chemical research. Nutritive evaluation of forages has come into new prominence in the past decade as evidenced by the increasing amount of published information relating to the development of valid in vivo, in vitro and chemical techniques used in measuring forage quality.
1. **Chemical composition**

Nutrient availability of a feed is limited by chemical composition. Limits imposed by composition consist of two kinds: the quantity of totally unavailable substances and the factors which influence the rate of digestion (Van Soest, 1968). Crampton (1957) stated that chemical composition data of forages are useful in determining the relative amount of each constituent, but are not consistently correlated with animal performance criteria. The partitioning of feedstuffs into their chemical components — moisture, ether extract, crude protein, crude fiber, ash and nitrogen-free extract — owed its origin to the work of two German scientists (Henneberg and Stohmann, 1864). The crude fiber and NFE represent the carbohydrate portion of the feed; the crude fiber was designated as the portion that is relatively indigestible while the NFE contains the relatively soluble carbohydrates. Many workers have criticized this division of carbohydrates (Norman, 1935; Crampton and Maynard, 1938; Ferguson, 1942; Ellis et al., 1946; Moxon and Bentley, 1953; and Ely et al., 1953), especially in the case of roughages where the crude fiber could be as well or better digested than the NFE fraction.
The lignin content of the forage has generally been associated with poor digestibility of the forage. Significant negative correlations have been demonstrated (Kamstra et al., 1958; Dehority and Johnson, 1961) between lignin content and the dry matter digestibility of various forages grazed by or cut and fed green to steers and wethers (Forbes and Garrigus, 1948, 1950). Later reports by some workers including Stallcup (1957) and Dehority et al. (1960) have shown that the observed reduction in cellulose digestion of lignified mature forages is due to the "incrusting" effect of lignin rather than its total concentration. Quicke and Bentley (1959) from their study of lignin content in hays at different stages of maturity concluded that lignin content per se may not be the sole factor responsible for the differences in cellulose digestibility.

The crude protein content of forages has been generally related to the feeding quality. The fact that the biological availability of crude protein to the animal is variable, puts a limit to the use of this constituent as a measure of nutritive quality of forages.
2. **Digestibility (or availability) of forage nutrients**

Much of the earlier work on the nutritive value of herbage expressed nutritive quality in terms of total digestible nutrients (TDN), starch equivalent (SE) or net energy (NE). Now, however, there is increasing realization that in practice, animal production from herbage depends on the level of nutrient intake, that is, on the product of the weight of food intake and the nutritive value of the food per unit weight (Crampton *et al.*, 1960). Nutrient intake is affected by three major factors, namely, food intake, digestibility and utilization of absorbed nutrients. Digestibility is an important component of all three parameters, as it is now known that high digestibility is necessary for both high intake and for efficient utilization of metabolizable energy.

During the execution of many *in vivo* experiments on the digestibility of herbage, chemical analyses of the fodder have been carried out in an attempt to develop a mathematical relationship between digestibility and its contents of crude fiber (Gaillard, 1962; Wilson *et al.*, 1966), lignin (Dehority and Johnson, 1961; Blaxter, 1964; Armstrong *et al.*, 1964) and acid detergent fiber (Van Soest; 1963). Butterworth (1963) has shown that the relationship between digestibility and crude fiber content of tropical forages differ markedly from those found for corresponding forages of temperate zones, so that data derived in temperate regions should not be applied to tropical conditions.

The most promising approach to the
estimation of forage digestibility in the laboratory has been the attempt to simulate \textit{in vitro} the biological processes of rumen digestion and correlate the results so obtained with those achieved \textit{in vivo} (Donefer \textit{et al}., 1960).

3. \textbf{Voluntary feed intake}

Voluntary intake as a measure of the feeding value of a forage has long been recognized (Armsby, 1896). Voluntary intake may be defined as the maximum consumption of a feed under \textit{ad libitum} feeding conditions. It is generally agreed that voluntary intake of roughage by ruminant animals is directly related to its digestibility and that this is the reverse of what normally occurs in monogastrics or ruminants eating non-roughage diets (Blaxter \textit{et al}., 1961). The problem of poor quality roughages is that their rate of digestion is so slow that sufficient quantities of undigested residues remain in the rumen to limit further consumption of the feed. When feed components are examined for their availability and the rate at which they are digested, the cell-wall fractions, including hemicellulose, cellulose and lignin stand out as the slowly fermenting fraction. The sugars, starches, proteins and other substances ferment much faster than cellulose and hemi-cellulose and do not contribute to the fill-passage problem (Van Soest, 1968).
It is known that forage quality, intake level and production are closely related. According to the classification scheme for forages proposed by Cramptom (1956), average daily voluntary intake was directly proportional to the available energy content of the forage providing protein is adequate. It was further shown (Crampton, 1957) that the feeding value of a forage depends on its contribution towards the energy requirement of the animal, and that differences between forages are almost completely a consequence of the relative amounts in which they are voluntarily consumed. Voluntary intake of timothy hay has been shown to decrease with advancing maturity (Jeffers, 1960) while Smith (1958) and Beacom (1959) found significant correlations between voluntary intake and liveweight gains. Factors affecting the voluntary intake of forages by ruminants have been reviewed by a number of authors including Campling (1964), Van Soest (1965), Conrad (1966) and Baumgardt (1970).

4. **Available energy**

It has been demonstrated by many workers including Reid *et al.* (1959) that the primary purpose served by forages in the diet of ruminants is the provision of energy. Blaxter (1956) in his review of the nutritive value of feeds as sources
of energy concluded that, the primary consideration in the feeding of the individual animal is the adequacy of energy supply. Blaxter (1956) further elaborated that shortages of dietary energy are usually far more important causes of low productivity in farm animals, than are dietary deficiencies of vitamins, minerals or protein. Crampton (1957) pointed out that available energy rather than some specific nutrient is the fundamental limiting factor in the nutritive value of forages, because if a forage is consumed in amounts sufficient to meet the energy requirements, it will most likely meet the animal's needs with respect to protein, calcium and phosphorus. Swift (1957) showed that much more nutrient is required to maintain normal energy metabolism than all other purposes combined.

C. **Low-quality forages - their future in ruminant feeding**

Examples of low-quality forages are illustrated by material such as straw, grain hulls, corn cobs, sugarcane bagasse, sawdust, wood shavings, etc. The common characteristic shared by these types of materials is the fact that they are extremely low in protein and digestible energy but are rather high in crude fiber and lignin. Low-quality forages, particularly mature grasses, are abundant all over the world
but much more so in the tropical regions where the effects of high air temperature and heavy rainfall are conducive to rapid plant growth and subsequent over-maturity. The grasses mature very rapidly such that during the dry season large quantities of dry materials are available but are generally of such poor quality that grazing animals lose weight and some even die of starvation even though apparently in the midst of plenty.

Whereas the gross energy of less mature forage plants can be utilized (digested) to the extent of 50-70%, increased lignification with advancing plant maturity can result in only 20-50% of the potential energy being made available to the animal (Donefer et al., 1969). Equally, or of more importance than the effect of lignification in decreasing digestibility is the marked reduction in voluntary intake by ruminants of plant material of advanced maturity. As a result of both these effects, the ruminant animal is unable in many cases to obtain its maintenance energy requirements when fed highly lignified forage plants.

That cellulose is a potential energy source for ruminants has been known for years. But the availability of cellulose and hemi-cellulose of low-quality roughages is hampered by the effect of lignin. Lignin is not a well-defined chemical
entity, but its increased association with cellulose and hemi-celluloses in plant materials as the plant matures is well known (Dehority and Johnson, 1960). Crampton and Maynard (1938) found that lignin occurs in plant as ligno-cellulose. These workers were of the opinion that substances of the glucosanxylan series are the forerunners of lignin, but that neither its exact chemical structure nor the manner in which it is combined with cellulose is fully understood. They concluded that its behaviour in nutrition is likewise unsettled, with different feeding tests yielding conflicting results. Woodman and Stewart (1932) were of the opinion that lignocellulose is entirely indigestible and thus the digestibility of the crude fiber fraction is inversely proportional to the content of lignocellulose. Crampton and Maynard (1938), Gray (1947) and many others have also reported that lignin is practically non-digestible. However, Sullivan (1955) noted that the digestibility of lignin could exceed 10% in some cases. Nehring and Laube (1955) also reported that in the case of straw, lignin digestibility could be as high as 20%. Balch et al. (1954) were of the opinion that the different chemical methods used for the determination of lignin could be responsible for the inconsistent digestibility results reported by most workers.

Most reports indicate that the association between lignin and cellulose is a physical one (Clarke, 1938; Kamstra
et al., 1958; Freudenberg, 1965). Dehority et al. (1960) showed that the effect of lignin in decreasing cellulose digestion was most probably due to its incrusting effect rather than its total concentration. A similar observation was made by Stallcup (1957) when he added commercially purified lignin to in vitro flasks at four different levels, with no significant difference in cellulose digestion in any of the flasks. He then suggested that the reduction in cellulose digestibility usually associated with increasing lignification might be due to its role in the physical structure of the plant, rather than its chemical concentration.

Because of the importance of cellulose as a source of energy to ruminants and the abundance of this plant constituent in lignified roughages, efforts have been directed towards the dissociation of the physical bond between lignin and cellulose which would no doubt result in improved cellulose digestibility of roughages. In many areas, particularly in the tropics, highly lignified plant by-products such as straws, although available in large supply, are not efficiently utilized and in many cases are completely wasted. The utilization of low-quality roughages has become a necessary step in the present attempts to increase world food supplies, because one of the major factors limiting the production of high-quality proteins through animal agriculture is the shortage of suitable feedstuffs for these animals.
D. Improvement of low-quality forages

The lignocellulose complex accounts for most of the organic matter and hence, gross energy of common forages and wood. The ruminant animal can readily and efficiently extract most of the energy from the lignocellulose of immature plant materials, but is poorly equipped to remove it from mature forage plants and wood. The problem resolves itself into three components: (1) breaking down the cell wall material into particle sizes which facilitate bacterial attack and allow the feed to move through the alimentary tract efficiently; (2) improving the availability of the energy in the lignocellulose fraction; and (3) providing adequate nutrients for the rumen microflora to utilize the available energy. Nutritionally, the gross energy of forages and wood consists of an unavailable fraction including compounds such as lignin which for practical purposes is not degraded by rumen microflora, the digestible energy (DE) fraction representing the carbohydrates which are normally available for bacterial degradation, and the potentially digestible energy (PDE) fraction which includes the carbohydrates not normally available to rumen microflora because of chemical and or physical associations within the lignocellulose complex, but which can be made available by appropriate treatment and supplementation (Pigden and Hearney, 1969). The different
treatments of lignocellulosic materials can be divided into two major classes; physical (including steaming, grinding and irradiation) and chemical (particularly the use of alkalis).

1. Physical Treatments

(a) Steaming

Very few investigations have been conducted using this approach to delignify forages. The reason is probably due to the fact that the results obtained were not encouraging and the method itself appears to have very little to offer in commercial animal production. Honcamp (1932) and Kormanovskaya (1956) studied the decomposition of straw by steaming. The method was shown to result in a loss of the crude protein and an increase in the starch equivalent value.

(b) Grinding

The results obtained by Dehority and Johnson (1960) from their in vitro studies of forages cut at different stages of maturity indicated that the extent of lignin deposition around the cellulose fiber (forming a physical barrier rather
than its total concentration) is responsible for the decreased digestibility of mature forages. These workers also reported that ball-milling of bromegrass and orchardgrass for 72 hours resulted in increased \textit{in vitro} cellulose digestibility especially in the more mature samples. Rony (1964) similarly reported higher \textit{in vitro} cellulose digestion at all stages of growth when the forage was ground in a ball-mill. \textit{In vivo} studies reported by Lloyd \textit{et al.} (1960) indicated that grinding of a forage (early or late cut) in a hammermill caused slight reduction in apparent digestibility of the gross energy, although marked increases were observed for intake and nutritive value index as a result of grinding. This observation appears to suggest that the increased cellulose digestion \textit{in vitro} as a result of fine grinding has not been demonstrated \textit{in vivo}.

(c) \textbf{Irradiation}

Gamma irradiation of wheat straw at levels of $1 \times 10^8$ and $2.5 \times 10^8$ rads had been shown to increase the dry matter digestibility \textit{in vitro} from 40% to approximately 70% (Pritchard \textit{et al.}, 1962). The results obtained by Kitts \textit{et al.} (1969) also showed that \textit{in vitro} cellulose digestion and dry matter disappearance of hemlock sawdust increased with increasing
irradiation dosage. The increased volatile fatty acid (VFA) production during the in vitro fermentation indicated that the breakdown products of the irradiation were largely available to rumen microorganisms. Nevertheless, the levels of gamma irradiation necessary to release the nutrients encrusted with lignin, are well above what are economically feasible for commercial feed processing.

2. Chemical Treatments

(a) Sodium hydroxide (NaOH)

The use of chemical procedures to effect delignification have been elaborated particularly through the efforts of the pulp and paper industry. Efforts to increase the nutritive value of low-quality forages such as straw date back to the beginning of this century (Kellner and Kohler, 1900) and were high-lighted by the procedure reported by Beckmann (1921). The Beckmann procedure consists of steeping chopped straw in 8 times its weight of 1.5% NaOH solution for 4 to 8 hours at atmospheric temperature and pressure. The treated straw is then washed free of alkali and can be fed to animals as such, stored in silos or dried. While the Beckmann process has proved popular in small-scale farm operations, wide-scale
use has been limited owing to the large volume of dilute NaOH solutions required, the tedious washing operations to remove excess alkali and the losses of soluble nutrients caused by washing. In an attempt to minimize the amount of water used in washing, a number of workers including Williamson (1941), Godden (1942), Arrazola (1950), Lucifero (1958) and Homb (1958), have used more concentrated alkali than the concentration used in the Beckmann procedures. However, the process of washing was not completely eliminated. In order to overcome the need for washing, Wilson and Pigden (1964) developed the "dry" process of alkali treatment, in which excess alkali was neutralized with acetic acid. The newer methods which tend to overcome the use of excess alkali (Singh and Jackson, 1971; and Chandra and Jackson, 1971) thereby eliminating washing or neutralization with acid, have been demonstrated to be as effective in increasing digestibility as the older procedures.

3. **Supplementation of low-quality forages**

   (a) **Readily digestible carbohydrates**

   Not only have *in vitro* and *in vivo* studies helped our understanding of the nutrient requirement and utilization by
ruminant animals, these techniques have also pointed to new areas of research and improved feeding practices. The beneficial effects of soluble carbohydrates on the synthesis of bacterial protein from non-protein nitrogen sources have been demonstrated (Mills, 1942; Pearson and Smith, 1943; Smith and Baker, 1944). These early reports indicated that there is a requirement for a small amount of readily fermentable carbohydrate to stimulate fermentation of the lignocellulose complex. Burroughs et al. (1950) showed that, the requirement is of the order of 5-10% of the ration. Larger amounts of readily fermentable material frequently have a depressing effect on lignocellulose utilization. This inhibition is believed to be primarily caused by competition between cellulolytic and amylolytic groups of bacteria (El-Shazly, et al., 1961). Loosli (1963) has confirmed El-Shazly's observation by demonstrating that large intake of molasses reduced cellulose digestion in sheep and cattle particularly when protein was low or marginal. Other investigators have suggested different reasons for the depression of cellulose digestion when readily fermentable carbohydrates were added to low-quality roughage. Hamilton (1942) was of the opinion that rumen microorganisms preferentially attack the soluble carbohydrates, while Zafren (1960) attributed the reduction in cellulose digestion to the fact that the microorganisms are unable to cope with the increased acid production resulting from the fermentation of the soluble
carbohydrates. Coombe and Tribe (1962) compared starch and molasses and concluded that starch was of low palatability compared with molasses and therefore unsatisfactory as a carbohydrate supplement.

(b) **Nitrogen supplementation**

Whereas delignification procedures, especially NaOH treatment, result in large increases in cellulose digestibility, no effect on voluntary intake is achieved (Donefer et al., 1969). It has been suggested and shown experimentally that the major factor limiting the intake of delignified low-quality forages is the low protein content (El-Shazly, 1961; Loosli, 1963). Zafren (1960) used ammonium hydroxide (NH₄OH) as the treatment alkali and concluded that the ammonium acetate resulting from the neutralization of excess NH₄OH with acetic acid could supply up to 25% of the supplemental nitrogen.

One of the most important advances that have been made in respect of ruminant nutrition has been related to the role of rumen microorganisms as synthesizers of protein from low-cost non-protein nitrogen sources (Johnson et al., 1944; Belasco, 1954; Oltjen, 1967). Studies dealing with NPN in ruminant rations have indicated that a considerable proportion
of the protein ultimately utilized by the ruminant is bacterial protein, regardless of the nature of the nitrogen contained in the ration. Several excellent reviews on the various aspects of NPN utilization by ruminants have been written recently (Hungate, 1966; McLaren, 1966; Briggs, 1967; Chalupa, 1970).

Urea is currently the most widely used NPN source. Growth, reproduction and lactation on protein-free diets containing excess of 97% of the nitrogen from urea has been demonstrated (Virtanen, 1966; Oltjen, 1969). In spite of the tremendous research effort, problems still exist in the utilization of urea (Chalupa, 1968). Substitution of urea for protein has been shown to cause feed intake depressions. Huber and Cook (1969) have suggested that the intake depression on high urea diets was due to the undesirable taste of urea and not to ruminal or post-ruminal effects. Using two choice preference tests with sheep, Goatcher and Church (1970) reported that consistent rejection of urea solutions did not occur until concentrations of 2.5 and 5% were reached. At the higher concentration, sufficient urea was ingested to cause illness and death. With low-quality forages, addition of nitrogen has often led to greater voluntary consumption (Chalupa, 1968, and Donefer et al., 1969). The effect of dietary nitrogen upon intake level is attributed to increases
in fermentation and rate of passage (Elliot and Topps, 1963). Urea can be used safely and economically as a substitute for protein provided the biochemical and physiological aspects of urea metabolism are understood and advantage is taken of this knowledge. In general, the rumen fermentation system must be supplied with materials which will allow for maximum and continuous rates of fermentation. In practice, this requires the supply of the needed types and amounts of carbohydrates, minerals and other growth factors (Beames, 1959, 1960; Coombe and Tribe, 1962; Coombe et al., 1971).

The field of non-protein nitrogen supplements for ruminants continues to be an active one in an effort to find materials of higher replacement value than urea. Biuret is one such material. It has been shown that biuret is less toxic than urea for protein replacement in ruminant diets (Meiske et al., 1955; Repp et al., 1955; Berry et al., 1956; Hatfield et al., 1959 and Ioset, 1969). Early reports on the utilization of biuret-N were conflicting. Belasco (1954) reported a reduction in cellulose digestion by rumen bacteria in in vitro studies when biuret replaced urea as a source of nitrogen. However, later reports (Gaither et al., 1955; Ewan et al., 1958; Campbell et al., 1960; Oltjen, 1968 and Schroder and Gilchrist, 1969) indicate comparable utilization of biuret and urea by ruminants as sources of supplemental nitrogen
provided that animals fed biuret supplemented diets were allowed to adapt to biuret utilization. Most reports indicate that ruminants require a longer period for adaptation to biuret than to urea (Repp et al., 1955 and Oltjen, 1968).

Another material which has found alternative use in ruminant feeding is organic wastes (particularly from poultry operations). Poultry manure is used primarily as a fertilizer for crops but recent reports (El-Sabban et al., 1970; Lowman and Knight, 1970) have indicated that it could be successfully used as a nitrogen supplement in ruminant diets. Detailed chemical analyses have revealed that poultry waste contains a considerable amount of nutrients, particularly nitrogen (Bhattacharya and Fontenot, 1966; Leibholz, 1969). Approximately, 30 to 45% of this nitrogen is uric acid nitrogen (Leibholz, 1969; Lowman and Knight, 1970). In vitro studies have shown that rumen microorganisms can utilize uric acid as a source of nitrogen for protein synthesis (Belasco, 1954; Jurtshuk et al., 1955). Noland et al. (1955) found that nitrogen from poultry litter was equivalent to that from soybean meal for gestating-lactating ewes, while Fontenot et al. (1963) showed that poultry litter with a peanut hull or corn cob base could be used for fattening and wintering steers. Bhattacharya and Fontenot (1965) found that there was no reduction in the digestibility of nitrogen
in sheep when poultry manure supplied up to 50% of the nitrogen in the diet. Poultry litter, in addition to supplying nitrogen, could supply a substantial amount of energy for ruminants (Bhattacharya and Fontenot, 1966; Lowman and Knight, 1970).

In the comparison of urea, biuret, uric acid and urea phosphate as NPN sources in purified diets fed to cattle (Oltjen, 1967), the in vitro results indicated that the ruminal microorganisms must be adapted to uric acid and biuret before ruminal degradation of these compounds to ammonia occurs to any extent. Even after a 21-day adaptation, the ruminal ammonia concentrations of cattle fed biuret were much lower than those of cattle fed the other NPN sources. Metabolism results of the same study indicated that the apparent digestibility of dry matter and gross energy were significantly greater with uric acid than with biuret. Also, nitrogen retention was greatest with uric acid, followed by urea, biuret and urea phosphate in descending order.
OBJECT OF THE RESEARCH

The improvement of the nutritive value of low-quality forages by physical and chemical treatments is well established. Although such treatments result in significant increases in nutrient digestibility of the roughage, no effect on increasing voluntary feed intake has been demonstrated. It appears therefore, that the rate of microbial degradation of the fibrous constituents of the roughage is limited not only by over-maturity and lignification of the roughage but also by deficiencies in available nitrogen, minerals and vitamins.

The research work reported in this thesis was undertaken to investigate the interaction between physical treatment and nitrogen supplementation of high-roughage rations. The studies were divided into three parts.

The first part dealt with the chemical and biological examination of poultry wastes in an attempt to develop a processing method that will result in the production of poultry droppings and litter that are practically free of pathogenic bacteria and at the same time retain their nutritive value as a nitrogen supplement.
The second part involved the animal feeding trials to determine which non-protein nitrogen source can be used to replace more than one-third of the total ration nitrogen as is presently recommended for urea nitrogen. The nutritive value of the high-roughage rations supplemented with various nitrogen sources was evaluated on the basis of nutrient digestibility, nitrogen balance and voluntary consumption of the experimental diets by sheep.

The third part was concerned with the determination of cellulose digestibility in vitro of samples of the alkali treated oat straw and poplar wood (low-quality forages). Samples of the rations fed to sheep in the feeding trials were also included as substrates in the fermentation tests so that comparison between in vivo and in vitro cellulose digestibilities could be made.
IV

EXPERIMENTAL

SECTION I

CHEMICAL AND BIOLOGICAL EXAMINATIONS OF POULTRY WASTES
CHEMICAL AND BIOLOGICAL EXAMINATION OF POULTRY WASTES

Introduction

Generally the utilization of by-products or waste materials in animal feeding is stimulated by 3 main interests: (1) disposing of these wastes by beneficial and economical means (2) reducing the contribution of these wastes to environmental pollution and (3) sparing the land used in the production of livestock feeds for crops which can be used directly for human consumption.

As agricultural specialization and productivity become intensified, problems associated with the disposal of liquid, solid and gaseous waste products have greatly increased. In addition to the conflicts of interest over the environmental quality is the mammoth problem of disposal of solid wastes which are not only extremely offensive but have the potential to pollute both air, surface and sub-surface waters. After harvesting seed crops, farmers are usually faced with the problem of disposing the remainder of the plant. In many areas, the practice has been to burn the plant residues in the field causing great palls of smoke several weeks each year. Farmers are now finding that enforcement of air pollution laws makes it imperative to change current disposal practices.
The problems of animal wastes disposal are more complex. They include not only the engineering but also the social, legal and economic aspects. It is now absolutely essential that the cost of a livestock operation must include the waste handling and disposal activity as a total part of the management system. A great deal of investigation is being conducted in many institutions in disposal systems, prevention of water and air pollution, reutilization of animal wastes either as fertilizers or feedstuffs. With the development of any economically feasible method of processing and recycling these wastes, it may be possible to reduce air and water pollution, the cost of animal production and at the same time relieve poultry farmers of the problem of disposal of manure from poultry houses. Also, since many of the forages and waste product feedstuffs are very low in nitrogen, research is needed in which NPN is used to supply considerably more than one-third of the total nitrogen in the diet.
A. CHEMICAL ANALYSIS OF POULTRY WASTES

1. Introduction

There are two distinct types of poultry wastes: poultry droppings with litter; poultry droppings without litter. The litter may be described as a by-product containing a bedding material, usually wood shavings, saw-dust, peanut hulls, cereal hulls, or any other fibrous plant by-product. Poultry litter varies considerably in chemical composition depending on such factors as type of birds from which it comes, the age of the litter, type of bedding material used, management of the litter, and the number of birds kept on the bedding material.

2. Experimental Methods

Samples of poultry litter were collected from a broiler house on 3 occasions -- 2, 4 and 6 weeks following the date the birds were put on the bedding material. Chemical analyses data of the samples are presented in table 1. The litter consisted of bedding material, droppings, some feathers and wasted feed. No attempt was made to make the litter completely free of these extraneous materials. However, large feathers
and pieces of stones were hand-picked before the chemical analysis was done.

At each sampling date, the samples were taken from different spots and at different levels in order to obtain fairly representative samples. Moisture and nitrogen contents were determined on the wet fresh material. Nitrogen determination was done on the wet sample using the macro-Kjeldahl procedure (A.O.A.C. 1960). Thereafter, the remaining samples were dried in a forced-air oven at 85°C for 24 hours. The dried material was ground to pass a 20-mesh screen and analyzed for other proximate components. Uric acid nitrogen was determined on the dried samples by the spectrophotometric procedure as reported by Buys and Potgieter (1959). The uric acid nitrogen content was also expressed as percent of the total nitrogen of the litter.

Poultry droppings were similarly taken from the caged bird layers' house on three occasions following the periodic cleaning of the house. Samples were taken at 1, 2 and 4 weeks following the cleaning of the previously accumulated droppings. Chemical analyses and the procedures on the droppings were the same as that for the litter. The droppings consisted primarily of pure cage droppings, wasted feeds, feathers, broken eggs and a large population of housefly larvae and
and pupae. Infestation of housefly was high at the time of sampling as it was summer time. Separation of the pure cage droppings was not attempted and the analysis data in Table 2 represent the composition of the droppings as collected from the layers' house, each value representing the mean of 5 determinations.

3. Results and Discussion

The chemical composition data reported in Tables 1 and 2 confirm the general opinion as regards the considerable variation in the chemical composition of poultry wastes (Brugman et al., 1964; Mowat, 1965; El-Sabban et al., 1970). Greater variation in chemical composition in poultry wastes was observed between sampling dates than within samples taken on the same day.

Poultry droppings contained a higher moisture content at any sampling date than the broiler litter. The higher moisture content in the droppings could be explained by the fact that the dry wood-shaving bedding material has the tendency to dilute the chemical composition of the excreta mixed with it. Moisture content of both the droppings and litter increased progressively with length of accumulation, this increase being
more noticeable in the litter. The reason for this increase in moisture content can be attributed to many factors. The infestation of housefly - the presence of the housefly developmental stages -- larvae and pupae -- produce a moist environment. The decomposition of organic matter in the litter or droppings by the saprophytic group of bacteria (Alexander et al., 1968) would result in the accumulation of wet material especially in the lower portion. Wasted feed and water tend to increase the moisture content and also since the production of excreta is likely to be at a faster rate than the drying, accumulation of excreta would favour the production of wet litter or droppings.

The mean crude protein content of the droppings tended to be uniform over the sampling dates, but a great variation in the mean crude protein content was observed in the litter. This is expected since the distribution of excreta on the bedding material was uneven. The crude protein content of poultry litter or droppings is influenced by many factors, the most important of which is the decomposition of urea and uric acid by the saprophytic groups of bacteria and subsequent loss of nitrogen as ammonia. Other factors include the amount of wasted feed, shed feathers, broken eggs and the presence of housefly larvae and pupae (Miller, 1970).
# TABLE I

The Chemical Composition of Broiler Litter\(^1\) as Affected by Length of Time Birds Were Kept on the Litter

<table>
<thead>
<tr>
<th>Composition</th>
<th>Age of Litter (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Dry Matter (%)</td>
<td>80.1 ±3.5</td>
</tr>
<tr>
<td>Other components (DM basis)</td>
<td></td>
</tr>
<tr>
<td>Crude Protein (%)</td>
<td>16.3 ±1.9</td>
</tr>
<tr>
<td>Ether Extract (%)</td>
<td>1.93 ±0.6</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>26.1 ±3.4</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>10.7 ±1.8</td>
</tr>
<tr>
<td>NFE (%)</td>
<td>45.0 ±3.2</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>6.8 ±1.1</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td>3.88 ±0.7</td>
</tr>
<tr>
<td>Uric Acid - N (mg/g)</td>
<td>8.7 ±1.2</td>
</tr>
<tr>
<td>Uric Acid - N as % of total N</td>
<td>33.3</td>
</tr>
</tbody>
</table>

\(^{1}\)Each value is a mean of 5 determinations.
TABLE 2

The Chemical Composition of Hen Droppings as Affected by Length of Time the Droppings Were Allowed to Accumulate

<table>
<thead>
<tr>
<th>Composition</th>
<th>Age of Droppings (weeks)</th>
<th>1</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Matter (%)</td>
<td></td>
<td>61.7 ±2.7</td>
<td>56.2 ±3.1</td>
<td>50.5 ±3.6</td>
</tr>
<tr>
<td>Other components (DM basis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Protein (%)</td>
<td></td>
<td>34.2 ±1.1</td>
<td>32.6 ±0.9</td>
<td>31.8 ±0.9</td>
</tr>
<tr>
<td>Ether Extract (%)</td>
<td></td>
<td>1.21 ±0.6</td>
<td>0.97 ±0.3</td>
<td>0.76 ±0.4</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td></td>
<td>10.1 ±0.4</td>
<td>9.6 ±0.6</td>
<td>9.1 ±0.6</td>
</tr>
<tr>
<td>Ash (%)</td>
<td></td>
<td>24.5 ±2.6</td>
<td>26.9 ±2.4</td>
<td>28.9 ±3.1</td>
</tr>
<tr>
<td>NFE (%)</td>
<td></td>
<td>30.0 ±1.1</td>
<td>29.9 ±2.7</td>
<td>29.4 ±2.4</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td></td>
<td>3.6 ±0.9</td>
<td>3.1 ±0.6</td>
<td>2.8 ±0.7</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td></td>
<td>2.87 ±0.3</td>
<td>2.84 ±0.2</td>
<td>2.82 ±0.2</td>
</tr>
<tr>
<td>Uric Acid-N (mg/g)</td>
<td></td>
<td>22.9 ±0.6</td>
<td>22.5 ±0.5</td>
<td>21.4 ±0.6</td>
</tr>
<tr>
<td>Uric Acid-N as % of total N</td>
<td></td>
<td>41.9</td>
<td>43.1</td>
<td>42.0</td>
</tr>
</tbody>
</table>

1 Each value is a mean of 5 determinations.
Uric acid nitrogen constituted approximately one-third of the total nitrogen in the litter (33.3 to 35.0%), and between 41.9 and 43.1% of the total nitrogen in the droppings. These values are in close agreement with those reported by a number of workers including Fontenot et al. (1966) 30%, Leibholz (1969) 38.7% and Lowman and Knight (1970) 43%.

The mean ash content of the litter increased rapidly from the time birds were put on the new wood shaving bedding material. This increase in the ash content resulted from an increase in the ratio of droppings to woodshaving. The mean ash content of the droppings was more or less constant over the sampling period. However, there was a tendency for slight increases in the ash content as accumulation of droppings progressed. Although complete mineral analysis of the ash was not carried out, the results obtained by Perkins and Parker (1971) showed that calcium constitutes the major macro-element ranging between 2.0 and 4.8% of the hen droppings and between 1.2 and 3.8% of broiler litter. Other macro- and micro-elements are present in the droppings, but none is present in amounts that can lead to nutritional problems when used as a nitrogen supplement in ruminant rations.
The crude fiber content of broiler litter decreased progressively over the 6-week sampling period. This decrease is expected as the ratio of excreta to wood shaving bedding material increased with accumulation of droppings on the litter. Wasted feed accounted for a major portion of crude fiber and lignin present in the pure droppings. Usually poultry droppings are quite low in crude fiber and lignin (Leibholz, 1969).

The litter had a higher ether extract than the droppings at all sampling dates. The mean ether extract of the litter increased slightly over the sampling period while that of the droppings decreased. However, the mean ether extract values obtained for the litter at the end of six weeks (2.6%) agree well with those reported by Fontenot et al. (1966) 2.8%, Mowat (1965) 2.5% and Brugman et al. (1964) 2.53%. It does appear that the higher ether extract value in the litter as compared with the droppings is influenced by the presence of the bedding material in the litter.

The mean gross energy content (kcal/g) of the broiler litter was higher than that of the droppings irrespective of sampling dates. This difference in energy content could be explained by the fact that the litter is higher in crude fiber, ether extract and lower in ash contents than the
droppings. The gross energy content of the litter was observed to decrease with length of time of accumulation of excreta on the litter. The decreasing energy content of the litter can thus be attributed to the increasing ratio of droppings to the bedding material and thus an increase in the ash content which has no energy value.
B. EFFECT OF HEAT TREATMENTS ON THE CHEMICAL COMPOSITION AND BACTERIAL FLORA OF POULTRY WASTES.

1. Introduction

In the development of a suitable procedure for handling poultry wastes for ruminant feeding, the physical, chemical and microbiological properties of the wastes should be considered. Poultry waste has been shown to be quite high in bacteria, moulds and yeasts (Halbrook et al., 1951; Brugman et al., 1964; Schefferle, 1965; Alexander et al., 1968). The majority of the microflora in the waste are normal inhabitants of the intestinal tract of ruminants and therefore not pathogenic to livestock (Ivos et al., 1966; Schefferle, 1966). Nevertheless, the presence of certain pathogenic bacteria in the poultry wastes is of extreme concern when the wastes are used in ruminant feeding (Alexander et al., 1968). It is not certain whether application of heat treatments can affect the value of poultry waste as a feed supplement for ruminants. On the other hand, the presence of disease causing bacteria could constitute a potential health hazard to livestock and man.
2. **Experimental Methods**

A total of 12 samples consisting of 6 samples each of broiler litter and cage droppings were taken from the bulk of wastes collected to be used for the animal feeding trials. The 6 samples of each type of poultry waste were composited, mixed thoroughly and sub-sampled for microbiological tests following the procedure reported by Alexander *et al.* (1968) as outlined below.

A 10g portion of each specimen was suspended in 100 ml of phosphate buffered saline at pH 7.2 in a 250 ml Erlenmeyer flask. The flasks were well stoppered and put on an automatic agitator for 30 minutes. After this, the suspension was passed through a Berkefeld filter cylinder without a filter paper, to separate the large particles. The suspensions were allowed to settle for 30 minutes and the supernatant poured into dilution bottles. Different dilutions of this supernatant were prepared and used as the inoculum. Prior to the preparation of the inoculum, the culture media to be used in the studies were sterilized in an autoclave at 1.06 kg/sq. cm pressure and 121°C for 30 minutes.

The specimens were inoculated using a 2 mm. wire loop onto boric acid sheep blood agar (6.5 ml of 4% boric acid
solution in 250 ml. of 5% sheep blood agar), MacConkey agar (Difco)\(^1\) and brilliant green agar (Difco)\(^1\). Tubes of beef infusion broth were inoculated with 1 ml. of the supernatant and incubated at 37°C for 4 hours prior to inoculating tubes of selenite-F broth (Difco)\(^1\) with 3 ml. of this growth. The selenite-F broth was incubated for 24 hrs. before being subcultured to brilliant green agar. All the inoculated culture media were incubated at 37°C and inspected daily for 6 days for bacterial growth.

The remaining litter and cage droppings were subjected to three different heat treatments to produce oven-dried, autoclaved and cooked poultry wastes (El-Sabban \textit{et al.}, 1970). Autoclaved poultry waste (APW) was treated by steam at 1.06 kg/sq.cm. pressure and 121°C for 30 minutes. Cooked poultry waste (CPW) was prepared by first wrapping the fresh poultry waste in aluminium foil and steaming at atmospheric pressure for 30 minutes. Dried poultry waste (DPW) was prepared by spreading the material very thinly on aluminium foil and drying in a forced-air oven at 37.5°C for 72 hours.

Both the processed and unprocessed poultry wastes were dried in the oven, ground in the laboratory hammermill to pass the 20 mm. screen and analyzed for nitrogen (A.O.A.C., 1960) and uric acid (Buys and Potgieter, 1959). The processed

\(^1\)Difco Laboratories Inc., Detroit, Michigan, U.S.A.
TABLE 3

The Effect of Heat Treatments on the Bacterial Growth in Poultry Wastes

<table>
<thead>
<tr>
<th>Media</th>
<th>Untreated</th>
<th>APW</th>
<th>CPW</th>
<th>DPW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood agar</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>MacConkey agar</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Brilliant green agar (Selinite-F broth)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1APW = autoclaved poultry waste
CPW = cooked poultry waste
DPW = dried poultry waste

++ = 50 or more colonies of bacteria observed

++ = 10 or less colonies of bacteria observed
media overgrown with moulds.
## TABLE 4

**RESULTS OF BACTERIOLOGICAL ANALYSIS OF FORTY-FOUR SAMPLES OF POULTRY LITTER**

<table>
<thead>
<tr>
<th>Types isolated</th>
<th>Number Isolated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clostridium perfringens</td>
<td>8</td>
</tr>
<tr>
<td>Clostridium chauvoei</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium novyi</td>
<td>8</td>
</tr>
<tr>
<td>Clostridium sordellic</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium butyricum</td>
<td>2</td>
</tr>
<tr>
<td>Clostridium cochlearium</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium multifermentans</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium carnis</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium tetanomorphum</td>
<td>1</td>
</tr>
<tr>
<td>Clostridium histolyticum</td>
<td>1</td>
</tr>
<tr>
<td>Corynebacterium pyogenes</td>
<td>1</td>
</tr>
<tr>
<td>Corynebacterium equi</td>
<td>2</td>
</tr>
<tr>
<td>Salmonella blockley</td>
<td>1</td>
</tr>
<tr>
<td>Salmonella saint-paul</td>
<td>1</td>
</tr>
<tr>
<td>Salmonella typhimurium var. copenhagen</td>
<td>1</td>
</tr>
<tr>
<td>Actinobacillus spp.</td>
<td>1</td>
</tr>
<tr>
<td>Yeast</td>
<td>1</td>
</tr>
<tr>
<td>Mycobacterium spp.</td>
<td>2</td>
</tr>
<tr>
<td>Enterobacteriaceae (other than Salmonella)</td>
<td>All samples</td>
</tr>
<tr>
<td>Bacillus spp.</td>
<td>All samples</td>
</tr>
<tr>
<td>Staphylococcus spp.</td>
<td>All samples</td>
</tr>
<tr>
<td>Streptococcus spp.</td>
<td>All samples</td>
</tr>
</tbody>
</table>

3. Results and Discussion

The effect of heat treatments of poultry waste on the bacterial growth is shown in table 3. A large number of bacterial colonies was observed in the media inoculated with the untreated poultry waste. A few colonies were also observed in the media inoculated with the dried poultry waste. No colonies were observed in either the autoclaved or cooked poultry waste indicating that the microorganisms in the waste were destroyed by the heat treatments. The differential media (brilliant green agar and selenite-F broth) used for the isolation of Salmonella spp did not show any growth. The birds from which the wastes were collected were fed antibiotic-supplemented feeds. Identification of the types of bacteria observed in the media inoculated with the untreated poultry waste was not carried out. However, table 4 shows the types of bacteria which were isolated from a total of 44 field samples of poultry waste obtained from six provinces in Canada (Alexander et al., 1968). The 44 samples were made up of 27 broiler, 15 hen and 2 turkey litter samples. Salmonella spp were isolated from only three samples. Thirteen of the 44
<table>
<thead>
<tr>
<th>Component</th>
<th>Untreated</th>
<th>APW</th>
<th>CPW</th>
<th>DPW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N (%)</td>
<td>5.09</td>
<td>4.97</td>
<td>4.86</td>
<td>4.30</td>
</tr>
<tr>
<td>Uric acid N (mg/g)</td>
<td>21.4</td>
<td>20.3</td>
<td>19.7</td>
<td>18.8</td>
</tr>
<tr>
<td>Uric acid as % of total N</td>
<td>42.0</td>
<td>41.3</td>
<td>40.1</td>
<td>43.7</td>
</tr>
</tbody>
</table>

**TABLE 5**

TOTAL NITROGEN AND URIC ACID NITROGEN CONTENT OF UNTREATED AND HEAT TREATED POULTRY DROPPINGS AND LITTER

(a) Poultry droppings

(b) Poultry litter

1APW = autoclaved poultry waste
CPW = cooked poultry waste
DPW = dried poultry waste
samples were negative for pathogenic bacteria. Most of the bacteria isolated by these workers are normal inhabitants of the intestinal tract of ruminants. It was observed that storage of litter for one or two months was probably sufficient to destroy salmonella present in the litter. The alkalinity of poultry wastes has been shown to increase with storage (Halbrook et al., 1951). Increased alkalinity therefore may be one of the factors affecting viability of bacteria in aged poultry wastes (Tucker, 1967; Carriere et al., 1968).

The total nitrogen and uric acid nitrogen content of the untreated and treated poultry droppings and litter are presented in table 5. The data indicated that steaming of poultry waste under pressure (APW) or at atmospheric pressure (CPW) had little effect on the total nitrogen and uric acid nitrogen content of the wastes. However, slight decreases in the content of these components were observed. Drying of the fresh poultry wastes resulted in greater decrease in the total and uric acid nitrogen content when compared with the heat treated samples. It appeared that air-drying of poultry wastes without first arresting the process of decomposition by heat treatment increased the nitrogen loss most probably by way of ammonia.
4. **Summary and Conclusion**

Analyses of broiler litter and hen droppings indicate that these wastes contain valuable nutrients, particularly nitrogen, and thus could be used to replace part of the nitrogen in the ration of ruminant animals. Broiler litter as removed from the house contained between 31.8 and 41.6% moisture. On an oven-dry basis, it contained between 3.2 and 4.8% N, 21.8 and 25.7% ash and a variable percent of crude fiber depending on the ratio of the droppings to the bedding material. Cage droppings contained higher moisture content on the average than broiler litter. As collected from the house, poultry droppings contained between 41.9 and 54.3% moisture. On dry basis, it contained between 4.1 and 5.8% N, and 26.2 and 33.1% ash. Approximately one-third of the total N in poultry litter is uric acid-N, while poultry droppings contained slightly higher values. Minor variations existed in the chemical analysis of poultry wastes collected in the same house at any sampling date as compared with samples collected on different dates.

Application of heat treatments (autoclaving and steaming) had little effect on the total and uric acid nitrogen of the wastes. Higher nitrogen loss was observed in the dried samples as compared with the heat treated samples. The reason for this
difference is most likely due to the fact that the process of decomposition by the saprophytic groups of bacteria was arrested by the heat treatments. The heat treatments were sufficient to destroy all microflora present in the wastes. The drying process resulted in the production of material that still contained some microorganisms, particularly moulds and yeasts. _Salmonella_ spp was not isolated in the poultry wastes tested.

A number of factors have been reported to contribute to decreased viability of pathogenic bacteria in poultry wastes. Among these factors are the storage or accumulation period, alkalinity of the wastes, high population of competing and saprophytic groups of bacteria. Water and type of feed are among the major factors which affect the microflora of the intestinal tract of chickens, and since most poultry producers are now using antibiotic-supplemented rations, the incidence of pathogenic bacteria in the feces of chickens is much less. Heat treatment of the wastes before being incorporated into ruminant diet will further ensure that the waste is free of pathogenic bacteria.
SECTION II

ANIMAL FEEDING TRIALS
A. **TRIAL I.** Supplementation of High-roughage rations with various Nitrogen sources (unpelleted rations).

Digestibility and Nitrogen Balance Studies

1. **Introduction**

A review of the literature shows that low-quality forages can serve as a potential energy source for ruminants if the effect of lignin, which reduces both nutrient availability and voluntary consumption can be circumvented. Various physical and chemical treatments have been used to effect delignification and thus increase the energy digestibility. However, it has been observed by many authors that the delignified material is in most cases not consumed by ruminant animals in amounts to meet the energy requirement. It has therefore been found necessary to accompany delignification procedures with energy and/or nitrogen supplementation in order to increase both the nutrient digestibility and voluntary consumption of low-quality forages by ruminants. In most cases, nitrogen supplementation alone has been found to be more beneficial as regards nutrient digestibility and consumption of roughages by animals.

The animal feeding trial and nitrogen balance studies to be reported were designed to evaluate the nutritive value
of a low-quality forage (Oat straw) when supplemented with five different nitrogen sources using soybean meal nitrogen as the reference nitrogen.

2. Design of Experiment

A randomized block design was used with the 4 NPN sources (urea, biuret, poultry droppings and broiler litter) and the reference nitrogen source (soybean meal) constituting the treatments. Eight lambs were assigned to each experimental ration. The male animals in each experimental group were to be used for digestibility and nitrogen balance studies while the female animals were to be group-fed to determine the relative feeding value of the experimental rations, using changes in body weight as the basis for comparison.

3. Preparation of ration components

(a) Grinding of Oat straw

Baled oat straw which was harvested in 1969 was used as the low-quality roughage. The straw was prepared for feeding by first chopping in a Haybuster model B No. 162, and

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1J.&J. Manufacturing Company, Minot, North Dakota, 58701, U.S.A.
then grinding in a Massey Harris laboratory hammermill. The average length of the resultant ground straw was about 0.35 cm.

(b) Preparation of the poultry wastes

Poultry droppings were collected from a caged layers' house. The droppings had accumulated for approximately 4 weeks following the last day of cleaning the house. Wood-shaving-base litter was collected from a broiler house. The litter had been used for about 6 weeks starting from the date the birds were first put on the new bedding. Samples were taken from the bulk of poultry droppings and litter and analyzed for chemical constituents as reported earlier. The litter consisted primarily of wood-shavings and chicken droppings but mixed with other extraneous materials such as shed feathers, wasted feed, housefly larvae and pupae. The cage droppings were mixed with shed feathers, wasted feed, housefly larvae and pupae and some broken eggs. No attempts were made to remove these extraneous materials.

The litter and droppings thus collected to be used for the feeding trial were air-dried, heated and ground before being mixed with the other ingredients in the experimental
ration. This procedure was deemed sufficient to eliminate pathogenic bacteria, if any, and still maintain a high nutritive value of the litter and droppings. Furthermore, the procedure is most likely to be more applicable and economical on small to medium-scale farms, than autoclaving.

The litter and droppings were prepared for air-drying by spreading very thinly (3 - 6 cm. deep) on polyethylene plastic sheets on concrete floors. Drying was in an open space for the first 2 weeks in order to accelerate the process of drying. The materials were turned occasionally with a wooden rake in order to expose the lower portion to the effects of sunshine and air. Extra plastic sheets were kept for protection in case of rain. After 2 weeks, the drying continued indoors and infra-red light bulbs were used to hasten drying. Drying was completed in approximately a week following the indoor drying. The air-dried litter and droppings were put in separate jute sacks and exposed to high temperatures of between 50-65.5°C for 48 hours. After this, the materials were passed through the hammermill in order to break up the lumps and facilitate proper mixing with other ration components. Before grinding however, pieces of stone, large feathers and other noticeable extraneous matters were removed. The resultant ground material was a free-flowing powdery substance, which was dark-brown in colour.
Samples were taken from the processed litter and droppings and analyzed for chemical components. Similar bacteriological studies reported earlier were carried out on the samples. The ground litter and droppings were stored in plastic bags until used, and required no further processing before being incorporated into experimental rations. The average chemical composition of the processed litter and droppings is shown in Table 6.

(c) Mixing of Experimental Rations

The percent composition of the experimental rations is given in Table 7. Soybean meal was used as the control nitrogen source in ration 1. In rations 2 and 3, 50 percent of the soybean meal nitrogen of ration 1 was replaced with urea and biuret respectively. Urea was incorporated at a level of 2% and biuret at a level of 2.3% of the total ration. Feed grade urea (262 percent protein equivalent) and biuret obtained from Dow Chemical Company, Canada, as "Keldor 230" feed compound (230 percent protein equivalent) were used.

Poultry droppings and broiler litter processed as described above were incorporated into rations 4 and 5 respectively at levels high enough to replace approximately 50
TABLE 6

MEAN CHEMICAL COMPOSITION OF WOOD-SHAVINGS BROILER LITTER AND CAGED LAYERS' DROPPINGS USED IN FEEDING TRIAL I

<table>
<thead>
<tr>
<th>Composition (%) on D.M. basis</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler litter:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Matter</td>
<td>62.6</td>
<td>±3.93</td>
<td>58.4 -- 68.2</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>26.4</td>
<td>±3.54</td>
<td>21.5 -- 30.4</td>
</tr>
<tr>
<td>Ether Extract</td>
<td>2.6</td>
<td>±1.12</td>
<td>1.5 -- 4.1</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>16.6</td>
<td>±2.66</td>
<td>13.6 -- 20.1</td>
</tr>
<tr>
<td>Ash</td>
<td>24.2</td>
<td>±1.67</td>
<td>21.8 -- 25.7</td>
</tr>
<tr>
<td>NFE</td>
<td>30.2</td>
<td>±2.54</td>
<td>26.9 -- 33.6</td>
</tr>
<tr>
<td>Lignin</td>
<td>5.1</td>
<td>±0.66</td>
<td>4.3 -- 5.8</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td>3.048</td>
<td>±0.14</td>
<td>2.871 -- 3.212</td>
</tr>
<tr>
<td>Uric Acid-N (mg/g)</td>
<td>14.4</td>
<td>±0.96</td>
<td>13.0 -- 15.4</td>
</tr>
<tr>
<td>Cage Droppings:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Matter</td>
<td>50.5</td>
<td>±4.82</td>
<td>45.7 -- 58.1</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>31.8</td>
<td>±3.84</td>
<td>26.3 -- 35.4</td>
</tr>
<tr>
<td>Ether Extract</td>
<td>0.76</td>
<td>±0.25</td>
<td>0.49 -- 1.12</td>
</tr>
<tr>
<td>Crude Fiber</td>
<td>9.1</td>
<td>±1.12</td>
<td>7.4 -- 10.2</td>
</tr>
<tr>
<td>Ash</td>
<td>28.9</td>
<td>±2.69</td>
<td>26.2 -- 33.1</td>
</tr>
<tr>
<td>NFE</td>
<td>29.4</td>
<td>±2.36</td>
<td>27.4 -- 33.4</td>
</tr>
<tr>
<td>Lignin</td>
<td>2.8</td>
<td>±0.44</td>
<td>2.4 -- 3.4</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td>2.821</td>
<td>±0.11</td>
<td>2.661 -- 2.956</td>
</tr>
<tr>
<td>Uric Acid-N (mg/g)</td>
<td>21.4</td>
<td>±1.96</td>
<td>19.8 -- 24.8</td>
</tr>
</tbody>
</table>

1 Mean of analyses of 5 samples.
### TABLE 7

**COMPOSITION OF RATIONS TRAIL I**

<table>
<thead>
<tr>
<th>Ingredients (%)</th>
<th>Soybean meal (1)</th>
<th>Urea (2)</th>
<th>Biuret (3)</th>
<th>Poultry droppings (4)</th>
<th>Poultry litter (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat straw</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Urea</td>
<td>---</td>
<td>2.0</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Biuret</td>
<td>---</td>
<td>---</td>
<td>2.3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Poultry droppings</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>20.0</td>
<td>---</td>
</tr>
<tr>
<td>Poultry litter</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>25.0</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>20.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Ground barley</td>
<td>23.0</td>
<td>31.0</td>
<td>30.7</td>
<td>29.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Cane molasses (dehydrated)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Sodium tripolyphosphate</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Cobalt iodized salt</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Vitamin premix(^1)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

\(^1\) Vitamin premix containing:

- Vitamin A 2,000 IU/kg feed
- Vitamin D 200 IU/kg feed
- Vitamin E 20 IU/kg feed
percent of the soybean meal nitrogen of the control ration (ration 1). The result obtained by McInnes et al. (1968), when they fed mixtures of litter and wheat to weaner sheep showed that poultry waste is highly unpalatable particularly when fed with low-quality roughage. Since urea and low-quality roughages are themselves unpalatable, dehydrated cane molasses was added to all rations at a level of 10 percent of the total ration in order to reduce any problems associated with unfavourable palatability. Chemical analyses of poultry litter and droppings (Brugman et al., 1964; Perkins and Parker, 1971) have shown that poultry wastes are high in calcium and relatively low in phosphorus. In an attempt to narrow the Ca:P ratio therefore, sodium tripolyphosphate (Na$_5$P$_3$O$_{10}$) was added to rations containing poultry droppings and litter (rations 4 and 5). Dicalcium phosphate was added to rations 1, 2 and 3 at a level of 1.5 percent of the total ration in order to bring the Ca and P contents of these rations to a similar level as those for rations 4 and 5. Cobalt iodized salt was added to all rations at 0.5 percent level.

Ground straw was used at a level of 45 percent of the total ration in rations 1, 2 and 3 and at 30 percent in rations 4 and 5 respectively. The remaining ration was made up of ground barley as this is one of the most common cereal grains used in ruminant feeding. Vitamin premix was added to all
rations to supply approximately 2,000 I.U. vitamin A, 200 I.U. vitamin D and 20 I.U. vitamin E per kilogram feed. Mixing of rations was done using a David Bradley vertical mixer.

(d) Animal preparation and feeding

Forty lambs of the Dorset Horn breed consisting of 15 males and 25 females ranging in age from 5-6 months and weighing between 23.6 and 39.1 kg. were used for this study. The animals were divided randomly on weight and sex basis into five groups each of 8 (3 males and 5 females). Each group of lambs were put in separate pens and fed approximately 1 kg rolled barley per head daily and free choice grass hay, pending the introduction of the experimental rations.

The five groups of 8 lambs were randomly assigned to the experimental rations. To commence the feeding of the rations, each group received a mixture of their respective experimental ration and rolled barley. Thereafter on each of the following days, the amount of the rolled barley was progressively decreased while that of the experimental ration was increased, so that by the fifth day, all animals were on their respective experimental rations with no mixture of rolled barley. The animals were group-fed twice daily at approximately
1 kg per head per day. Fresh tap water was available in automatic drinking troughs at all times. All animals were weighed at weekly intervals throughout the experimental period.

(e) **Metabolism Studies**

Only the male lambs in each group were used for metabolism studies in order to allow for an easy quantitative separation of feces and urine. These animals were confined in individual digestion cages designed to enable total collection of feces and urine. Since the animals had been introduced to the experimental ration in the pens and had been on their respective rations for about 3 weeks prior to being put in the digestion cages, 10 days were allowed for adjustment to the cages. A 10-day preliminary period has been reported to be quite adequate in the determination of nutrient digestibilities and voluntary consumption of penned sheep (Lloyd et al., 1956; Lister, 1957).

(i) **Voluntary feed intake determination**

In determining voluntary feed intake, the animals were fed *ad libitum* by offering each animal a known weight of the
experimental ration to insure an excess of at least 10% over the previous day's consumption. On the following morning, the feed left unconsumed was weighed and subtracted from the feed offered to obtain the actual consumption. Fresh tap water was available to individual caged animals at all times.

(ii) **Digestibility and Nitrogen Balance Determinations**

The 3 male animals in each experimental group were used for the digestibility of ration nutrients and nitrogen balance determinations because of the ease of quantitative separation of feces and urine. One male lamb from each group constituted a run or replicate. The animals were weighed prior to being put in the digestion cages and also immediately after the conclusion of a run. Total fecal collection was made during the last 7 days of each run which was preceeded by a 10-day adjustment period. Collection of feces was done each morning before feeding. The total fecal output was weighed, mixed thoroughly with a wooden spatula and a representative aliquot sample (approximately 10% by weight of the total feces) was taken and put in plastic bags. Sub-samples of these were weighed into petri plates and dried in a forced-air oven at 85°C for 48 hours. At the completion of a run, the dried fecal samples for each animal over the 7-day collection period were
composited, ground to pass the 20-mm screen mesh and stored in tight-fitting glass jars for subsequent chemical analysis.

(iii) Sampling of Experimental Rations

Samples of the experimental rations were taken daily for 7 days starting a day previous to the beginning of fecal collection. This was done in order to obtain a more representative sample of the ration the animals were consuming during the collection period. At the end of the 7 days, samples from each ration were composited and dried in the oven at 85°C for 24 hours. The dried samples were ground in a hammermill to pass the 20-mm mesh screen and stored in screw-capped bottles for chemical analysis.

(iv) Urine Collection

As in the case of fecal collection, total urinary collection was made during the last 7 days of each run. Urine was collected in narrow-necked plastic bottles in order to reduce the surface area of the urine exposed to the atmosphere. Also, to prevent decomposition and loss of nitrogen in the form of ammonia, approximately 2 ml. toluene and 2 ml.
concentrated $\text{H}_2\text{SO}_4$ were put in the receiving bottles after emptying the previous day's urine. The volume of daily output of urine was measured and a sample of the urine taken. Samples were refrigerated at $4^\circ\text{C}$ during the collection period. At the end of each run, urinary samples from each animal were composited and frozen until analyzed for total nitrogen.

(v) **Chemical analysis of feeds, feces and urine samples**

All chemical analyses were by A.O.A.C. (1960) methods where applicable and all results were expressed on Dry Matter (DM) basis, except for urine. Gross energy determinations were done on feed and feces samples only, using the Gallenkamp Adiabatic Bomb Calorimeter\(^1\) and expressing the results (kcal/g) on DM basis.

Cellulose content in the feed and feces samples were determined using the Crampton and Maynard (1938) procedure, slightly modified as reported by Donefer et al. (1960). Acid-detergent fiber (ADF) and lignin contents were determined in feed and feces samples according to the procedure of Van Soest (1963) and Van Soest and Wine (1968).

Nitrogen determinations were made on feed, feces and urine samples using the A.O.A.C. (1960) macro-Kjeldahl method. Nitrogen content was converted to crude protein by multiplying the percent nitrogen by the factor 6.25 and expressing the result on DM basis.

(f) Calculations

(i) Apparent Digestibility Coefficients

The apparent digestibility coefficients of the dry matter (DM), gross energy (G.E.), cellulose, crude protein, ether extract, crude fiber and nitrogen-free extract (NFE) were calculated as the difference between the nutrient intake and excretion in the feces expressed as a percent of nutrient intake. Since no corrections were made for fecal components of endogenous origin, it was assumed that the feces represented residues of dietary origin only, and thus, the term apparent digestibility would describe all such coefficients calculated in this manner. The following formula was used to calculate digestibility.
Digestibility (%) = \frac{(F_0 \times A_o) - (F_e \times A_e)}{(F_0 \times A_o)} \times 100

where \( F_0 = \) g feed consumed.
\( A_o = \) percent nutrient (DM, energy, protein etc.) content in the feed.
\( F_e = \) g feces excreted.
\( A_e = \) percent nutrient (DM, energy, protein etc.) content in the feces.

(All values are on dry matter basis.)

(ii) **Nitrogen Balance**

Total daily nitrogen intake per animal was calculated from the daily voluntary consumption of the feed and the nitrogen content of the ration. Nitrogen excretion was determined both in the feces and in the urine. All values were expressed on the metabolic size (\( W_k^{0.75} \)) of the animal in order to eliminate differences due to body weight of the animals. Nitrogen retention was calculated as the difference between nitrogen intake and excretion (fecal plus urinary) and was expressed both as per cent of nitrogen intake and absorbed (or digested) nitrogen.
(iii) **Relative Intake (RI)**

Relative Intake (RI) was calculated from the average daily voluntary consumption of the experimental rations and expressing this relative to \(80g/W_{kg}^{0.75}\) according to the method of Crampton *et al.* (1960) using the formula:

\[
RI = \frac{100 \times (\text{Voluntary Intake})}{80W_{kg}^{0.75}}
\]

(iv) **Nutritive Value Index (NVI)**

The Nutritive Value Indices (NVI) were calculated by multiplying the gross energy per cent digestibility by the RI value (Crampton *et al.*, 1960).

\[
\text{Per cent gross energy digestibility} \times RI = NVI
\]

(v) **Digestible Energy (DE) Intake**

The digestible energy intake potential was calculated either directly as kcal. of digestible energy per kg metabolic size of the animal (kcal. DE/\(W_{kg}^{0.75}\)) or indirectly by multiplying
the NVI of the ration by its gross energy content (kcal/g) and dividing by the factor 1.25 (Crampton et al., 1962).

(vi) **Statistical Procedures**

All data were subjected to statistical analysis using the analysis of variance procedure (Snedecor and Cochran, 1968). Statistical significance between treatment means was determined using Duncan's (1955) Multiple Range Test.
RESULTS AND DISCUSSION

a. Chemical Composition of Experimental Rations

Chemical analyses data of the experimental rations are presented in Table 8. The crude protein content of all rations are in the range recommended for fattening lambs of similar age and weight (NRC, 1968). It could however be observed that the crude protein content of the poultry litter supplemented ration (ration 5) was slightly lower than that for the other rations. In a series of paired feeding experiments with growing lambs, Hamilton et al. (1948) showed that the total ration protein equivalent should be about 12% and that at least 25% of the ration nitrogen should be provided as protein nitrogen for the most efficient utilization of urea or other NPN. In this trial, the total crude protein of all the experimental rations was higher than 12% and more than 25% of the ration nitrogen was provided as protein nitrogen (Table 9). The per cent of total ration nitrogen furnished by NPN source in the urea and biuret supplemented rations (rations 2 and 3 respectively) was in the range of 33% to 50% suggested as optimal by a number of workers including Perham et al. (1955), Brown et al. (1956) and Davis et al. (1957).

The crude fiber content of rations 1, 2 and 3 in which oat straw was used at a level of 45% of the total ration, was
TABLE 8

AVERAGE CHEMICAL ANALYSIS OF THE RATIONS FED TO LAMBS IN FEEDING TRIAL I

<table>
<thead>
<tr>
<th>Composition</th>
<th>Soybean meal (1)</th>
<th>Urea (2)</th>
<th>Biuret (3)</th>
<th>Poultry droppings (4)</th>
<th>Poultry litter (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Protein (%)</td>
<td>14.90</td>
<td>15.10</td>
<td>15.50</td>
<td>14.90</td>
<td>13.70</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>25.90</td>
<td>27.70</td>
<td>26.70</td>
<td>23.00</td>
<td>27.60</td>
</tr>
<tr>
<td>Ether Extract (%)</td>
<td>0.79</td>
<td>0.64</td>
<td>0.63</td>
<td>2.33</td>
<td>0.10</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>7.50</td>
<td>6.80</td>
<td>6.70</td>
<td>9.40</td>
<td>12.30</td>
</tr>
<tr>
<td>NFE (%)</td>
<td>50.91</td>
<td>49.76</td>
<td>50.47</td>
<td>50.37</td>
<td>44.30</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td>4.20</td>
<td>4.18</td>
<td>4.20</td>
<td>4.08</td>
<td>3.96</td>
</tr>
<tr>
<td>Acid-detergent fiber (%)</td>
<td>29.80</td>
<td>32.20</td>
<td>30.80</td>
<td>25.90</td>
<td>32.00</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>4.00</td>
<td>4.50</td>
<td>4.70</td>
<td>460</td>
<td>9.90</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>25.80</td>
<td>27.70</td>
<td>26.10</td>
<td>21.30</td>
<td>22.10</td>
</tr>
</tbody>
</table>

All values are expressed on dry matter basis.
### TABLE 9

THE PERCENTAGE OF TOTAL NITROGEN ATTRIBUTABLE TO NON-PROTEIN NITROGEN (NPN) SUPPLEMENTS IN THE RATIONS FED TO LAMBS IN FEEDING TRIAL I

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Supplemental Nitrogen Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soybean meal</td>
</tr>
<tr>
<td>Percent supplementation with NPN source</td>
<td>(control)</td>
</tr>
<tr>
<td>Total ration N (%)</td>
<td>2.36</td>
</tr>
<tr>
<td>NPN (%)</td>
<td>--</td>
</tr>
<tr>
<td>NPN as % of total N</td>
<td>--</td>
</tr>
</tbody>
</table>
about the same (25.9, 27.7 and 26.7% respectively). The crude fiber content of the poultry dropping-supplemented ration (ration 4) in which oat straw was used at a level of 30% was lower than those for other rations. The crude fiber content of the litter supplemented ration (ration 5) was about the same as those for rations 1, 2 and 3, despite the fact that oat straw was used at a level of 30% as in ration 4. The higher crude fiber content in ration 5 as compared to ration 4 could be explained by the fact that the litter contained a wood-shaving base which would no doubt contribute to a higher crude fiber content. The acid detergent fiber (ADF) and cellulose contents of the rations followed a similar pattern as that for the crude fiber content and could therefore be explained in the same manner.

The ether extractives (EE) in rations 4 and 5, in which poultry droppings and litter were used as supplemental nitrogen source respectively, were considerably higher than the EE contents of rations 1, 2 and 3 where poultry wastes were not included. This shows that the poultry wastes contributed a higher EE in rations 4 and 5. Similarly, the ash contents of the poultry droppings and litter supplemented rations (4 and 5) were higher than those for the other rations. This could be explained on the basis of the high ash content in poultry wastes (Brugman et al., 1964; Fontenot et al., 1966; Leibholz, 1969; Perkins and Parker, 1971). As a result of the higher ash
content of the poultry droppings and litter supplemented rations (4 and 5) the gross energy (kcal/g) of these same rations were slightly lower than those for rations 1, 2 and 3.

The NFE values for all the rations were about equal with the exception of the litter supplemented ration (5) which had a slightly lower value. Also to be noted was the lignin content of the litter supplemented ration which was more than double the lignin content of any of the other rations. This was most likely due to the presence of wood in the litter and agrees well with the observations of Brugman et al. (1964).

b. **Dry Matter Digestibility**

Data on average dry matter (DM) intakes and apparent digestibility coefficients are presented in Table 10. Each value represents the mean of 3 individual sheep determinations. A highly significant ($P < 0.01$) decrease in DM digestibility was observed in animals fed the poultry litter supplemented ration (ration 5). The reason for this significant decrease in DM digestibility of the ration in which poultry litter replaced part of the nitrogen, could be explained on the basis of the results obtained by Leibholz (1969). All of Leibholz's diets in which 40–47% of the meat meal nitrogen was replaced
TABLE 10

AVERAGE FEED INTAKE AND APPARENT DIGESTIBILITY BY SHEEP OF THE EXPERIMENTAL RATIONS

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Soybean meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>^Digestibility coefficients (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Matter</td>
<td>60.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>58.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>59.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>61.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>42.3&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>71.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>73.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>67.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>68.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>56.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cellulose</td>
<td>49.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>45.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>48.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>46.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24.3&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gross Energy</td>
<td>61.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>59.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>59.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>62.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>43.8&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Crude Fiber</td>
<td>43.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>40.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>44.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>42.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>13.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Relative Intake (%)</td>
<td>73.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>66.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>79.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nutritive Value Index (NVI)</td>
<td>45.4</td>
<td>39.6</td>
<td>47.3</td>
<td>49.7</td>
<td>38.1</td>
</tr>
<tr>
<td>Digestible Energy Intake Potential</td>
<td>152.4</td>
<td>132.4</td>
<td>158.9</td>
<td>162.3</td>
<td>120.8</td>
</tr>
</tbody>
</table>

<sup>1</sup>Represents the average of 3 digestibility trials using 3 male lambs per treatment.

Means on the same line bearing different superscript letters differ significantly:

   a, b (P < 0.05)  c, d (P < 0.01)
with poultry droppings resulted in comparable nutrient digestibility to the control ration. However, addition of sawdust at a level of 15 and 30% in addition to the wheat straw used as the low-quality roughage, resulted in a significant reduction in the overall digestibility of the nutrients. This is probably a reflection of the low digestibility of the fiber in the added sawdust.

Although a slight difference existed in the average DM digestibility coefficients for the other rations these differences were not significant (p < 0.05). It is interesting to note that the average DM digestibility coefficient of the poultry droppings supplemented ration (4) was slightly higher than that of the control ration (1). Similar results have been reported by other workers including El-Sabban et al. (1970) when they obtained an average of 76.27% DM digestibility for sheep fed a ration that was supplemented with poultry waste as compared with 75.3% for sheep on the control ration in which soybean meal was used as the nitrogen source.

The results obtained by Fontenot et al. (1966) similarly failed to show significant difference in the DM digestibility coefficients when 25 and 50% of the soybean meal nitrogen of the control ration was replaced with autoclaved peanut-hull broiler litter. However, 100% replacement of the soybean meal
nitrogen of the control ration with litter resulted in significant decreases in DM digestibility coefficients.

Both the urea and biuret supplemented rations (2 and 3 respectively) had DM digestibility coefficients which were slightly lower than that of the control, but showed no significant differences. The DM digestibility coefficients of the urea and biuret supplemented rations were about equal, indicating that these two nitrogen sources are equally well utilized by ruminants if a sufficient adaptation period was allowed (Hatfield et al., 1955; Ewan et al., 1958 and Oltjen et al., 1968). This probably explains the lack of significant differences between the DM digestibilities of the urea and biuret supplemented rations in this trial.

c. Gross Energy Digestibility

The average gross energy digestibility coefficients are presented in Table 10. It is interesting to note that the pattern of the results obtained for the DM digestibility discussed earlier is similar to that obtained for the gross energy digestibility. However, the coefficient of gross energy digestibility values are slightly higher than those for the DM digestibility. This similarity could be explained by the fact that the dry matter fraction (excluding the ash) is predominantly a source of energy.
A highly significant (P < 0.01) decrease in gross energy digestibility was obtained as a result of the partial replacement of the soybean meal nitrogen of the control ration with poultry litter in ration 5. The replacement of approximately 50% of the soybean meal nitrogen of the control ration (1) with either urea, biuret or poultry droppings (rations 2, 3 and 4 respectively) did not result in any significant (P < 0.05) differences in the gross energy digestibilities when compared to the control ration. The highly significant decrease in the gross energy digestibility of the poultry litter supplemented ration is probably due to the low digestibility of the fibre of the wood shavings present in the litter. When poultry droppings alone were used as in ration 4, the gross energy digestibility was quite comparable to that obtained for the control ration.

The gross energy digestibility coefficients obtained for the urea and biuret supplemented rations (2 and 3) were slightly but not significantly lower than those for the control and poultry droppings supplemented rations (1 and 4). However, the gross energy digestibility coefficients for the urea and biuret supplemented rations were about equal. Many authors including Hatfield et al. (1955), Meiske et al. (1955), Hatfield et al. (1959), Karr et al. (1963) and Oltjen et al. (1968) have reported on comparable utilization of urea and biuret nitrogen
especially when sufficient time is allowed for the adaptation of the animals to biuret.

d. **Crude Fiber and Cellulose Digestibility**

The mean crude fiber and cellulose digestibility coefficients are presented in Table 10. A significantly ($P < 0.01$) lower crude fiber digestibility was observed in the poultry litter supplemented ration. Although slight differences were noticed in the crude fiber digestibility of the other rations, these differences were not significant ($P < 0.05$). The significantly lower crude fiber digestibility of the poultry litter supplemented ration is probably due to the low digestibility of the fiber in the litter (Leibholz, 1969). Bhattacharya and Fontenot (1966) in their studies on the utilization of different levels of poultry litter nitrogen by sheep also reported that crude fiber digestibility was significantly depressed when the level of litter was increased from 25 to 50%.

The coefficients of cellulose digestibility were similar to those of fiber, but the coefficients for the crude fiber digestibility were lower than those for cellulose digestibility.
e. Crude Protein Digestibility

The mean crude protein digestibility coefficients are presented in Table 10. The poultry litter supplemented ration (5) had a significantly (P ≤ 0.01) lower crude protein digestibility value than the other rations. The depressed digestibility coefficients of all nutrients in the poultry litter supplemented ration could be attributed to the unfavourable influence of the wood-shavings litter base. This hypothesis is justified when one compares the nutrient digestibility coefficients of the poultry droppings supplemented ration (4) with those of the control ration in which there were no significant differences. Although many workers have reported on the comparable utilization of poultry litter nitrogen as compared to soybean meal and other conventional protein supplements (Noland et al., 1955; Fontenot et al., 1964; Mowat, 1965; Bhattacharya and Fontenot, 1966; Fontenot et al., 1966; McInnes et al., 1966 and Lowman and Knight, 1970), differences in the litter composition, especially the bedding (or base) materials could influence the utilization of the litter by ruminants. Fontenot et al. (1964) found that feed efficiency and carcass grades of steers fed the peanut hull poultry litter were higher than those fed the wood-shavings poultry litter. It appears that the inclusion of wood-shavings poultry litter to diets already high in low-quality roughage depresses the coefficients of nutrient digestibility. This
observation was also reported by Leibholz (1969) who found that the addition of sawdust at or above 30% level to the wheat straw used as the low-quality forage, depressed nutrient digestibility and body weight gains in sheep. It could be concluded therefore, that poultry litter should be used with high energy diets as was reported in the studies conducted by McInnes et al. (1968) who observed satisfactory performance of weaner sheep when poultry litter was used along with high energy diets -- mixtures of poultry litter and wheat (1:1 ration). Mowat (1965) also reported weight gains of 2.6 to 2.8 lbs. (1.18 to 1.27 kg) per day when 3 parts high energy feed and 1 part poultry litter were fed to fattening steers.

Crude protein digestibility coefficients of urea, biuret, and poultry droppings supplemented rations (2, 3 and 4 respectively) were not significantly different from that of the control ration. The crude protein digestibility coefficient for the urea supplemented ration was highest. This probably shows that urea is rapidly and completely hydrolyzed in the rumen, thus accounting for very small fecal nitrogen and high digestibility. The crude protein digestibility coefficient of the biuret supplemented ration was slightly, but not significantly, lower than that for the urea supplemented ration. Similar results were reported by Hatfield et al. (1959) when they found that steers fed either the soybean meal or urea
supplemented rations had a better nitrogen digestibility and utilization than the steers fed the biuret supplemented ration. Welch et al. (1956) also reported depressed apparent nitrogen digestibility with crude biuret when compared to urea. Most of the differences observed in the nitrogen utilization of urea and biuret supplemented rations could be explained on the basis of adaptation of the ruminant animals to urea and biuret. Welch et al. (1956), Berry Jr. et al. (1956), Repp et al. (1955), Ewan et al. (1958), Schroder and Gilchrist (1969) and many others have shown that biuret nitrogen is as well utilized by ruminants as urea nitrogen but that animals require a longer period of adaptation when fed biuret supplemented rations.

f. Relative Intake

The voluntary consumption of the experimental rations were expressed relative to the voluntary intake of good quality hay (Crampton et al., 1960), assuming that sheep will voluntarily consume about 80g of good quality hay per unit of metabolic size. In order to demonstrate the overall nutritive value of the test rations, the voluntary consumption of the experimental rations was related to the observed Relative Intake (RI) reported by Crampton et al. (1960). A summary of the RI data is shown in Table 10, in which each value represents the mean of 3 animal determinations.
The RI value for the urea supplemented ration (2) was significantly \(P < 0.05\) lower than the RI values for the other rations. This might have been due to the poor palatability of urea which has been reported by a number of workers including Anderson (1967) and Ioset (1969). Differences in the RI values of the other rations were not significant. The poultry droppings and litter supplemented rations (4 and 5 respectively) showed the highest RI values. It is difficult to explain why there was a higher RI value for the litter supplemented ration as compared with the other rations. It appeared that intake of the litter supplemented ration was increased to compensate for the lower nutrient digestibility of this ration. This observation is contrary to what normally occurs in ruminants fed low-quality forage. Baumgardt (1970) showed that at low nutritive value, intake is limited by the gut fill and thus feed (dry matter) intake is positively related to digestibility. Since the litter supplemented ration had a dry matter digestibility value (42.3\%) lower than that of any of the other rations, its intake was expected to be lower than the intake of any of the other rations. However, it could be mentioned that nutrient availability is only one of the many factors involved in feed intake regulation in ruminants. The control of feed intake by an animal is a result of mechanisms which work to maintain a desirable constancy of the internal environment or homeostasis of the animal. The precise interaction of these mechanisms is still not fully understood (Baumgardt, 1970).
g. **Nutritive Value Index (NVI).**

The NVI is a numerical description of the "overall" nutritive value of a forage and it is calculated as the product of gross energy digestibility coefficient and the RI (Crampton et al. 1960). The summary of the nutritive value indices for the experimental rations is presented in Table 10. Although no significant (P < 0.05) differences were observed in the NVI values for all rations, the values for the urea and poultry litter supplemented rations (2 and 5 respectively) tended to be lower than the value for the control ration. Biuret and poultry droppings supplemented ration (3 and 4) had NVI values slightly higher than the control. Lack of significant differences in the indices could be explained if the two factors involved in the calculation of NVI are examined. Of the two factors involved (per cent energy digestibility and RI) the RI accounts for the larger contribution to the NVI (Crampton et al., 1960). This is clearly shown in the poultry litter supplemented ration (5) in which the high RI resulted in NVI that was no longer significantly (P < 0.05) different from the other rations despite the significantly (P < 0.01) lower energy digestibility for this ration. Using the same explanation, the NVI value for the urea supplemented ration (2) was lower than that for the control ration as a result of the significantly (P < 0.05) lower RI for this ration.
h. **Digestible Energy (DE) Intake Potential**

The DE intake Potential \((\text{kcal DE/W}^{0.75}_{\text{kg}})\) of the experimental rations were calculated by multiplying the NVI values of the rations by their respective gross energy content \((\text{kcal/g})\) and dividing the product by the factor 1.25 (Crampton et al. 1962). A summary of the DE intake values is presented in Table 10. As would be expected, statistical analysis failed to indicate any significant differences in the DE intake values of all rations. This lack of significant difference is mainly due to the fact that the DE intake values were calculated using the NVI values, which were themselves not significantly different from one another. The trend in magnitude of the DE intake values is similar to that for the NVI values. It is however worthy of note that NPN supplementation of the high roughage rations resulted in DE intakes equal to that expected for high-quality forages such as legume hay.

i. **Nitrogen Balance**

The mean nitrogen balance data are presented in Table 11. There was no significant difference \((P < 0.05)\) in the observed total daily nitrogen intake by sheep on all experimental rations. But it could be seen that nitrogen intake by animals fed the urea supplemented ration (2) tended to be slightly lower than for the other rations. This is a reflection of the marked decrease in voluntary consumption of ration 2 as compared with the other
TABLE II

AVERAGE NITROGEN BALANCE OF LAMBS FED THE EXPERIMENTAL RATIONS

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Soybean meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of animals</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>N Intake (g/W(^{0.75})/day)</td>
<td>1.49</td>
<td>1.29</td>
<td>1.59</td>
<td>1.53</td>
<td>1.51</td>
</tr>
<tr>
<td>N excretion:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fecal (g/W(^{0.75})/kg./day)</td>
<td>0.42</td>
<td>0.34</td>
<td>0.51</td>
<td>0.47</td>
<td>0.66</td>
</tr>
<tr>
<td>Urinary (g/W(^{0.75})/kg./day)</td>
<td>0.62</td>
<td>0.80</td>
<td>0.59</td>
<td>0.57</td>
<td>0.74</td>
</tr>
<tr>
<td>N retention (g/W(^{0.75})/kg./day)</td>
<td>0.45(^{a})</td>
<td>0.15(^{b})</td>
<td>0.47(^{a})</td>
<td>0.49(^{a})</td>
<td>0.11(^{b})</td>
</tr>
<tr>
<td>N retention as % of N intake</td>
<td>20.2(^{a})</td>
<td>11.6(^{b})</td>
<td>29.9(^{a})</td>
<td>32.0(^{a})</td>
<td>7.3(^{b})</td>
</tr>
<tr>
<td>N retention as % of absorbed N</td>
<td>42.1(^{a})</td>
<td>15.8(^{b})</td>
<td>44.3(^{a})</td>
<td>46.2(^{a})</td>
<td>12.9(^{b})</td>
</tr>
</tbody>
</table>

\(^{1}\)Represents the mean of 3 determinations using 3 male lambs per treatment.

Means on the same line bearing different superscript letters differ significantly: \(a, b (P \leq 0.05)\).
The highest fecal nitrogen loss was observed in the animals fed the poultry litter supplemented ration (5). This observation agrees with the results obtained by Fontenot et al. (1966) who reported highly significant increase in fecal nitrogen when litter supplied 100% of the nitrogen in the sheep ration. The high fecal nitrogen observed in animals fed ration 5 was a confirmation of the lower crude protein digestibility of this ration. Fecal nitrogen of the biuret and poultry droppings supplemented rations (3 and 4 respectively) were slightly higher than that for the control. El-Sabban et al. (1970) reported similar results. However the fecal nitrogen content of the urea supplemented ration was lower than that for the control.

Differences in the fecal nitrogen content of urea and biuret supplemented rations are most probably due to the fact that hydrolysis of urea in the rumen is rapid (Schwartz, 1967) while that of biuret is slow (Ioset, 1969). Schroder (1970) also showed that the breakdown of biuret in the lower gut of sheep was very small. This probably means that any biuret that passes into the lower gut from the rumen will be excreted in the feces. The rapid hydrolysis of urea into ammonia which in turn is absorbed into the blood stream probably accounts for
the lower fecal nitrogen loss in the urea supplemented ration as compared with the control ration.

Highest urinary nitrogen losses were observed in animals fed the urea and poultry litter supplemented rations. The high urinary nitrogen loss in animals fed the urea supplemented ration could be explained on the basis of rapid hydrolysis of dietary urea in the rumen. Since the utilization of ammonia by the rumen microorganisms for protein synthesis is slower than the release, part of the ammonia nitrogen is absorbed into the blood stream, which will cause a rapid elimination of urea by the kidney (Lewis 1957). It is difficult to explain what contributed to the high urinary nitrogen loss in the animals fed the poultry litter supplemented ration. However it could be theorized that since the litter supplemented ration had the lowest DE intake value, nitrogen excretion in the urine might be increased due to deamination of feed protein as an energy source.

Nitrogen balance was calculated as the difference between nitrogen intake and excretion. Expressing nitrogen retention as per cent of nitrogen intake and absorbed nitrogen show similar trend. Although all animals were in positive nitrogen balance, the high fecal and urinary nitrogen losses observed in animals fed the litter supplemented ration and the
high urinary nitrogen loss in animals fed the urea supplemented ration, resulted in significantly \( P < 0.05 \) lower nitrogen retention for these two rations when compared with the other rations. The higher nitrogen retention by animals fed the poultry droppings supplemented ration compared with the poultry litter ration indicates that poultry feces \textit{per se} is an excellent source of NPN for ruminants and that the availability of nitrogen from this source is hampered by the presence of wood-shavings as in the litter.

Numerous workers including Meiske \textit{et al.} (1955), Repp \textit{et al.} (1955), Gaither \textit{et al.} (1955), Ewan \textit{et al.} (1958), and Hatfield \textit{et al.} (1959) have shown by means of balance studies that biuret nitrogen is retained by lambs as well as urea nitrogen if an adequate adaptation period is allowed. The significantly \( P < 0.05 \) lower nitrogen retention observed in lambs fed the urea supplemented ration as compared with that for the biuret supplemented ration could be due to the variability in response of lambs fed urea-containing rations (Anderson, 1967).

\textbf{j. Body Weight Gain and Feed Efficiency}

The summary of data on body weight changes and feed efficiency of lambs fed the experimental rations is presented
in Table 12. The weights of male lambs used for the balance studies were not included in the calculations because the stress of confinement in the digestion cages was not conducive to normal weight gain. Although all rations produced positive average weight changes, urea and poultry litter supplemented rations (2 and 5 respectively) had significantly \( P < 0.05 \) lower weight gains compared with the other ration. The marked decreases in nitrogen retention by animals fed rations 2 and 5 as compared with the other rations, have most probably contributed to the observed significant depression in average weight gain.

Group mean values of efficiency of feed utilization indicated that the poultry litter supplemented ration had a lower feed efficiency value than the control. Both the urea and biuret supplemented rations tended to produce feed efficiency values that were intermediate between the control and that for ration 5. Poultry droppings supplemented ration had a value comparable to that for the control.
AVERAGE BODY WEIGHT GAINS AND FEED EFFICIENCY OF LAMBS FED THE EXPERIMENTAL RATIONS

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Soybean meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of animals</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>Av. initial weight (kg.)</td>
<td>30.7</td>
<td>30.6</td>
<td>30.6</td>
<td>30.7</td>
<td>30.6</td>
</tr>
<tr>
<td>Av. final weight (kg.)</td>
<td>34.9</td>
<td>33.8</td>
<td>34.7</td>
<td>36.2</td>
<td>33.6</td>
</tr>
<tr>
<td>Av. weight change (%)</td>
<td>13.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Av. daily feed consumption (g)</td>
<td>830</td>
<td>770</td>
<td>900</td>
<td>970</td>
<td>1010</td>
</tr>
<tr>
<td>Av. daily weight gain (g)</td>
<td>110</td>
<td>70</td>
<td>90</td>
<td>130</td>
<td>70</td>
</tr>
<tr>
<td>Feed efficiency</td>
<td>7.55</td>
<td>11.00</td>
<td>10.00</td>
<td>7.46</td>
<td>14.43</td>
</tr>
</tbody>
</table>

Supplemental nitrogen sources

<sup>1</sup> Only female animals used for the determination
<sup>2</sup> The animals were on the test rations for 42 days.

Means on the same line bearing different superscript letters differ significantly: a, b (P < 0.05).
Summary and Conclusions:

The results of this study have shown that fattening lambs can make live-weight gains when fed high-roughage rations in which up to 50% of the total nitrogen is replaced by urea, biuret or poultry wastes. However, the use of poultry wastes as supplemental nitrogen source must be considered not only with respect to its physical and chemical composition but also on the type of bedding material used in the litter. The results of the animal feeding trial just reported indicate that the ration containing wood-shaving poultry litter was inferior in all attributes to that containing cage droppings only.

The dry matter (DM) digestibility coefficients for the rations in which urea, biuret and cage droppings were used as the supplemental nitrogen sources (58.1, 59.9 and 61.2% respectively) did not differ significantly from that of the control ration (60.6%) in which soybean meal was used as the nitrogen source. Nevertheless, the wood-shaving poultry litter supplemented ration had a significantly lower DM digestibility coefficient (42.3%) as compared with the control ration. This significant decrease in DM and other nutrient digestibility coefficients was due to the increase in the crude fiber content as a result of the addition of poultry litter which contained wood-shavings as the bedding material. It can thus be concluded
that poultry litter should be used as a nitrogen supplement in high energy diets rather than in high-roughage rations.

Supplementation of the high roughage rations with biuret, poultry droppings and litter did not affect the voluntary consumption of the diets by sheep when compared with the soybean meal supplemented control ration. However, a significant decrease in voluntary feed consumption was observed in animals fed the urea supplemented ration. This might be due to uneven mixing of urea with the ration, because addition of urea at low levels to low-protein roughages has often led to greater voluntary feed consumption.

The nutritive value index (NVI) data indicated some differences, however, these differences were not significant. The high voluntary feed consumption observed in animals fed the litter supplemented ration compensated for the significant decrease in gross energy digestibility of this ration, thus making the NVI comparable to those of the other rations. The amount of digestible energy (DE) intake (kcal DE/W\textasciitilde{0.75} kg\textasciitilde{kg}) for all the rations, showed no significant differences.

Nitrogen digestibility coefficients for the urea, biuret and poultry droppings supplemented rations (73.5, 67.6 and 68.9% respectively) did not differ significantly from that
for the control (71.5%). However, the coefficient for the poultry litter supplemented ration (56.4%) was significantly lower than that for the control. Although all animals were in positive nitrogen balance, those fed the urea and poultry litter diets had significantly lower nitrogen retention than those animals on the control diet. The significant decreases in nitrogen retention most probably contributed to lower body weight gains of the animals fed the urea and litter containing diets when compared with the weight gains of animals on the other rations.

The efficiency of feed utilization by animals fed the poultry droppings supplemented ration (4) was comparable to that by animals fed the control ration. Feed efficiency by the animals fed the litter supplemented ration (5) was lowest, while those of animals fed the urea and biuret supplemented rations (rations 2 and 3 respectively) were intermediate.
B. TRIAL II. Supplementation of High roughage Rations with various Nitrogen sources. (Pelleted rations).

Digestibility and Nitrogen Balance Studies

1. Experimental Methods

A second trial was carried out using the same ration ingredients as were used in trial I. The rations were pelleted before being fed to the lambs.

Fifteen male lambs consisting of Dorset Horn, Black-face and White face breeds with body weights ranging between 28.6 and 48.5 kg were randomly divided on weight basis into five groups of three lambs. Each group was assigned to an experimental ration. The animals were fed their respective rations for approximately three weeks in the pens before being put in metabolism cages. This period of time was deemed sufficient for adaptation of the animals to NPN utilization, particularly biuret and poultry wastes.

Total fecal and urinary collections were made for a 10-day period which was preceded by a 4-day adjustment period to the cages. The animals were fed ad libitum in order to allow for voluntary intake determinations. Samples of feed, feces
and urine obtained during the 10-day collection period were composited for each lamb and separately prepared for chemical analysis. Chemical analyses of the feeds and feces for dry matter, crude protein, ether extract and ash were done using the A.O.A.C. (1960) methods. Acid-detergent fiber (ADF) and lignin were determined using Van Soest (1968) procedure. Cellulose was determined using Crampton and Maynard (1938) methods, modified by Donefer et al. (1960). Urinary nitrogen was determined by the macro Kjeldahl method. All other calculations were as reported in the feeding trial I.

2. Results and Discussion

The average chemical composition of the experimental rations is presented in Table 13. The crude protein content of the rations varied between 14.84 and 15.80%. These amounts are within the requirements recommended for sheep of similar age and weight (NRC, 1968). However, it must be mentioned that sheep do not efficiently digest the crude protein in poor-quality, mature and weathered roughages. The crude fiber content of the litter supplemented ration was highest while that of the cage dropping ration was least. This was probably due to the presence of wood-shavings in the litter which contributed to the crude fiber. The gross energy content of the
## Table 13

**Average Chemical Analysis of Rations Fed to Lambs**

<table>
<thead>
<tr>
<th>Prosimate composition</th>
<th>Soybean meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (%)</td>
<td>15.48</td>
<td>15.68</td>
<td>15.80</td>
<td>14.84</td>
<td>15.22</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>25.10</td>
<td>26.20</td>
<td>26.10</td>
<td>23.60</td>
<td>27.50</td>
</tr>
<tr>
<td>Ether extract (%)</td>
<td>0.69</td>
<td>0.61</td>
<td>0.63</td>
<td>2.27</td>
<td>2.01</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>6.93</td>
<td>7.25</td>
<td>7.18</td>
<td>12.00</td>
<td>7.78</td>
</tr>
<tr>
<td>Nitrogen-free extract (%)</td>
<td>51.80</td>
<td>50.26</td>
<td>50.29</td>
<td>47.29</td>
<td>47.49</td>
</tr>
<tr>
<td>Gross energy (kcal/g)</td>
<td>4.22</td>
<td>4.20</td>
<td>4.21</td>
<td>3.98</td>
<td>4.07</td>
</tr>
<tr>
<td>Acid-detergent fiber (%)</td>
<td>27.10</td>
<td>29.63</td>
<td>28.86</td>
<td>27.52</td>
<td>30.01</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>4.29</td>
<td>3.56</td>
<td>3.72</td>
<td>3.59</td>
<td>4.04</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>22.81</td>
<td>26.07</td>
<td>25.14</td>
<td>23.93</td>
<td>25.97</td>
</tr>
</tbody>
</table>

1 All values are expressed on dry matter basis.
cage dropping ration was slightly lower than those of the other rations, and this is explained by the higher ash content of this ration (12.00%) as compared with that (6.93%) for the control ration.

Data on average feed intakes and apparent nutrient digestibilities are presented in Table 14. The coefficients of nutrient digestibility for dry matter (DM) showed small differences among rations, but these differences were not significant. The poultry litter supplemented ration had the lowest DM digestibility coefficient (61.9%) as compared with that for the control ration (66.5%). The coefficients for gross energy digestibility were similar to those of DM digestibility, indicating that a major portion of the dry matter (excluding ash) is primarily a source of energy. Crude protein digestibility coefficients also did not show significant differences among rations. However, the highest value was observed in animals fed the urea-supplemented rations. This could be explained by the fact that, urea is rapidly and completely hydrolyzed in the rumen resulting in very small fecal nitrogen and thus high digestibility. The mean crude fiber and cellulose digestibility coefficients did not show significant differences. It could however, be observed that the coefficients of crude fiber and cellulose digestibility are highest in the poultry dropping ration and lowest in the litter supplemented ration.
### TABLE 14

AVERAGE FEED INTAKE AND APPARENT DIGESTIBILITY BY SHEEP OF EXPERIMENTAL RATIONS

<table>
<thead>
<tr>
<th>Supplemental nitrogen source</th>
<th>Soybean meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criteria</strong></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>Digestibility coefficients (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>66.5</td>
<td>65.2</td>
<td>63.8</td>
<td>64.1</td>
<td>61.9</td>
</tr>
<tr>
<td>Crude protein</td>
<td>71.4</td>
<td>72.3</td>
<td>71.9</td>
<td>68.7</td>
<td>70.7</td>
</tr>
<tr>
<td>Cellulose</td>
<td>47.2</td>
<td>50.2</td>
<td>45.5</td>
<td>53.6</td>
<td>47.3</td>
</tr>
<tr>
<td>Gross energy</td>
<td>67.2</td>
<td>65.7</td>
<td>64.3</td>
<td>64.8</td>
<td>62.9</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>44.1</td>
<td>44.8</td>
<td>40.2</td>
<td>46.4</td>
<td>39.3</td>
</tr>
<tr>
<td>Relative Intake (%)</td>
<td>120.1</td>
<td>111.0</td>
<td>105.0</td>
<td>135.2</td>
<td>127.5</td>
</tr>
<tr>
<td>Nutritive Value Index (NVI)</td>
<td>80.7</td>
<td>72.8</td>
<td>67.1</td>
<td>87.6</td>
<td>79.8</td>
</tr>
<tr>
<td>Digestible Energy (DE) intake</td>
<td>272.4</td>
<td>244.7</td>
<td>226.1</td>
<td>278.8</td>
<td>259.7</td>
</tr>
</tbody>
</table>
TABLE 15

AVERAGE NITROGEN BALANCE OF LAMBS FED THE EXPERIMENTAL RATIONS

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Supplemental nitrogen source</th>
<th>Soybean Meal</th>
<th>Urea</th>
<th>Biuret</th>
<th>Poultry droppings</th>
<th>Poultry litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of animals</td>
<td></td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>N intake</td>
<td></td>
<td>2.38</td>
<td>2.23</td>
<td>2.12</td>
<td>2.57</td>
<td>2.48</td>
</tr>
<tr>
<td>N excretion:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fecal</td>
<td></td>
<td>0.61</td>
<td>0.47</td>
<td>0.57</td>
<td>0.60</td>
<td>0.93</td>
</tr>
<tr>
<td>Urinary</td>
<td></td>
<td>1.03</td>
<td>1.44</td>
<td>0.92</td>
<td>1.12</td>
<td>1.21</td>
</tr>
<tr>
<td>N retention</td>
<td></td>
<td>0.74&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.34&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>N retained as % of N intake</td>
<td></td>
<td>31.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.7&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>N retained as % of N absorbed</td>
<td></td>
<td>41.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>43.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a, b</sup> Means on the same line bearing different superscript letters differ significantly: 
(P ≤ 0.05)
In order to be able to demonstrate the overall nutritive value of the rations, the mean voluntary consumption of the test rations was expressed relative to voluntary consumption by sheep of good quality hay (Crampton et al., 1960). The relative intake (RI) values indicated that the poultry litter and dropping supplemented rations were as well consumed as the soybean meal supplemented control ration. The urea and biuret containing rations had lower RI values than the control ration but the differences were not significant. Similarly, the nutritive value index (NVI) values calculated from the gross energy digestibility and RI data did not show significant differences. However, the urea and biuret rations had lower NVI values than the control ration. The digestible energy (DE) intake values calculated from the NVI data also failed to show any significant differences.

3. **Nitrogen Balance**

The average balance data of the animals are presented in Table 15. There was no significant difference in the total daily nitrogen intake for all rations. The minor difference observed in the nitrogen intake between groups was due to differences in feed intake. Fecal nitrogen losses were greatest in animals fed the poultry litter supplemented ration
while highest urinary nitrogen losses were observed in animals fed the urea supplemented ration. These higher nitrogen losses (fecal or urinary) resulted in a significantly ($P < 0.05$) lower nitrogen retention for animals fed the urea or poultry litter supplemented rations as compared with the control ration. The animals fed the biuret and poultry dropping supplemented rations had nitrogen retention values which were not significantly different from that for the soybean meal supplemented ration (control diet). These observations are similar to those reported for the ground un pelleted rations used in trial I.
Summary and Conclusions

The results of this trial have indicated that sheep can perform well on high roughage rations supplemented with urea, biuret, poultry droppings or litter. In the present trial, the increases in the apparent nutrient digestibility coefficients of the rations as a result of pelleting is of particular interest especially with the poultry litter supplemented diet (ration 5). This observation has confirmed the widely held view that the best effects on animal performance of pelleted as compared to unpelleted feeds are observed with roughages of relatively high fiber content (Davidson and Hoodham, 1966). In feeding trial I, nutrient digestibility of the poultry litter supplemented ration was significantly inferior to those of the other rations, but in trial II, nutrient digestibility among rations failed to show any significant differences. This observation appears to be justified by the suggestion of Cate et al., (1955) that, as the quality of the ration decreased the differences in efficiency of feed utilization between animals given the pelleted and those given the unpelleted diets progressively increased. The higher nutrient digestibilities of the litter supplemented ration used in the second trial as compared to those of trial I could be due in part of the slight differences in the chemical composition of these rations. The litter supplemented ration of trial II contained higher nitrogen and NFE content and less lignin and ash than the same ration in trial I.
The effect of pelleting was particularly noticeable on the voluntary consumption of the high-roughage ration (Table 13). Relative intakes (RI) of the same rations in the ground form varied between 66.1 and 87.0% while the RIs of the pelleted rations varied between 105.0 and 135.2%. Similarly, the amount of DE intake available to the lambs from the pelleted rations was about twice that from the same ration in the ground form. Often, opinion is divided on the whole question of pelleting, especially of good-quality feeds, and whatever benefit the process has for the animals, its costs always have to be set against any savings made by increased efficiency of utilization of the feed.
C. **TRIAL III.** Supplementation of Different Low-quality Forages with Poultry Droppings (Pelleted rations).

1. **Introduction**

The results obtained in Trial 1 have shown that poultry droppings can be used as the main supplementary sources of nitrogen when sheep are fed low-protein poor-quality roughage rations. In the present trial therefore, it is intended to investigate the feeding value of poultry droppings when it constitutes the main supplementary source of nitrogen in the diets of sheep high in low-quality roughage.

2. **Preparation of ration components**

Oat straw harvested in 1970 was prepared as was reported in the feeding trial 1. Extruded wood was used as the other low-quality roughage. Grass hay which was ground in a similar manner as the straw was used as the control forage.

Poultry droppings were collected from a caged layers' house at the University poultry farm. The droppings had accumulated for at least 6 weeks before the collection. Wasted feed, shed feathers, broken eggs and a large population of
housefly larvae and pupae were found mixed with the droppings. No attempts were made to remove these extraneous materials. The droppings were spread very thinly on plastic sheet indoors and infra-red light bulbs used to hasten the drying process. Air-drying of the poultry droppings was completed in about 2 weeks. The dried poultry droppings were not sterilized as the diseases of poultry, apart from salmonellosis, are not thought to be of major importance in the feeding of ruminants (Alexander et al., 1968). Brugman et al. (1967) have reported that sterilization of poultry litter reduced its digestibility and overall nutritive value. The air-dried poultry droppings were therefore incorporated into the experimental rations without further processing.

a. Mixing and pelleting of experimental rations

The composition of the experimental rations is shown in Table 16 and the average chemical analysis in Table 17. Good-quality grass hay was used as the control forage in ration 1 at a level of 40 percent of the total ration (DM basis). Ground oat straw was used as the low-quality roughage in ration 2 at a level of 40 percent of the total ration (DM basis); while extruded wood was used as the low-quality roughage in ration 3 at a level of 35% of the total ration (DM basis).
TABLE 16

COMPOSITION OF RATIONS FED TO THE LAMBS IN THE FEEDING TRIAL

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Rations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Grass hay</td>
<td>40.0</td>
</tr>
<tr>
<td>Oat straw</td>
<td>--</td>
</tr>
<tr>
<td>Extruded wood</td>
<td>--</td>
</tr>
<tr>
<td>Ground barley</td>
<td>54.0</td>
</tr>
<tr>
<td>Poultry droppings</td>
<td>6.0</td>
</tr>
<tr>
<td>Corn oil</td>
<td>--</td>
</tr>
</tbody>
</table>
Ground barley was used as the readily available energy source in all rations and was used at a level of 54, 45 and 40 percent of the total ration (DM basis) in rations 1, 2 and 3 respectively. Air-dried poultry droppings were incorporated into the rations in order to bring the crude protein content of the rations to a level that is adequate for fattening lambs. Corn oil was added to the ration containing extruded wood (ration 3) at 5 percent level in order to enhance pelleting and to increase the digestible energy.

Mixing of the rations was done in a David Bradley vertical mixer. Adequate time for mixing was allowed in order to break up the lumps in the dried poultry droppings to ensure uniform distribution in the ration. Immediately following mixing, the rations were pelleted using the 1 cm die. During pelleting, a lot of heat was generated by the pelleting machine and this heat was assumed sufficient to destroy and pathogenic organisms that might still be present in the air-dried poultry droppings. The hot pellets were spread on concrete floors to cool before being put in plastic buckets. Samples of the pelleted rations were taken and tested microbiologically for pathogenic bacteria following the procedure described earlier. No pathogenic bacteria were isolated.
3. **Metabolism studies**

Twelve male lambs, consisting of a mixture of Black-face and Dorset Horn breeds, approximately 6 months of age and with initial body weight ranging from 23.1 to 31.3 kg., were divided into 3 groups of 4 lambs on weight basis and were randomly allotted to the experimental rations. The lambs were group-fed in the pens for approximately two weeks before the metabolism studies started. While in the pens, the lambs were fed approximately 1 kg. feed per head daily.

Two metabolism trials were carried out using 2 lambs from each group at each trial. The lambs were confined into digestion cages designed to enable total collection of feces and urine. The lambs having been fed the experimented rations in the pens for about 2 weeks were allowed another 10 days for adjustment to the cages and for stabilizing intake at about 1 kg. feed per head daily. The 10-day adjustment period was followed by 8-day collection period. While in the digestion cages, the lambs were individually fed their respective experimental rations. Exactly 1 kg. of feed was offered to each animal per day, which was fed in two batches of 500g in the morning and afternoon. Unconsumed feed was weighed back the following morning and deducted from the offered feed in order to determine actual consumption.
Total fecal collection was made during the last 8 days of each trial. Collection of feces was done each morning before the morning feeding. The total fecal output was weighed, mixed thoroughly and sampled. Similarly total urinary collection was made. The volume of daily output of urine was recorded and aliquot samples taken for analysis. All lambs were weighed prior to being put in the digestion cages and also immediately after the conclusion of the trial. This was necessary in order to be able to calculate the Relative Intake of the rations.

4. Chemical Analyses of feeds, feces and urine samples

Samples were prepared for chemical analysis and chemically analyzed as reported earlier.

5. Calculations

Apparent digestibility coefficients for dry matter, gross energy, crude fiber, cellulose, and crude protein were calculated as reported earlier. All other calculations were the same as those reported in trial I.
RESULTS AND DISCUSSION

The chemical composition data of the experimental rations are presented in Table 17. The crude protein contents were about equal in the three rations. However the percent of the total ration nitrogen supplied by poultry dropping nitrogen were 18.7, 50.2 and 64.2 percent for rations 1, 2 and 3 respectively. The remaining ration nitrogen was contributed by grass hay and barley in ration 1, straw and barley in ration 2 and barley in rations 3.

The crude fiber content of the hay ration was considerably lower than those for the straw and wood rations. Although grass hay and oat straw were each used at 40 percent of the total ration in rations 1 and 2 respectively, the crude fiber in the hay ration was lower than that for the straw ration. This is because the straw is a by-product of cereal which is characterized by high fiber content. Extruded wood is similarly high in crude fiber and despite its being used at a level of 35 percent of ration 3, the crude fiber content of the wood ration was slightly higher than that for the straw ration. The ADF and cellulose contents of all rations followed a similar pattern as that for the crude fiber content. The lignin content for the rations were 3.55, 6.64 and 9.06 percent for the hay, straw and wood.
TABLE 17

AVERAGE CHEMICAL ANALYSIS OF RATIONS FED TO LAMBS IN FEEDING TRIAL III

<table>
<thead>
<tr>
<th>Composition</th>
<th>Rations</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>11.74</td>
<td>10.95</td>
<td>11.53</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>18.50</td>
<td>24.80</td>
<td>25.50</td>
</tr>
<tr>
<td>Ether extract (%)</td>
<td>2.20</td>
<td>1.70</td>
<td>5.80</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>6.05</td>
<td>6.51</td>
<td>8.01</td>
</tr>
<tr>
<td>Nitrogen-free extract (%)</td>
<td>61.51</td>
<td>56.04</td>
<td>49.16</td>
</tr>
<tr>
<td>Gross Energy (kcal/g)</td>
<td>4.22</td>
<td>4.13</td>
<td>4.05</td>
</tr>
<tr>
<td>Acid-detergent fiber (%)</td>
<td>19.9</td>
<td>28.3</td>
<td>29.2</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>3.55</td>
<td>6.64</td>
<td>9.06</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>16.35</td>
<td>21.66</td>
<td>20.14</td>
</tr>
</tbody>
</table>

\(^1\) All values are expressed on dry matter basis.
rations respectively. This is indicative of the effect of lignification as maturity of plants progressed.

The ether extractives (EE) of the wood ration (5.8%) was higher than those for the other rations. This was because corn oil was used in the wood ration at a level of 5% of the total ration in order to enhance pelleting. The EE content for the hay ration was slightly higher than that for the straw ration. The reason for this value might be due to the extraction of a greater amount of non-lipid materials from the hay.

The extruded wood ration had a higher ash content than the other rations. The lower ash content in the hay ration could be due to the fact that poultry droppings were used at a lower percent of the total ration as compared to the straw and wood rations. The gross energy content (kcal/g) of the hay ration was higher than for the other rations most likely as a result of the lower ash content of the hay ration. The corn oil used in the wood ration might have increased the gross energy content of this ration slightly. Nonetheless, the gross energy content of the wood ration was still slightly lower than that for the straw ration.
6. **Apparent Digestibility Coefficients:**

a. **Dry Matter**

Data on average feed intakes and apparent nutrient digestibilities are presented in Table 18. A highly significant (P < 0.01) decrease in dry matter digestibility was observed in animals fed the extruded wood ration as compared with the hay or straw ration. The reason for this significant decrease in dry matter digestibility of the wood ration might be due to lower fiber digestibility of the wood (Leibholz, 1969; Fontenot *et al.* 1966). The dry matter digestibility of the straw ration was significantly (P < 0.05) lower than that for the hay ration. This would be expected since straw, a low-quality forage, is not degraded to the same extent as good quality forage such as hay.

b. **Gross Energy**

The average gross energy digestibility coefficients are presented in Table 18. As would be expected, the pattern of the results obtained for the gross energy digestibility coefficients was quite similar to those for the dry matter digestibility. However the coefficients of gross energy
### TABLE 18

AVERAGE FEED INTAKE AND APPARENT DIGESTIBILITY BY LAMBS OF POULTRY DROPPINGS SUPPLEMENTED RATIONS

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Digestibility coefficients (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Dry Matter</td>
<td>64.6&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>Crude Protein</td>
<td>62.2</td>
</tr>
<tr>
<td>Cellulose</td>
<td>38.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Gross Energy</td>
<td>66.0&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>Crude Fiber</td>
<td>42.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ether Extract</td>
<td>82.0</td>
</tr>
<tr>
<td>Relative Intake (%)</td>
<td>93.7</td>
</tr>
<tr>
<td>Nutritive Value Index (NVI)</td>
<td>61.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Digestible Energy Intake Potential</td>
<td>209.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Means on the same line having different superscript letters differ significantly:  
a, b (P < 0.05)  
c, d (P < 0.01)
digestibility were slightly higher than those for the dry matter digestibility particularly in the hay and straw rations. A highly significant ($P \leq 0.01$) lower gross energy digestibility was obtained in the wood ration as compared with the hay or straw ration. This lower gross energy digestibility was most probably as a result of low digestibility of wood. Also, the gross energy digestibility of the straw ration was significantly ($P < 0.05$) lower than that for the hay ration. The lower gross energy digestibility of the straw ration could be attributed to reduced digestibility of straw as a result of advanced maturity and lignification.

c. **Crude Fiber**

The average crude fiber and cellulose digestibility coefficients are presented in Table 18. A highly significant ($P < 0.01$) lower crude fiber and cellulose digestibility was obtained in the extruded wood ration. This observation confirmed the results obtained by Fontenot et al. (1966) when they reported that crude fiber digestibility of wood-shaving poultry litter ration was depressed when the level of litter increased from 25 to 50 percent. Leibholz (1969) noted a similar reduction in crude fiber digestibility when sawdust was included in the ration for sheep at a level
above 15 percent of the total ration. Although no significant difference ($P < 0.05$) was observed in the crude fiber digestibility coefficient between the hay and straw rations, the coefficients for the hay ration were higher than those for the straw ration; indicating that the crude fiber of straw was degraded to a lesser extent as a result of advanced maturity of the straw as compared with the hay (Reid et al., 1959; Dehority and Johnson, 1960: Wilson et al., 1966).

The coefficients for the cellulose digestibility were similar to those of crude fiber. Since a high proportion of the crude fiber is cellulose, differences in cellulose digestibility between rations could be explained in similar fashion as those between crude fiber digestibility.

d. **Crude Protein**

The mean crude protein digestibility coefficients are presented in Table 18. Although no significant differences ($P < 0.05$) were observed in the average crude protein digestibility between rations, the crude protein digestibility coefficient for the straw ration was slightly lower than that for the hay or wood ration. This slight decrease might be due to the fact that crude protein in the straw is relatively unavailable for microbial degradation (Crampton and Maynard, 1938; Dehority and Johnson, 1960). The lack of a significant ($P < 0.05$) difference in the crude protein digestibility between rations could be attributed to the
large variation observed between animals in the same group. Despite the fact that poultry droppings were used at very wide levels (6, 15 and 20 percent of the total ration) the overall crude protein digestibility did not reveal any significant differences between rations.

e. **Relative Intake (RI)**

The feed consumption of the lambs were expressed relative to the voluntary consumption of good quality hay assuming that sheep will voluntarily consume about 80g good quality hay per unit of metabolic size (Crampton et al., 1960). In this trial however, the lambs were not fed *ad libitum*; each animal was offered 1000g feed daily. Actual voluntary consumption was therefore difficult to determine since some of the animals ate all the feed, indicating that these animals had not reached their maximum voluntary consumption. It was nevertheless necessary to calculate the Relative Intake (RI) in order to be able to compare the relative feeding value of the test rations with conventional good quality feedstuffs. The calculated RI's for all rations (Table 18) failed to show any significant \( P \leq 0.05 \) difference. However, the mean RI value for the hay ration tended to be slightly higher than for the other rations. The lack of significant
difference could be attributed to the fact that a few of the animals, particularly those on hay ration, did not reach their maximum voluntary consumption.

f. Nutritive Value Index (NVI)

The summary of the nutritive value indices for all given (or shown) rations is in Table 18. The hay had a significantly (P < 0.05) higher NVI value than the other rations. Although no significant differences were observed between the NVI values for the straw and wood rations, the value for the straw ration was slightly higher than that for the wood ration.

It is interesting to note that the NVI values for the straw and wood rations (47.6 and 40.8 respectively) were quite comparable to the NVI values obtained in trial I for the poultry droppings and litter supplemented rations (49.7 and 38.1 respectively). The greater proportion of the differences in the observed NVI values in this trial could be accounted for by the differences in gross energy digestibility, as there appeared to be very little difference in the relative intake values.
g. **Digestible Energy (DE) Intake Potential**

The DE intake was calculated from the NVI values and the gross energy content of the rations according to the method of Crampton *et al.* (1962). A summary of the DE intake values is presented in Table 18. The hay ration had a significantly (*P < 0.05*) higher DE intake value than the other rations. The trend in magnitude of the DE intake values among rations was very similar to that for the NVI values. This is so because the DE intake values were calculated using the NVI values. No significant differences were observed between the DE intake values for the straw and wood rations, however, the values for the straw ration appeared to be slightly higher than that for the wood ration.

h. **Nitrogen Balance Determinations**

Total daily nitrogen intake was calculated from the feed intake and the percentage nitrogen in the ration. In an attempt to eliminate differences due to liveweight, the nitrogen intake, excretion and retention were expressed on the metabolic size of each animal. Nitrogen intake by the lambs fed the hay ration was higher than those fed either the straw or wood ration. Nitrogen intake by the lambs fed the
TABLE 19

AVERAGE NITROGEN BALANCE OF LAMBS FED POULTRY DROPPINGS SUPPLEMENTED RATIONS -- TRIAL III

<table>
<thead>
<tr>
<th>Criteria</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of animals</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>N Intake (G/W$_{kg.}^{0.75}$/day)</td>
<td>1.42</td>
<td>1.17</td>
<td>1.31</td>
</tr>
<tr>
<td>N excretion:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fecal (g/W$_{kg.}^{0.75}$/day)</td>
<td>0.54</td>
<td>0.51</td>
<td>0.49</td>
</tr>
<tr>
<td>Urinary (g/W$_{kg.}^{0.75}$/day)</td>
<td>0.47</td>
<td>0.54</td>
<td>0.41</td>
</tr>
<tr>
<td>N Retention (g/W$_{kg.}^{0.75}$/day)</td>
<td>0.41$^c$</td>
<td>0.12$^d$</td>
<td>0.41$^c$</td>
</tr>
<tr>
<td>N Retention as % of N Intake</td>
<td>28.7$^c$</td>
<td>9.2$^d$</td>
<td>31.1$^c$</td>
</tr>
<tr>
<td>N Retention as % of digested N</td>
<td>46.3$^c$</td>
<td>15.1$^d$</td>
<td>49.6$^c$</td>
</tr>
</tbody>
</table>

Means on the same line having different superscript letters differ significantly: $c$, $d$ (P $\leq$ 0.01).
straw ration was lowest. This might have been due to low nitrogen content of the straw ration as compared with the other rations and also to the slight reduction in feed consumption.

Nitrogen excretion in the feces and urine were determined as previously reported. Fecal nitrogen loss in all lambs appeared to be quite comparable, however, lambs on the hay ration had slightly higher fecal nitrogen loss than those on straw or wood ration. The mean urinary nitrogen loss in lambs fed the straw ration was higher than those for the hay and wood rations. It is important to report that one lamb in the group fed the straw ration was in negative nitrogen balance. As a result of this, the group mean was greatly reduced and this might have accounted for the highly significant \((P < 0.01)\) difference in nitrogen retention (Table 18). The negative nitrogen balance observed in the lamb on the straw ration could be attributed to either the effect of reduced feed consumption which might have resulted in decreased nitrogen intake, high urinary nitrogen loss probably as a result of tissue mobilization for energy purposes or the presence of worms in the feces which might have elevated the fecal nitrogen content. By eliminating the data on this particular sheep, mean nitrogen retention for all groups became quite comparable. Expressing nitrogen retention as percent of nitrogen intake and digested showed a similar trend.
Weight gain and feed efficiency for the lambs were not calculated because liveweight gains or losses cannot be considered an important criterion in evaluating the nutritive value of the experimental rations in this trial because; the stress of confinement in the digestion cages is not conducive to normal weight gain. Also, each experimental diet was offered to the lambs for a short period of time to permit reliable weight changes values. Furthermore, the experimental diets were possibly still deficient in other nutrients - vitamins and minerals - which are essential for proper physiological functions. But because of the short-term nature of the experiment, supplementation was limited to energy and protein.
Summary and Conclusions

The results of this feeding trial had clearly shown that poultry droppings could be used as the main supplementary nitrogen source for sheep fed low-quality roughage rations. The reports of Parham et al. (1955), Brown et al. (1956), and Davis et al. (1956) indicate that urea can satisfactorily replace natural protein in ruminant feeds without affecting the growth gains or milk yields, provided the protein replacement with urea does not exceed one-third of the total protein in the ration. In the feeding trial just reported, despite the fact that complete supplementation of the roughage rations was not effected with regards to vitamins and minerals, the inclusion of air-dried poultry droppings to supply approximately 50.2 and 64.2 percent of the total crude protein in the straw and wood rations respectively has resulted in voluntary consumption and digestible energy intake that would be expected for high quality forages such as grass hay.
SECTION III

IN VITRO CELLULOSE DIGESTION OF CHEMICALLY TREATED LOW-QUALITY ROUGHAGES. THE EFFECT OF SUPPLEMENTAL NITROGEN SOURCE ON THE IN VITRO CELLULOSE DIGESTION OF RATIONS FED TO LAMBS IN SECTION II.
1. Introduction

Within the past decade, nutritive evaluation of forages has come into new prominence as evidenced by the number of studies dealing with the development of valid *in vivo* and *in vitro* techniques to be used in forage evaluation programs. Several workers including Barnett (1957), Quicke *et al.* (1958) and Hershberger *et al.* (1959) have demonstrated a high correlation between *in vivo* and *in vitro* digestibility of forage cellulose. *In vitro* dry matter and cellulose digestion have also been shown to be highly correlated with *in vivo* criteria of available energy, such as the digestibility of dry matter and gross energy (Donefer *et al.*, 1960). The Nutritive Value Index (NVI) proposed by Crampton *et al.* (1960), provides a complete description of the feeding value of a forage, because it measures both the voluntary intake and energy digestibility of the forage. Studies with a number of forages have indicated that the NVI could be predicted by means of an *in vitro* rumen fermentation method (Donefer *et al.*, 1960; 1962). A complication in assessing the validity of the various *in vitro* techniques is the difference of opinion as to what *in vivo* criteria are most meaningful in the evaluation
of forages. The reason being that any in vitro procedure, no matter how precise, can only be as accurate as the in vivo measure of nutritive value it attempts to predict. Nevertheless, the high correlation that exists between in vivo and in vitro techniques has raised the question as to whether the costly and time-consuming in vivo trials could be replaced by the in vitro techniques in estimating the nutritive value of forages.

The chief advantages of the artificial rumen appear to be the speed with which determinations can be carried out in the laboratory, the precision and control which can be exercised over various conditions in the laboratory as opposed to the intact animal, and the great reduction in the expense of experimentation, not only of caring for animals but also in the amount of different feed ingredients needed. However, the above advantages should not be over-emphasized since the artificial rumen is only an approximation of the natural condition in the intact animal. There is always doubt whether the in vitro set-up is truly representative of the natural conditions in the live animals. The types of microorganisms which develop in the artificial rumen might be different from the flora maintained in a rumen proper. The above limitations are doubtlessly incomplete and any interpretation placed upon results obtained by in vitro methods must be tempered
with reservations embodying such limitations. Nevertheless, there is considerable evidence indicating that these limitations are of minor importance and that the approximations made to rumen conditions in the laboratory flask are, for the most part, satisfactory. Perhaps the strongest evidence to date supporting this contention is the ability to maintain over long periods of time high degrees of cellulose digestion in artificial rumens which compare favourably with the degree of cellulose digestion which occurs in live ruminants. It would seem that the artificial rumen can best be used as a screening device in studying influential factors of feeds in rumen physiology, from which the most promising results must be ultimately tested in animal experimentation.

2. Experimental methods.

The procedure adopted for all the fermentation runs was that reported by Donefer et al. (1960) with very sight modifications, and is outlined below.
a. In vitro systems and substrates

The in vitro systems consisted of 36 fermentation tubes (90 ml. Pyrex No. 8260), each fitted with a 1-hole rubber stopper (No. 6) through which was inserted a glass delivery tube attached by means of rubber tubing to a gas manifold with 36 outlets. Flow of gas into the fermentation tubes was controlled by means of clip valves, at approximately 160 bubbles per minute (unused outlets were completely closed). The gas manifold was connected to a large (50 lb. capacity) tank of CO₂ fitted with a pressure regulator. The delivery tube was adjusted so that its tip was approximately 40 mm. from the bottom of the fermentation tube, and this together with the relatively slow gasing rate enabled the substrates to settle to the bottom of the tube during fermentation. Gas was exhausted by way of clearance between the pouring lip of the tube and the rubber stopper. Fermentation was maintained at a temperature of approximately 40°C±0.5°C in a water-bath.

Total liquid volume in each tube was 50 ml. with 200 to 700 mg. of substrates and standards supplying approximately 200 mg. cellulose.

Substrate samples from the rations used for animal feeding in trials I and III were included in the fermentation
run. Samples of the chemically treated oat straw and poplar wood were also included. Chemical treatment of the oat straw and poplar wood and preparation for in vitro fermentation run was as follows: oat straw and poplar wood ground to pass the 20 mm. screen mesh were separately treated with NaOH and NH₄OH solutions. Exactly 60 ml. of 13.3% solutions of NaOH were used to treat 100 g of either straw or wood; while 24 ml. of 12.5% NH₄OH solution were used to treat separate batches of 100 g of straw and wood. The decision to use the above concentrations and dilutions was based on the results obtained by Donefer et al. (1969) and Zafren (1960). The ground oat straw or poplar wood was treated in 100 g batches in 500 ml. Erlenmeyer flasks. After thorough mixing with the appropriate alkali, the flasks were covered with aluminium foil and the chemical reaction allowed to continue for 24 hrs. After this, acetic acid (50% v/v) was added to the treated samples to adjust the pH to neutrality. The treated material was then allowed to dry in open dishes before being weighed into the fermentation tubes for in vitro cellulose digestion.

The effect of nitrogen source on cellulose digestion in vitro was investigated on the untreated and alkali treated straw and wood. Nitrogen sources used were urea, biuret and uric acid. The reason for using uric acid was that this compound constitutes between 30 and 40% of the total nitrogen
in poultry excreta (Fontenot et al., 1966; Leibholz, 1969) and rumen microorganisms had been shown to utilize it for their body protein (Belasco, 1954; Jurtshuk et al., 1955). The level of nitrogen supplementation in the fermentation substrates were 2.0, 2.3 and 2.5 percent for urea, biuret and uric acid respectively, in order to supply equivalent amounts of nitrogen in the fermentation medium.

Standard substrates were included in each run in order to test the repeatability of results between runs. These standards consisted of alfalfa, Solka floc\(^1\) and Avicel\(^1\). All substrates to be tested were prepared for \textit{in vitro} fermentation by grinding in the hammermill fitted with the 20 mm. screen mesh. Samples containing between 26 and 34% cellulose were used at a substrate level of 700 mg. per tube thus supplying a cellulose level of approximately 200 mg. Samples containing less than 26% or more than 34% cellulose were used at a level of 800 mg. or or 600 mg. respectively to maintain the same approximate level of cellulose (200 mg.) in all tubes. In relation to substrate level, Quicke et al. (1959a) had demonstrated that varying forage levels from 0.6 to 1.3 gm. per tube had no effect on percent cellulose digestibility.

\(^1\)purified cellulose source.
b. Preparation of inoculum (Phosphate Buffer Extract)

Rumen ingesta was collected from a Hereford steer fitted with a permanent rumen fistula. The steer was maintained on an all alfalfa hay diet, supplemented with trace mineralized salt. Feed was not available to the animal for about 12 hours prior to sampling. A polyethylene bucket lined with 2 layers of cheesecloth was used to collect a sample of approximately 6 liters of rumen ingesta. The ingesta was pressed and the liquid discarded. Approximately 4 lb. of the resultant solid material was mixed with 1500 ml. of phosphate buffer solution (pH 7) according to the method described by Johnson et al. (1958). Prior to making the extract, the phosphate buffer solution (1.059 g Na$_2$HPO$_4$ + 0.436 g KH$_2$PO$_4$ per liter) was preheated to 45°C (to compensate for drop of temperature to approximately 40°C during extracting procedures) and 25 ml. saturated Na$_2$CO$_3$ solution added to it and CO$_2$ bubbled through the mixture until the pH was 7. After moderate agitation of the ingesta with the phosphate buffer solution, the mixture was pressed again and the resultant liquid which constituted the inoculum and designated as phosphate buffer extract (PBE) was filtered through 4 layers of cheesecloth into preheated thermos containers for transportation to the laboratory.
c. Preparation and dispensation of basal medium

All the basal medium (Table 20) except iron and calcium were premixed in a 2-liter Erlenmeyer flask in quantities sufficient for the inoculation of 40 fermentation tubes. The mixture was heated to 40°C, saturated with CO₂ and the pH adjusted to 7. Following this, 800 ml. of the inoculum (PBE) and 20 ml. of Ferric chloride and Calcium chloride mixture were added to the flask containing the basal medium and the total mixture adjusted with distilled water to 2 liters. The mixture was then poured into the New Zippett¹ flask, placed on a magnetic stirrer and 50 ml. of the mixture were manually dispensed into each of the fermentation tubes into which the substrates had been preweighed.

Urea and glucose were omitted from the basal medium used for the preparation of the inoculum used for substrates containing samples of the rations fed to lambs in trials I and III. The reason for this was that the rations contained adequate crude protein and an easily available source of energy in the form of molasses. Urea was similarly omitted from the inoculum used for some of the alkali treated oat straw and poplar wood in which the effect of nitrogen source on cellulose digestion in vitro was being studied.

¹ Manufactured by Jencons (Scientific) Ltd., Mark Road, Hemel Hempstead, Hertfordshire, England.
<table>
<thead>
<tr>
<th>Solution</th>
<th>Volume used per tube (ml.)</th>
<th>Amount used per tube (mg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral mixture&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.0</td>
<td>(see a)</td>
</tr>
<tr>
<td>Iron and Calcium chloride&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.5</td>
<td>4.845</td>
</tr>
<tr>
<td>Glucose (100 mg./ml.)*</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>Urea (126 mg./ml.)*</td>
<td>0.5</td>
<td>63</td>
</tr>
<tr>
<td>Biotin (10 mg./ml.)</td>
<td>1.0</td>
<td>10</td>
</tr>
<tr>
<td>PABA (100 mg./ml.)</td>
<td>0.25</td>
<td>25</td>
</tr>
<tr>
<td>n-Valeric acid (5 mg./ml.)*</td>
<td>3.0</td>
<td>15</td>
</tr>
<tr>
<td>Casein hydrolysate-enzymatic&lt;sup&gt;c&lt;/sup&gt; (20 mg./ml.)*</td>
<td>2.5</td>
<td>50</td>
</tr>
<tr>
<td>Sodium carbonate (200 mg./ml.)</td>
<td>1.5</td>
<td>300</td>
</tr>
<tr>
<td>Phosphate buffer&lt;sup&gt;d&lt;/sup&gt; extract (inoculum)</td>
<td>20.0</td>
<td>(see d)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Na<sub>2</sub>HPO<sub>4</sub> 5.65 g.; NaH<sub>2</sub>PO<sub>4</sub>·2H<sub>2</sub>O 6.27 g.; KCl 2.15 g.; NaCl 2.15 g.; MgSO<sub>4</sub>·7H<sub>2</sub>O 0.582 g.; and Na<sub>2</sub>SO<sub>4</sub> 0.75 g. per liter.

<sup>b</sup>FeCl<sub>3</sub>·6H<sub>2</sub>O 4.4 mg./ml.; CaCl<sub>2</sub>·2H<sub>2</sub>O 5.29 mg./ml.

<sup>c</sup>Nutritional Biochemicals Corp.

<sup>d</sup>Na<sub>2</sub>HPO<sub>4</sub> 1.059 g. and KH<sub>2</sub>PO<sub>4</sub> 0.436 g. per liter.

*Prepared prior to each fermentation run.
d. **Initiation and termination of the fermentation run**

The addition of the inoculum and the basal medium to the substrates marked the beginning of the fermentation run. Two drops of mineral oil were added to each tube in order to prevent foaming, after which the tubes were connected to the CO$_2$ gas supply and placed in the water bath. The tubes were shaken hourly for the first 5 hours of fermentation to effect adequate mixing of the substrate and inoculum. At the end of 24 hours, the tubes were removed from the water bath, substrate materials at the sides of the tubes were washed down with distilled water and the tubes were immediately centrifuged at 2200 r.p.m. for 8 minutes. The supernatant was discarded and the residue was immediately analyzed for cellulose or refrigerated for subsequent cellulose analysis.

e. **Cellulose analysis**

The procedure used for the cellulose analysis of the original substrate samples and the residues from the in vitro fermentation, was that reported by Crampton and Maynard (1938) slightly modified by Donefer *et al.* (1960), and is outlined below.
(i) **Acid digestion**

The acid digestion mixture was prepared by mixing 650 ml. acetic acid (99.7% v/v), 80 ml. concentrated nitric acid, and 150 ml. distilled water. Approximately 25 ml. of the acid digestion mixture was dispensed into each fermentation tube. A glass stirring rod was inserted in each tube and the contents well mixed, with the stirring rod left in the fermentation tube during the entire digestion period. The tubes were placed in a steel wire basket and immersed in a boiling water bath for 30 minutes. Contents of the tubes were mixed every ten minutes with the stirring rod. At the end of the digestion period, the tubes were removed from the boiling water bath and allowed to cool for about 5 minutes.

(ii) **Filtration**

After cooling for 5 minutes, 25 ml. of 95% ethanol were added to each tube mixing the contents with the stirring rod. The contents were immediately transferred quantitatively into filtering crucibles (Selas - coarse porosity), using a polyethylene wash bottle containing 95% ethanol to wash down the sides of the tubes. Filtration was aided by applying suction. The precipitate in the crucible was then washed with
approximately 10 ml. each of acetone and ethyl ether in succession.

(iii) **Drying and ashing**

The crucibles together with their contents were dried in an oven at approximately 100°C for 12 hours, after which they were cooled in a desicator and weighed. The crucibles with their contents were then ashed in the muffle furnace (600°C) for 8 hours, cooled in the desicator and weighed.

(iv) **Calculation of cellulose content**

Cellulose content of the original substrate or of the fermentation residue was calculated as the loss in weight on ashing the oven-dried acid digested material using the following formula:

\[
\text{Cellulose content (g)} = \text{Weight (g) dry crucible and contents minus, weight (g) ashed crucible and contents.}
\]

\[
\text{Cellulose (\%)} = \frac{\text{Weight (g) cellulose}}{\text{Weight (g) of substrate}} \times 100
\]
(v) Calculation of cellulose digestibility in vitro.

Cellulose digestibility in vitro was calculated as the difference between initial cellulose content of the substrate and the cellulose content of the fermentation residue, expressing this as a per cent of the initial cellulose content. The following formula was used:

\[
\text{Cellulose digestibility (\%)} = \frac{W_0 - W_f}{W_0} \times 100
\]

where \( W_0 \) = Weight of cellulose (g) in the substrate

\( W_f \) = Weight of cellulose (g) in the fermentation residue.
RESULTS AND DISCUSSION

Data presented in Table 21 show the cellulose content and in vitro cellulose digestion of ground untreated and alkali treated oat straw and poplar wood. There was a greater decrease in the cellulose content of the NaOH treated straw and wood than the NH\textsubscript{4}OH treated samples. Similar reduction in the cellulose content of NaOH treated oat straw was reported by Adeleye (1969). The explanation for this apparent reduction in the cellulose content could be attributed to the diluting effect of the sodium hydroxide. The ash content of the NaOH treated straw increased from an initial value of 5.21% to 14.10% after NaOH treatment and acid neutralization, with the decreased cellulose content directly attributable to the increased ash content. When NH\textsubscript{4}OH was used, very slight decrease in cellulose content was observed. This might be explained by the fact that HN\textsubscript{4}OH is volatile so that after drying of the NH\textsubscript{4}OH treated materials, very little difference in cellulose content was observed between the treated and untreated samples.

The in vitro cellulose digestion of the untreated oat straw (41.3%) was significantly (P < 0.01) lower than those for the NaOH and NH\textsubscript{4}OH treated straw samples -- 78.7 and 66.5% respectively. The almost two-fold increase in cellulose
## TABLE 21

THE EFFECT OF NaOH AND NH₄OH TREATMENT ON THE IN VITRO CELLULOSE DIGESTION OF OAT STRAW AND POPLAR WOOD.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Chemical treatment</th>
<th>Cellulose content (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>In vitro cellulose digestibility (%)&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat straw</td>
<td>None</td>
<td>40.06</td>
<td>41.3</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>34.77</td>
<td>78.7</td>
</tr>
<tr>
<td></td>
<td>NH₄OH</td>
<td>39.04</td>
<td>66.5</td>
</tr>
<tr>
<td>Poplar wood</td>
<td>None</td>
<td>53.36</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>46.26</td>
<td>71.4</td>
</tr>
<tr>
<td></td>
<td>NH₄OH</td>
<td>52.55</td>
<td>57.6</td>
</tr>
</tbody>
</table>

<sup>a</sup> Each value is a mean of 3 determinations

<sup>b</sup> Each value is a mean of 4 determinations
digestibility observed for the NaOH treated straw (78.7%) as compared with the untreated straw (41.3%) was expected since the NaOH treatment acted to solubulize lignin, thereby exposing cell nutrients particularly cellulose, to the action of microbial degradation. Cellulose digestibility of the NaOH treated straw was significantly (P < 0.05) greater than the NH₄OH treated straw. It is difficult to explain why this significant difference in cellulose digestion occurred. However, it might be suggested that the higher cellulose digestion of the NaOH treated straw was most probably due to the fact that different volumes of alkali were used to treat equal weights of material - 60 ml. of NaOH as against 24 ml. of NH₄OH. The effect of this is that more uniform mixing of straw with NaOH was achieved and thus the reaction would be more complete. Furthermore, less complete chemical reaction might be obtained with the NH₄OH treatment due to the volatility of ammonia.

Similar results as those for straw were obtained with poplar wood. However poplar wood appeared to be more responsive to alkali treatment than was oat straw. The in vitro cellulose digestion of the untreated wood was increased significantly (P < 0.01) from a mean value of 16.4% to 71.4% with NaOH treatment and 57.6% with NH₄OH treatment. Similar observations were made by Huffman (1970) in his study of the effect of NaOH treatment on the in vitro cellulose digestion of four wood types.
The effect of nitrogen source on the \textit{in vitro} cellulose digestion of untreated and alkali (NaOH or NH$_4$OH) treated straw and poplar wood is shown in Table 22. Urea solution was omitted from the basal medium used for the preparation of the inoculum, in order to eliminate its effect on the other sources of nitrogen used as the supplement to the untreated and treated material. With the untreated oat straw, the source of nitrogen had no significant effect on the \textit{in vitro} cellulose digestion. However, cellulose digestion values obtained when biuret and uric acid were used as the nitrogen source, were slightly lower than when urea was used. NaOH or NH$_4$OH treatment of the straw significantly ($P < 0.01$) increased cellulose digestion, and digestibility values obtained were comparable to those observed with the usual medium, regardless of nitrogen source used.

With the poplar wood, supplementation of the untreated material with nitrogen from urea, biuret or uric acid resulted in \textit{in vitro} cellulose digestion values that were not significantly ($P < 0.05$) different from one another and from the value obtained when the usual medium was used. Alkali treated poplar wood had similar cellulose digestibility values as those observed when the usual medium was used. However, there was a tendency for slight decreases in the cellulose digestion of both untreated and alkali treated oat straw and
THE EFFECT OF NITROGEN SOURCE ON THE IN VITRO CELLULOSE DIGESTION OF UNTREATED AND ALKALI TREATED OAT STRAW AND POPLAR WOOD

<table>
<thead>
<tr>
<th>Sample</th>
<th>Chemical treatment</th>
<th>Cellulose content (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nitrogen source</th>
<th>In vitro cellulose digestibility (%)&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat straw</td>
<td>None</td>
<td>40.06</td>
<td>Urea</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>40.06</td>
<td>Biuret</td>
<td>38.4</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>40.06</td>
<td>Uric acid</td>
<td>37.8</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>34.77</td>
<td>Urea</td>
<td>77.9</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>34.77</td>
<td>Biuret</td>
<td>69.6</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>34.77</td>
<td>Uric Acid</td>
<td>71.3</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>39.04</td>
<td>Urea</td>
<td>63.1</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>39.04</td>
<td>Biuret</td>
<td>60.3</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>39.04</td>
<td>Uric acid</td>
<td>60.7</td>
</tr>
<tr>
<td>Poplar wood</td>
<td>None</td>
<td>53.36</td>
<td>Urea</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>53.36</td>
<td>Biuret</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>53.36</td>
<td>Uric acid</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>46.26</td>
<td>Urea</td>
<td>73.5</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>46.26</td>
<td>Biuret</td>
<td>69.4</td>
</tr>
<tr>
<td></td>
<td>NaOH</td>
<td>46.26</td>
<td>Uric acid</td>
<td>68.6</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>52.55</td>
<td>Urea</td>
<td>54.9</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>52.55</td>
<td>Biuret</td>
<td>54.1</td>
</tr>
<tr>
<td></td>
<td>NH&lt;sub&gt;4&lt;/sub&gt;OH</td>
<td>52.55</td>
<td>Uric acid</td>
<td>51.8</td>
</tr>
</tbody>
</table>

<sup>a</sup>each value represents the mean of 3 determinations

<sup>b</sup>each value represents the mean of 4 determinations
poplar wood when biuret or uric acid was used as the nitrogen source. It is difficult to suggest the actual reason for this observation, but it can be postulated that the solubility of the nitrogen compound used will affect its utilization by the rumen microorganisms. Nevertheless, the data indicate that \textit{in vitro} cellulose digestion of oat straw and poplar wood was little affected by the source of nitrogen when urea, biuret or uric acid was used as nitrogen supplement.

Data presented in Table 23 shows the cellulose content, the \textit{in vivo} and \textit{in vitro} cellulose digestibility values for the rations used in the animal feeding trials I and III. Cellulose content of the rations of trial I ranged between 21.3 and 27.7%. The \textit{in vivo} cellulose digestibility values showed that ration 5 (poultry litter supplemented) had a significantly ($P < 0.01$) lower cellulose digestion value. The significantly lower cellulose digestibility observed in this ration could be attributed to the low digestibility of crude fiber of wood which was used as the base material for the litter (Bhattacharyya and Fontenot, 1966; Leibholz, 1969). The \textit{in vitro} cellulose digestibility values for these rations were significantly ($P < 0.01$) higher than the \textit{in vivo} values. The reason for this is most likely due to the greater control and precision which could be exercised over the various conditions of the \textit{in vitro} systems as compared with studies.
TABLE 23

IN VIVO AND IN VITRO CELLULOSE DIGESTION OF THE RATIONS FED TO LAMBS IN TRIALS I AND III

<table>
<thead>
<tr>
<th>Feeding Trial</th>
<th>Description of Ration</th>
<th>Cellulose Content (%)</th>
<th>In Vivo Cellulose Digestibility (%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>In Vitro Cellulose Digestibility (%)&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial I</td>
<td>control (Soybean meal)</td>
<td>25.8</td>
<td>49.1</td>
<td>58.2</td>
</tr>
<tr>
<td></td>
<td>urea supplement</td>
<td>27.7</td>
<td>45.9</td>
<td>56.7</td>
</tr>
<tr>
<td></td>
<td>biuret &quot;</td>
<td>26.1</td>
<td>48.1</td>
<td>57.4</td>
</tr>
<tr>
<td></td>
<td>poultry droppings</td>
<td>21.3</td>
<td>46.3</td>
<td>52.1</td>
</tr>
<tr>
<td></td>
<td>poultry litter</td>
<td>22.1</td>
<td>24.3</td>
<td>32.8</td>
</tr>
<tr>
<td>Trial III</td>
<td>grass hay</td>
<td>16.35</td>
<td>38.1</td>
<td>62.1</td>
</tr>
<tr>
<td></td>
<td>oat straw</td>
<td>21.66</td>
<td>37.5</td>
<td>53.6</td>
</tr>
<tr>
<td></td>
<td>extruded wood</td>
<td>20.14</td>
<td>13.7</td>
<td>21.5</td>
</tr>
</tbody>
</table>

<sup>a</sup>Each value represents the mean of 3 lambs determinations.

<sup>b</sup>Each value represents the mean of 4 determinations.
dealing with live animals. Another possible reason might be due to the differences in substrate particles used in the \textit{in vivo} and \textit{in vitro} systems. The use of finer particles for the \textit{in vitro} would no doubt result in greater surface area exposed to the action of microorganisms. A correlation of 0.985 was observed between the \textit{in vivo} and the \textit{in vitro} cellulose digestion of the trial I rations.

Cellulose content of the rations used in the feeding trial III varied between 16.35 and 21.66\%. The \textit{in vivo} cellulose digestibility value (13.7\%) of ration 3, in which extruded wood was used as the roughage, was significantly (P \textless{} 0.01) lower than those for rations 1 and 2 in which grass hay and oat straw were used as the roughage source respectively. The significantly lower cellulose digestibility of the ration in which extruded wood was used as the roughage source might suggest that the full potential of wood and woody by-products is not realized unless the material is subjected to chemical treatment. This statement might be justified by the data presented by Kitts \textit{et al.} (1969) in their study of the effect of the incorporation of alder sawdust in beef cattle rations. These workers reported a small degree of actual utilization of the alder sawdust by the animals as indicated by the percent dry matter digestibility of the rations containing 13.3\% sawdust. However, they suggested that the beneficial effects
of incorporation of sawdust in the ration of ruminants are possibly the stimulation of rumination and support of a more sustained fermentation in the rumen thereby causing a more efficient utilization of other digestible nutrients of the ration.

The *in vitro* cellulose digestibility values for the 3 rations used in feeding trial III were significantly (\( P < 0.01 \)) higher than the *in vivo* values. Cellulose digestibility values between rations were significantly different, with the grass hay exhibiting the highest *in vitro* cellulose digestibility followed by oat straw and extruded wood in descending order. A highly significant positive correlation (\( r = 0.974 \)) was observed between the *in vivo* and *in vitro* cellulose digestibilities.
SUMMARY AND CONCLUSIONS

The utilization of three nitrogen sources, urea, biuret and poultry wastes, to replace a portion of a conventional protein supplement (soybean meal) in high roughage rations for sheep was investigated.

Chemical analysis showed that poultry wastes are quite variable in composition. Greater variation existed in the chemical composition of poultry litter (bedding material plus droppings) than in that of cage droppings alone. It is possible that the bedding material in the litter must have been responsible for the dilution of chemical components in this material. Poultry litter contained 21.5 to 30.4% protein equivalent while the cage droppings contained 26.3 to 35.4% protein equivalent. Approximately 33% of the poultry litter nitrogen and 40% of the poultry droppings nitrogen was in the form of uric acid nitrogen.

The total nitrogen or the uric acid nitrogen of poultry droppings or litter was not significantly affected by autoclaving or steaming. These heat treatments however were sufficient to destroy all the microflora in the wastes.

No significant differences were observed in the digestibility coefficients of dry matter, crude protein, crude fiber or gross energy when approximately 50% of the soybean meal (SBM) nitrogen of the control ration was replaced by urea, biuret or poultry droppings in the rations of fattening lambs fed in the unpelleted
form. However, similar replacement of 50% of the SBM nitrogen of the control ration by poultry litter resulted in significantly lower nutrient digestibility coefficients of this ration when compared with the control. It appeared that the presence of bedding material as in the litter hampered the availability of nitrogen from this source.

A significantly lower voluntary intake was observed in animals fed the urea supplemented ration when compared with the animals fed the soybean meal containing ration. This apparent depression in intake could not however be explained only by the effect of reduced palatability. The data obtained indicated that palatability probably played only a minor role in determining voluntary intake of the test rations as evidenced by the presence of other supposedly unpalatable substances (biuret, poultry wastes and straw) in the rations.

When the rations were offered in the pelleted form, the differences in nutrient digestibility coefficients particularly between the control and the litter supplemented rations were no longer significant. Pelleting was also found to increase the voluntary consumption of the rations irrespective of the source of nitrogen supplementation.

Although all animals were in positive nitrogen balance, those fed the urea and poultry litter supplemented rations had significantly lower nitrogen retention than those fed soybean meal, biuret or poultry droppings supplemented rations. This
observation was also reflected in the lower body weight gains and feed efficiency of the animals fed the urea and litter containing diets. Reduced feed intake and high urinary nitrogen loss of animals fed the urea supplemented rations and the high fecal nitrogen loss of animals fed the litter supplemented rations might have been responsible for the lower nitrogen retention observed in these animals.

When poultry droppings were incorporated into high-roughage rations to supply approximately 18.7, 50.2 and 64.2% of the total nitrogen in rations in which grass hay (control), oat straw and extruded wood were used as the roughage sources respectively, no significant differences were observed in the voluntary consumption of the rations. This indicated that, as a source of NPN, poultry droppings had an equally effective replacement value at all the three levels studied.

Alkali (NaOH or NH₄OH) treatment of oat straw and poplar wood significantly increase cellulose digestibility in vitro. Cellulose digestibility was slightly, but no significantly, affected by the type of nitrogen source used in the in vitro basal medium. The maximum cellulose digestibility in vitro was obtained with the urea nitrogen, followed by biuret and uric acid nitrogen in descending order. Cellulose digestibility in vitro appeared to bear a positive relationship with the solubility of the nitrogen source used in the basal medium.
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