SECTION B -- THE DIGESTION OF FEED

Earlier, it was pointed out that ruminants are relatively inefficient in the conversion of feed. The suggestion was made that the production of lamb (and beef) could only be economical when feed costs are low. Thus, economics dictate that sheep production be forage-based. The ability of sheep and ruminants in general, to utilize forage is a function of their unique digestive system.

The digestive systems of mammals are broadly divided into two classes:
1. **Monogastric** – meaning one stomach, includes: human, horse, pig
2. **ruminant** – includes: sheep, cattle, goats, deer, bison

In order to understand some of the unique properties of the ruminant system, it will be helpful to briefly discuss the simpler monogastric system.

**MONOGASTRIC DIGESTION**

An outline of the human system is shown in figure B1. Food, upon entering the mouth, is subdivided by chewing. At the same time lubricating digestive juices containing enzymes are secreted from the salivary glands. These particular enzymes are responsible for initiating the breakdown of starches.

Food, now mixed with these secretions, passes down the esophagus into the stomach, where the digestion of protein, fats and oils is initiated by acid and other specific enzymes. In monogastrics, the stomach also serves as a reservoir for food which has been rapidly ingested.

When the initial stages of digestion in the stomach are completed, the contents pass into the small intestine. Here, bile from the liver and gall bladder, as well as enzymes from the pancreas are added. Breakdown continues as the digesta travel the 10-20 meter length of the small intestine, while at the same time the products of digestion are absorbed into the bloodstream.

Enzymatic breakdown of most of the organic constituents of food is complete by the time the unabsorbed digesta reach the large intestine. One of the main functions of this part of the system is the absorption of water and minerals of both dietary and secretory origin. In addition, further breakdown is carried out here by a permanent population of microbes (bacteria and protozoa) with some proportion of the products being absorbed into the blood. Food material which has escaped both enzymatic and microbial digestion is excreted.

Some monogastrics, like the horse and rabbit, have a relatively large capacity for microbial digestion in the large intestine and cecum. Table B1 compares the size of several parts of the monogastric digestive system. Notice that where the large intestine and cecum make up only 19% of the digestive system in the human, they represent over 60% of the total

<table>
<thead>
<tr>
<th>Digestive Compartment</th>
<th>Cattle</th>
<th>Sheep</th>
<th>Horse</th>
<th>Pig</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rumen…………………...</td>
<td>56.9</td>
<td>52.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reticulum…………….</td>
<td>2.1</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omusum……………….</td>
<td>5.3</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abomasum……………...</td>
<td>8.5</td>
<td>7.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Stomach………..</td>
<td>70.8</td>
<td>66.6</td>
<td>8.5</td>
<td>29.2</td>
<td>13.8</td>
</tr>
<tr>
<td>Small Intestine……..</td>
<td>18.5</td>
<td>20.5</td>
<td>30.2</td>
<td>33.3</td>
<td>62.4</td>
</tr>
<tr>
<td>Cecum………………….</td>
<td>2.8</td>
<td>2.6</td>
<td>15.9</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>Large Intestine………</td>
<td>7.9</td>
<td>10.3</td>
<td>45.3</td>
<td>31.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Total Capacity (litres)</td>
<td>356.0</td>
<td>44.0</td>
<td>211.0</td>
<td>28.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
volume in the horse. The implications of this will become clear when we discuss microbial digestion in the ruminant.
THE SHEEP'S DIGESTIVE SYSTEM

The main feature which distinguishes our own digestive system from that of the sheep is the complex stomach shown in figure B2. The first two sections, the *rumen* and *reticulum* comprise a large fermentation compartment. Ingested feed passes rapidly, with very little chewing, down a muscular esophagus into the rumen. Later, boluses (cuds) of feed are regurgitated, broken down by chewing and mixed with saliva. The sheep, in fact, produces large volumes of saliva, perhaps up to 25 litres per day. The absence of adequate fibre in the ration to permit cud formation may account for the wool picking and wood chewing which is sometimes seen in feedlot lambs on concentrate rations.

On entering the rumen, feed is immediately subjected to microbial digestion. An extremely varied population of bacteria and protozoa (fig. B3) attach themselves to the feed and begin the breakdown process. This is facilitated by the secretion of enzymes onto the feed and into the fluid contents of the rumen. It should be noted that the microbial population which becomes attached to a particle of grain will be quite different from that which attaches to a forage leaf. This has important implications when changes in ration are contemplated (p. 50). A slow transition is necessary to allow time for alternations in microbial populations.

The lining of the rumen is like pile carpet having innumerable small, flat projections called papillae. These serve two main functions. They vastly increase the area for absorption of nutrients and they also provide attachment sites for additional populations of bacteria. Figure B4 is an electron photo-micrograph of bacteria attached to rumen papillae. These bacteria, like the ones attached to feed particles, produce enzymes which are secreted into the fluid contents of the rumen. One of the important contributions of this particular population is the enzyme *urease* which is responsible for the breakdown of urea. Feed, then, is subjected to digestion both by enzymes dissolved in the general milieu of the rumen and, more specifically, by those produced by attached microbes.

Continual mixing of rumen contents is essential to efficient fermentation. The muscular walls of the rumen and reticulum produce waves of contraction traveling their combined lengths at about half-minute intervals. This process, in addition to mixing the rumen contents, facilitates both regurgitation for further “cud-chewing” and belching, which releases gases produced by fermentation (mainly hydrogen and methane). Under some conditions (e.g., grain overload) the muscular walls may stop contracting resulting in *rumen stasis*, which can place the animal at serious risk of bloating.

![Figure B2 The digestive system of the sheep.](image-url)
After the feed has been sufficiently chewed and broken down by microbial action, the digesta enters the **omasum**. Flow into this third segment of the ruminant stomach is regulated by a small opening called a **reticulo-omasal orifice** which prevents large particles from leaving the rumen. It is the small caliber of this orifice which makes it possible for sheep to utilize whole grains. The larger orifice in cattle allows particles the size of whole grain to pass into the lower gut and be excreted.

The omasum itself is a muscular organ which is thought to have two main functions. The first is the extraction of water from the rumen fluid yielding a product for further digestion which has a significantly higher proportion of dry matter. Secondly, the omasum serves as a pump, propelling digesta from the rumen and reticulum into the fourth segment of the stomach, the abomasum.

The ruminant **abomasum** is analogous to the true stomach of the monogastric with its digestive processes being very similar to those described earlier for the human. Digestion and absorption of its products progress as the digesta passes down the **small intestine**.

The large intestine and **cecum** of the sheep represent only about 12% of the total volume of its digestive system.

This may seem quite insignificant in comparison with the horse (table B1). However, fermentation in this area can make a significant contribution to overall digestion. This will be discussed further in the section on Carbohydrate Digestion (p. 12).

**Development of the Ruminant Stomach**

At birth, the lamb’s rumen and reticulum have a capacity roughly equal to that of the abomasum (fig. B5). They contain no micro-organisms and, as a consequence, are not capable of functioning as they do in the adult. Bacteria begin to populate the rumen shortly after birth as the lamb begins to nurse and explore its environment. However, it takes several weeks before a stable microbial population is established which is capable of efficient digestion.

Scientists at Agriculture and Agri-Food Canada’s Lethbridge Research Station have attempted to hasten the establishment of functional microbial populations in newborn lambs. There are two reasons for this. First, many of the bacteria which contaminate the digestive tract from the environment early in life are capable of producing digestive upsets such as scours.
By inoculating the rumen and reticulum with a more appropriate microbial population, the digestive tract can be protected from the adverse effects of such contaminants through competition.

The second reason for attempting to establish a functional population is to hasten the ability of the rumen and reticulum to digest solid feed. This would make it possible to wean lambs earlier, a particular advantage when accelerated lambing is being attempted.

The Esophageal Groove

Since the rumen and reticulum are non-functional in the newborn lamb, a mechanism has evolved which allows milk to flow directly to the omasum. A reflex reaction causes a muscular fold on the wall of the reticulum to form a closed tube leading from the end of the esophagus to the reticulo-omasal orifice (fig. B5). This fold is called the esophageal groove and an appreciation of its function will affect some of the management aspects of feeding newborn lambs.

The esophageal groove closes in response to behavioural stimuli associated with the ingestion of liquid feed such as nursing from the ewe or feeding from a nipple pail. Even the sight of a nipple bottle may elicit the response in an orphan lamb. The reflex, however, requires some degree of training. Therefore, it is used to best advantage when feeding routines are well established.

If at all possible, weak newborn lambs should be encouraged to suckle either from the ewe or from a bottle. Although feeding by stomach tube may be the only alternative in many cases, this will invariably result in milk being deposited in the reticulum. A similar situation arises when milk is ingested too rapidly to be accommodated by the esophageal groove. This can occur when milk replacer is fed from a bottle or from the bottom of a nipple pail where a round-holed (rather than a cross-cut) nipple is used.

Milk which finds its way into the rumen and reticulum is subjected to fermentation by bacterial contaminants early in life. Such fermentation may result in significant gas production resulting in a typical pot-bellied lamb. The young lamb cannot expel this gas efficiently since the belching mechanism is poorly developed.

Lambs being fed through a rubber nipple should be encouraged to suck. Frequent feedings of small volumes are usually more successful than large volumes fed infrequently. These management considerations are discussed in more detail later (p.52).

Effect of Feeding Management

Between birth and maturity, the rumen and reticulum increase tenfold in volume in relation to the abomasum; the rate at which this proceeds can be significantly altered by nutritional management.

Most newborn lambs show little interest in consuming solid feed before they are two or three weeks of age. Consequently, until that time they must be nourished exclusively by milk or milk replacer. After this time it is possible to accelerate rumen development through feeding practices.

The closure of the esophageal groove only occurs when liquid feed is ingested. Therefore when solid feed is consumed it travels directly to the rumen where it is fermented to produce volatile fatty acids (see section on Carbohydrate Digestion, p.12). The presence of volatile fatty acids (VFA) has a direct effect on rumen development and, furthermore, higher rates of VFA production will accelerate this development. These observations have a direct bearing on management practices in feeding young lambs.

Creep feeding has become common practice in most successful sheep operations. The aim is to provide palatable, high quality solid feed to encourage consumption as early in life as possible. Restriction of milk intake after solid feed consumption is well established. This further promotes the intake of creep ration. The higher the quality and the greater the quantity consumed, the higher will be the rate of VFA production and the more rapid will be the rate of rumen development. Creep feeding is an essential practice in maximizing
lamb growth potential through increasing the ability of the lamb to consume nutrients. It also facilitates early weaning in accelerated lambing systems.

**CARBOHYDRATE DIGESTION**

As pointed out earlier, forages contain only low levels of fats and oils. Consequently, the main sources of energy for the ruminant are the carbohydrates.

**Monogastric Carbohydrate Digestion**

Carbohydrate digestion in the monogastric begins when food is mixed with saliva containing enzymes which begin the breakdown of starch. The process continues in the small intestine, facilitated by enzymes secreted by the pancreas. As digestion progresses, the end products (the simple sugars: glucose, galactose, etc.) are absorbed into the bloodstream. Depending on the energy status of the animal the sugars may be used as immediate energy sources or stored for later use. In the lactating female, glucose is used in the manufacture of the milk sugar, lactose.

**Ruminant Carbohydrate Digestion**

The enzymes which mediate carbohydrate breakdown in the ruminant are mainly of microbial origin. Each of the several classes of carbohydrates is digested by specific enzymes produced by a distinct microbial population (fig. B6).

**Volatile Fatty Acids**

If oxygen were present in the rumen, the end-products of carbohydrate digestion would be carbon dioxide and water, the compounds from which the carbohydrates were originally synthesized in the plant (p.2). However, the microbial population in the rumen operates in the absence of oxygen (the rumen environment is anaerobic), resulting in incomplete carbohydrate breakdown. Under these conditions, the principal end-products of digestion are compounds referred to as the volatile fatty acids (VFA’s), including acetic acid, propionic acid and butyric acid. Incomplete breakdown in this case is analogous to the situation where wood is burned with limited air. The smoke produced is composed of the products of incomplete combustion.

**Figure B6 Volatile fatty acids are the main end products of carbohydrate digestion in the sheep.**

The breakdown of carbohydrates to VFA’s results in the release of significant amounts of feed energy. This energy is utilized in the rumen from microbial growth involving, for example, the synthesis of new microbial protein, fat and carbohydrate. The VFA’s are absorbed into the bloodstream through the wall of the rumen to serve as energy sources for the sheep itself.

Other important products of ruminant carbohydrate digestion are the keto acids. These are formed in much smaller quantities than the VFA’s, but serve an important role in microbial protein synthesis (p. 15).

Carbohydrates which escape digestion in the rumen and those associated with the microbial population may be utilized further down the digestive tract. For example, carbohydrates which are components of microbial cells are digested and the resulting sugars absorbed in the small intestine, as in monogastrics. The contributions of these simple sugars to the overall energy requirements of the sheep are minor.
Further carbohydrate breakdown may also occur in the large intestine. Experimental results suggest that 5-10% of the energy requirement of lambs could be met from VFA’s produced by the microbial population found here.

**Cellulose Digestion**

The microbial populations of both the rumen and the cecum produce the enzyme cellulase which is responsible for the breakdown of cellulose. It is this feature which makes ruminants and monogastrics like the horse unique in their ability to utilize forages in the production of meat, milk and fibre. Mammals are incapable of digesting cellulose without the aid of these microbes. Several features of cellulose utilization should be appreciated when feeding sheep.

The digestion of cellulose is a relatively slow process (fig. B12). One implication of this is the fact that feed consumption is limited by the rate at which feed is digested. Feed can be introduced into the rumen only as rapidly as the products of digestion are discharged. In practical terms this means that rations high in fibre (ADF) may be consumed in lower quantity than those which are low in fibre.

A second consideration is the degree to which the cellulose in a feed is associated with lignin. As forages mature, the cellulose found in plant cell walls becomes more lignified. The result is that the cellulose becomes less digestible. This is reflected in higher ADF and lower TDN values for forages as they mature (table A2). Several chemical treatments of low quality (high ADF) forages have been developed which essentially break the association between cellulose and lignin. One of the more successful has been the treatment of straw with gaseous ammonia. In addition to increasing the digestibility of cellulose, this treatment increases the crude protein level of the end product.

**Other Carbohydrates**

Starch, pentosans, hemicelluloses, and sugars are rapidly fermented in the rumen to produce VFAs, CO$_2$, keto and lactic acids. Under most conditions, lactic acid production is low. However, when feeds containing large quantities of readily fermented carbohydrates are rapidly consumed, lactic acid production may be significant. As a result, the level of acidity in the rumen may rise (pH decreases). Since the level of acidity (pH) is critical to proper rumen function, rapid changes can cause digestive problems. For example, grain overload results in decreased rumen pH which leads to rumen stasis (p.9). The animal becomes unable to expel gases by belching and bloat occurs.

One of the main advantages of feeding whole grain to sheep lies in the reduced rate of fermentation since the starch is not as immediately available to microbial breakdown as it is in the milled grain. This results in a more prolonged digestion accompanied by a stabilization of rumen pH. The effects are also seen in the health of the rumen papillae (fig. B7).

**Figure B7** Whole grain feed permits the maintenance of healthy rumen papillae shown above. Prolonged feeding of milled grain may produce papillae like those shown below.

**PROTEIN DIGESTION**

Proteins, as suggested earlier, contain carbon, hydrogen, oxygen, nitrogen, usually sulfur and sometimes phosphorus. In order to understand how proteins are digested, a further explanation of their nature is required.

**Amino Acids**

Each different protein consists of a specific combination of 20 amino acids. In turn each amino acid contains a single atom of nitrogen in combination with two atoms of hydrogen called an amino group (NH$_2$). Not all proteins contain all
amino acids. These concepts are illustrated in figure B8.

Figure B8 Proteins are composed of long chains of amino acids. Each different protein has a specific sequence of amino acids and a unique shape.

Monogastric Protein Digestion

When protein is digested by the monogastric animal (fig. B9), the long chains are first broken down into shorter chains called peptides, a process which begins in the stomach. In the small intestine, further digestion releases the individual amino acids which are absorbed into the bloodstream.

The monogastric now uses these absorbed amino acids as building blocks for its own particular types of protein.

Protein Quality

Because the animal has specific requirements for amino acids to be incorporated into its own proteins, the concept of protein quality arises. If the balance of amino acids in the feed protein is very similar to that required by the animal, the protein is said to be of high quality (table B2).

TABLE B2 Quality comparison for proteins from various sources. Protein quality is expressed in terms of relative biological value.

<table>
<thead>
<tr>
<th>Protein Source</th>
<th>Protein Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Forage</td>
<td>38</td>
</tr>
<tr>
<td>Legume Forage</td>
<td>52</td>
</tr>
<tr>
<td>Corn Grain</td>
<td>58</td>
</tr>
<tr>
<td>Wheat Grain</td>
<td>59</td>
</tr>
<tr>
<td>Canola Meal</td>
<td>82</td>
</tr>
<tr>
<td>Mixed Microbes</td>
<td>65</td>
</tr>
<tr>
<td>Soyameal</td>
<td>70</td>
</tr>
<tr>
<td>Oats Grain</td>
<td>70</td>
</tr>
<tr>
<td>Barley Grain</td>
<td>72</td>
</tr>
<tr>
<td>Fishmeal</td>
<td>77</td>
</tr>
<tr>
<td>Milk</td>
<td>87</td>
</tr>
<tr>
<td>Egg</td>
<td>99</td>
</tr>
</tbody>
</table>

Figure B9 Protein digestion in the monogastric animal.
If the amino acid composition of feed proteins is poorly matched to requirements, the protein is of low quality. Surplus amino acids are broken down in the liver and kidney. The amino group is removed and may be recycled or excreted in the form of urea in the urine while the remainder of the molecule is utilized as an energy source.

Ten of the 20 amino acids can be manufactured by mammalian tissues as long as a source of nitrogen is available. For this purpose nitrogen may be obtained from urea or from the amino groups of surplus amino acids. The remaining 10 essential amino acids must be supplied in the diet of the monogastric animal. It is the availability of these essential amino acids which usually limits the synthesis of animal proteins. For example, when corn is fed to pigs, the limited availability of the essential amino acid lysine usually restricts growth. When corn-based rations are supplemented with lysine, a significant improvement in feed conversion efficiency occurs.

Ammonia in the rumen can also be derived from non-protein nitrogen (NPN) sources. Mention was made earlier of the large quantities of saliva produced by the sheep. This saliva serves as a vehicle for recycling amino groups in the form of urea (fig. B11) back into the digestive system from amino acid breakdown elsewhere (eg. liver). Urea may also be included in the feed as an inexpensive source of crude protein. Urea is broken down in the rumen by the enzyme urease and its amino groups are released as ammonia. Reference has already been made to the fact that the bacterial population adherent to the rumen papillae is a major contributor of urease (p. 9). The practical implications of this will be discussed later.

The first stage of nitrogen digestion in the sheep is completed with the production of amino acids and ammonia accompanied by the release of energy. The second stage involves the use of these products by the bacteria and protozoa in the rumen to build new microbial protein. This process, illustrated in figure B10, requires recapturing some of the energy released in the first stage as well as energy released from carbohydrate breakdown. The keto acids released during both protein and carbohydrate digestion are combined with ammonia to form new amino acids and, subsequently, new microbial protein.

Having completed the processes of plant protein degradation and microbial protein synthesis, microorganisms are drawn through the omasum and into the abomasum. Here the digestion of microbial protein begins in a manner similar to that in the monogastric. Digestion continues in the small intestine with amino acids being absorbed into the bloodstream to provide building blocks for animal protein as before.

Since the microbial population in the rumen has the capacity to synthesize essential amino acids, proteins considered “low quality” for monogastrics are actually improved by the rumen microbes. On the other hand “high quality” proteins are also modified with the result that the protein reaching the small intestine is of a relatively uniform medium
quality irrespective of the protein in the feed unless a significant proportion of bypass protein has been provided (p. 17).
Figure B11  Nitrogen flow in the sheep. MFN is metabolic fecal nitrogen (see page 24).

As described above, protein digestion in the ruminant involves two extra steps compared with that in the monogastric. Each extra step in the digestive process results in some loss of overall efficiency. This, combined with the fact that microbial protein is of mediocre quality, means that sheep are inefficient in utilizing high quality protein in comparison to monogastrics. Since high-quality protein sources are usually expensive, these observations reinforce the concept that sheep rations must be based on inexpensive forages.

Urea in Sheep Rations

As mentioned earlier, urea appears in the rumen in association with saliva. Urea and other non-protein nitrogen (NPN) sources may also be added to sheep rations to increase the level of crude protein. However, to make efficient use of urea it is necessary to appreciate a few features of its metabolism.

Urea and other sources of NPN added to sheep rations are not efficiently utilized until the rumen microbial population becomes adapted to their increased availability. Although this process begins within a few days of the introduction of additional NPN, it may take several weeks before maximum utilization is attained. Therefore, short-term feeding of NPN supplements makes little sense. In addition, for best results, NPN should be used to contribute no more than one-third of the total crude protein content of the complete diet.

The micro-organisms which produce urease (the enzyme responsible for urea breakdown) are concentrated on the lining of the rumen. Consequently, when large quantities of urea are fed over short periods of time, high concentrations of ammonia can accumulate near the rumen walls. This ammonia can produce a rapid increase in rumen pH and after passing into the blood stream can cause alkalosis (high blood pH). The effect is similar, but opposite to the effect produced by grain overload.

In order to be incorporated into microbial protein, the ammonia produced by urea digestion must be combined with organic keto acids to form amino acids (fig. B10). In addition, protein synthesis requires far more energy than is released by urea breakdown. It is important, therefore, when feeding urea to also provide readily fermentable carbohydrates as a source of both keto acids and energy. In fact, this principle applies to the efficient utilization of ammonia in the rumen irrespective of its source. Rations should contain approximately 100 grams of TDN for every 12 grams of crude protein degraded in the rumen.
When ammonia is produced in excess of the availability of keto acids and energy, it is absorbed through the walls of the rumen into the bloodstream. To some extent it may be recycled into saliva in the form of urea, but the greater proportion will be simply excreted (fig. B11).

The emphasis above was on readily fermentable carbohydrate. It is important that the rate of carbohydrate digestion be well matched to the rate of urea degradation when animals are fed on a periodic basis (i.e. not self-fed). Cellulose, for example, is inappropriate for this purpose because of its slow rate of digestion whereas the starch found in feed grains is ideal (fig. B12). Self feeding, where feed is consumed frequently results in more stable conditions in the rumen and these considerations become somewhat less important.

### Bypass Protein

It was suggested earlier that most of the feed protein entering the rumen is degraded to ammonia. In fact, the degree of degradation varies, depending on the source of protein (table B3). For most of the grass forages, protein degradability is in the 80% range; legume forage proteins are closer to 50% degradable. The figure for oats and barley protein is approximately 90%. Among the protein supplements, urea is considered 100% degradable; canola meal in the 90% range and soya meal being significantly lower at about 55%. Fish meal, which is rarely used in sheep rations is the extreme at approximately 35%.

Protein which is not degraded in the rumen is termed “bypass protein” or non-degradable dietary protein (UDP). Under some circumstances it is possible to use UDP to improve the overall quality of protein reaching the small intestine. Amino acids released from the UDP upon digestion there may complement the amino acids released from microbial protein resulting in a better balance of amino acids being absorbed into the bloodstream. This results in more efficient overall utilization of feed protein.

**TABLE B3 The degradability of protein from various sources**

<table>
<thead>
<tr>
<th>Protein Source</th>
<th>Degradability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass Hay</td>
<td>70-90</td>
</tr>
<tr>
<td>Grass Silage</td>
<td>80-90</td>
</tr>
<tr>
<td>Legume Hay</td>
<td>35-85</td>
</tr>
<tr>
<td>Barley Straw</td>
<td>75-85</td>
</tr>
<tr>
<td>Oats Grain</td>
<td>85-95</td>
</tr>
<tr>
<td>Barley Grain</td>
<td>89-95</td>
</tr>
<tr>
<td>Corn Grain</td>
<td>60-70</td>
</tr>
<tr>
<td>Soya meal</td>
<td>45-85</td>
</tr>
<tr>
<td>Fishmeal</td>
<td>25-45</td>
</tr>
<tr>
<td>Canola Meal</td>
<td>85-90</td>
</tr>
<tr>
<td>Urea</td>
<td>100</td>
</tr>
</tbody>
</table>

The concept of UDP explains why some feeds yield better performance results than others even though the total amount of crude protein provided in the ration is the same. For example, milk production is improved when soya meal or fish meal is used in place of urea. Similarly, the superiority of legume forages over grass forages for lactating animals is widely accepted.

### Heat Damaged Protein

When silage is poorly packed, excess air can result in significant heating. Similarly, hay which is baled when its moisture content is too high may produce heat. Heating is caused by chemical reactions in the feed which result in part of the protein combining with carbohydrates. The compounds formed are not digestible by rumen microbes. When heat damage is slight, these compounds may be digestible in the abomasum and small intestine serving a role similar to that of bypass protein. However, in most cases, heat
damaged protein will be totally indigestible, with the amount of loss being proportional to the degree of heating. A chemical test to determine the degree of loss was discussed in the section on Feed Analysis (p.3).