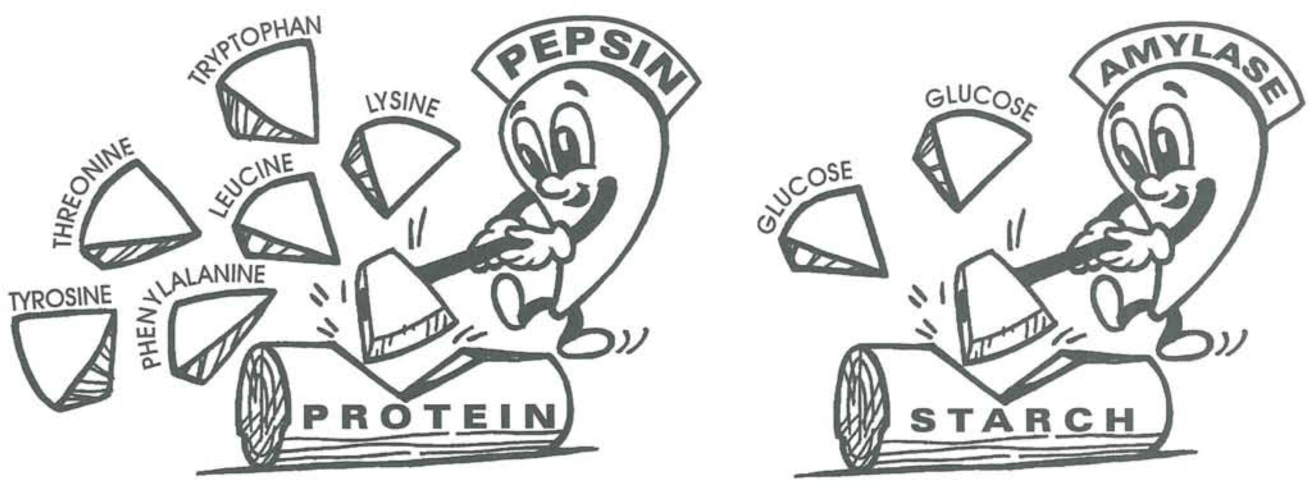
2. GASTROINTESTINAL PHYSIOLOGY

The science of nutrition is closely linked to other scientific disciplines, one of the most important being physiology. Gastrointestinal physiology is the study of the stomach, the small and large intestines and related tissues. It is a subject that helps us better understand nutrition.

The Role of the Digestive Tract

Before feed can be used by the pig, it must first be absorbed from the digestive tract into the body. From a physiological point of view, the material contained in the digestive tract is considered to be outside the body. There are very good reasons for this. Some parts of the undigested food are actually toxic to the body; the intestinal wall acts as a barrier to prevent, or at least attempt to prevent, the entry of unwanted compounds. For example, some intact proteins can cause an allergic reaction in the animal. The proteins in the diet are therefore broken down into their constituent parts called amino acids, before being allowed to enter the body.

The breakdown of food into simpler and smaller compounds is called digestion. Digestion not only converts proteins into amino acids, but it also breaks carbohydrates down into sugars such as glucose or fructose. Fats in the diet are converted into their constituent parts, largely free fatty acids, monoglycerides and related compounds. Minerals are also separated into individual elements. Salt is an example. Salt is chemically known as sodium chloride and is broken down into its individual molecules of sodium and chloride. Although not digested, some vitamins must be modified in the gut to facilitate their transfer across the gut wall. All of these processes are required in order to prepare the nutrients for absorption. The enzymes involved in the digestion of feed are represented below. The dual processes of digestion and absorption are discussed in more detail later in this chapter.



Feed ingredients must be broken down in the gastrointestinal tract into individual nutrients such as protein into amino acids or starch into glucose.

Types of Digestive Tracts

There is an old saying that "You are what you eat!" In actual fact, all animals must eat according to what "they are". Each member of the animal kingdom has a digestive tract that determines the type of diet best suited to the animal and dictates how it should be fed. For example, cattle and other ruminant animals have a complex stomach which includes four distinct segments each of which has a specific function. The rumen is the largest of these and functions as a large fermentation vat containing both bacteria and protozoa. The action of these microbes serves to degrade many feed components and convert them into more simple compounds. This fermentation process allows the cow to take advantage of the "bugs" that can break down fibre or roughage into products that, upon entering the intestinal tract, can be digested and absorbed.

Pigs differ from cattle in that they possess only a simple stomach. The pig must depend on its own digestive abilities because it cannot depend on microbes in a rumen to do the job for it. The pig is able to compensate for this, to some extent, because "bugs" do live in its large intestine and help to digest fibre after it leaves the small intestine. Bacterial digestion is believed to provide a significant amount of energy to the pig, somewhere in the range of 20 percent of its maintenance energy requirement.

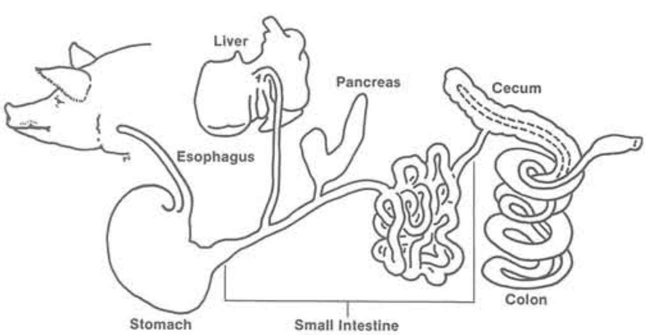
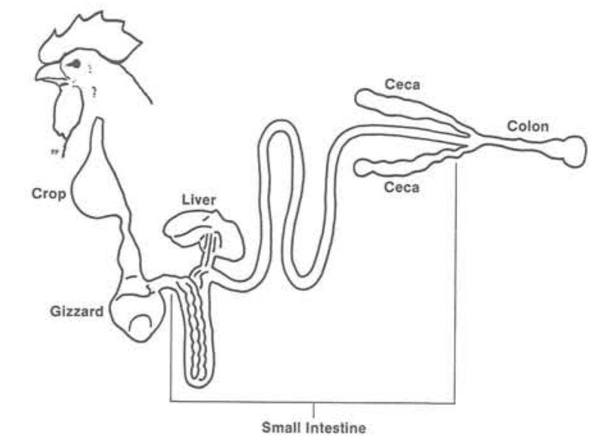
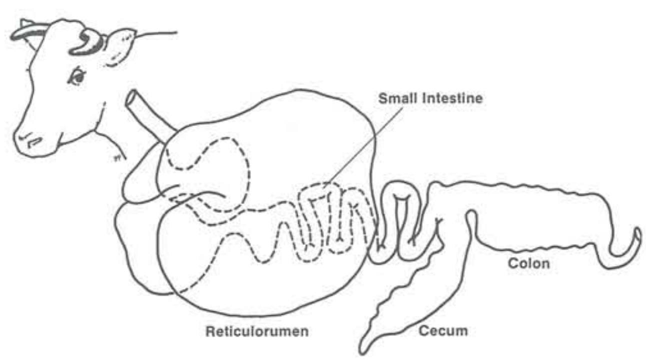


Figure 2-1. Gastrointestinal Tracts.

As a result of the differences in the digestive tracts of cattle and pigs, their diets are also different. The ruminant digestive tract lends itself to the use of feeds with a high fibre content while that of the pig utilizes more easily digested, low-fibre feeds such as grains.

All animals with a simple stomach are not alike in terms of nutrition. Chickens and pigs both have simple stomachs but differ in many areas.





When one considers all of these differences, it is easy to understand why the digestibility of lower quality feedstuffs such as barley or oats, is higher in swine than in poultry, while the digestibility of higher quality or more easily digested feed ingredients such as corn or fish meal, is higher in poultry. The reason appearers to be that the combination of rate of passage and mixing, which occurs in the intestinal tract of the chicken, maximizes the use of highly digestible ingredients, but reduces its ability to extract nutrients from feedstuffs requiring more prolonged digestion.

PIGS DIFFER FROM CHICKENS

* The pig has a stronger sense of taste, so palatability is of greater concern with swine than with poultry.

* Poultry have a shorter intestinal tract but compensate by moving digesta back and forth within it more effectively than pigs and thus enhance nutrient absorption.

* The rate of passage of material throughout the gut of the pig is slower than that of the chicken. This helps the pig increase its nutrient absorption.

* Chickens have a smaller total capacity in the large intestine than pigs, and thus the contribution of microbial fermentation is reduced.

The physiology of the gastrointestinal tract of the pig plays an important role in determining what constitutes a good or bad diet. Figure 2-2 illustrates the size and capacity of various segments of the gastrointestinal tract in the fully grown pig.

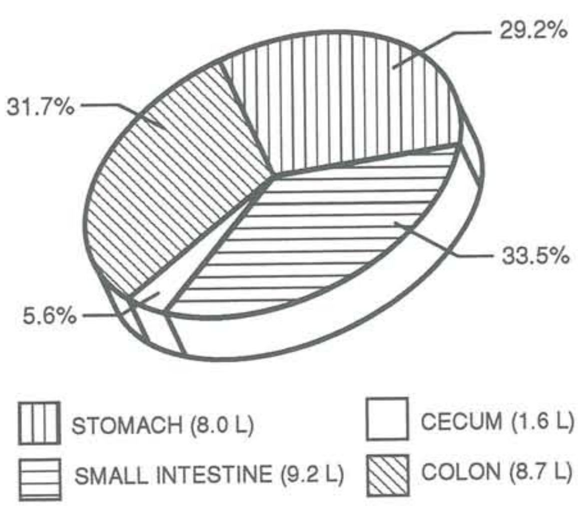


Figure 2-2a. Capacity of the Gastrointestinal Tract.

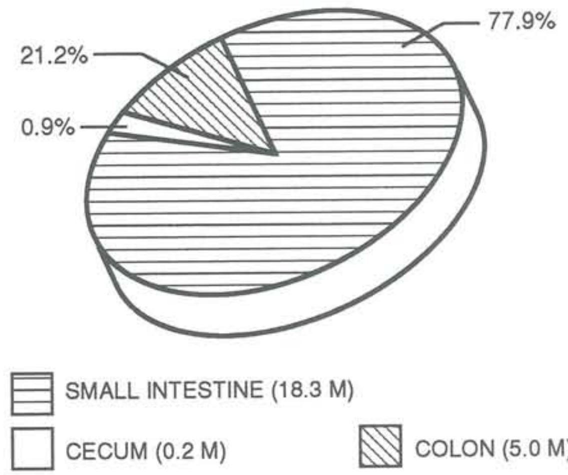


Figure 2-2b. Length of the Gastrointestinal Tract. Adapted from E.T. Moran, 1982.

Eating and Swallowing

Digestion of food actually begins in the mouth where chewing accomplishes at least two important objectives. The grinding action of the teeth serves to break down food particles into smaller pieces to facilitate swallowing and to increase their exposure to digestive enzymes.

Secondly, chewing mixes saliva into the food. The saliva lubricates the material to make swallowing easier. It also contains digestive enzymes which initiate the breakdown of the food bolus. For example, an enzyme called amylase, which helps to break down starches, is a component of saliva. The amount of starch digestion occurring in the pig due to salivary enzymes is not substantial. It has been estimated that the quantity of salivary amylase is less than 0.001 percent that of pancreatic amylase.

The Stomach

Once food enters the stomach, the next phase of digestion begins. The stomach serves as a large vat in which food is mixed with acid and digestive enzymes plus a substance called intrinsic factor. Because the stomach secretes acid into itself, its structure must be such that it does not digest itself! Mother nature works in wonderful ways, and in this case, the stomach also produces a mucous-like substance that lines the stomach and helps prevent acid from damaging it.

Acid secreted in the stomach serves to alter the structure of food proteins making them more accessible to digestive enzymes and initiating the action of certain digestive enzymes. For example, the stomach secretes a compound called pepsinogen. When pepsinogen is exposed to the acid of the stomach, it is converted into pepsin, a very potent enzyme involved in the digestion of proteins.

The intrinsic factor is an interesting compound also secreted by the stomach. It is absolutely critical in the prevention of a disease called pernicious anemia, which is due to a vitamin B_{12} deficiency. The intrinsic factor must bind to the vitamin B_{12} supplied by the diet if the vitamin is to be absorbed. Supplements of the vitamin will not prevent pernicious anemia if the intrinsic factor, which cannot be added to swine diets, is not present to allow for its absorption.

The secretory activity of the stomach must not be underestimated. For example, in one study, 40 kg pigs were found to secrete four to eight litres of total fluid per day.

A major role of the stomach is to control the rate of entry of food into the small intestine and thus contribute to a more gradual supply of nutrients from the gut. After a single meal, the stomach can mete out digesta to the lower gut over a period of 18 hours or more.

It has been postulated that in the young pig, the formation of the 'milk clot' in the stomach is critical in slowing the entry of food into a relatively immature small intestine. The problem with diets containing little or no milk is that clotting is impaired and transit time is increased. An excessive rate of passage of food into the small intestine overloads the system. The problem is compounded by the reduced digestive abilities of the small intestine of the young pig. This is extremely important to consider at the time of weaning. Once poorly digested material overwhelms the gut, undesirable bacterial fermentation begins and scouring results. It is recommended that recently weaned pigs fed non-milk diets should be limit-fed for five to seven days to help prevent scouring.

In summary, the stomach of the pig secretes acid, pepsinogen and intrinsic factor which all contribute to the digestion and absorbtion of food. The stomach also acts as a regulator of food entry into the small intestine, helping to prevent either overloading or deprivation.

The stomach of the pig is susceptible to ulcers, especially in the esophageal region. Ulcers are common in growing and adult swine, although most producers do not recognize the problem until death occurs. Symptoms of bleeding ulcers include dark feces and anemia, both due to the loss of blood into the intestinal tract. Animals with a chalky, white colour may also have a bleeding ulcer. Ulcers can impair growth in swine and in severe cases, result in death. Detailed information on ulcers is surprisingly limited, but it is suggested that economic losses are greater with subclinical ulcers which reduce animal performance, than from death loss itself.

The cause of gastric (stomach) ulcers is not really known. Many factors are associated with them but more research needs to be carried out in this area.

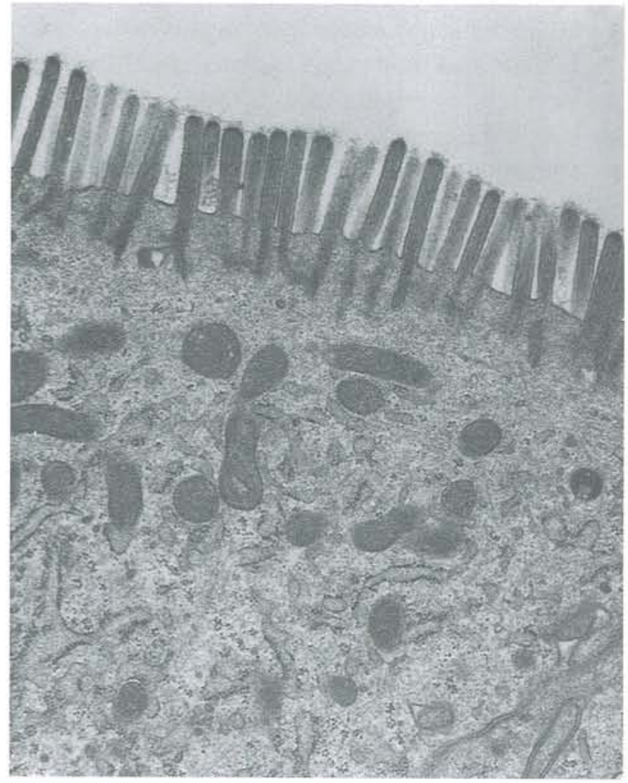
CURRENT THEORIES ON THE CAUSES OF ULCERS

* Some suggest that "stress" is involved but this has not really been studied nor quantified.
* Diet type may be involved with wheat and corn showing more of a connection with ulcers than barley or oats. This may be due to their different fibre contents.
* Pelleted diets may also contribute to ulcers and yet the number of animals fed pelleted diets without apparent problems suggest that it is not the sole cause. The fine grind required to manu facture firm pellets is probably more of a factor than the pelleting process itself.
* Other dietary factors that may be involved include fineness of grind, the presence of milk proteins, high fat content, especially of unsatu rated, long-chained triglycerides and deficiencies in thiamine and vitamin E.
* Ulcers also appear to be a greater problem in minimum disease herds, possibly because other health problems are reduced or because animal performance is higher.

Photo 2 - 1.

Cross section of the intestinal tract, showing the villi extending into the lumen of the gut(top). The muscles of the gut, which allow it to mix and move its contents, appear at the bottom of the photo. The micro-villi, too small to be seen in this photo appear opposite.

Photo 2 - 2.



A more powerful microscope shows the micro-villi (top) typical of the small intestine. The dark oblong structures below the micro-villi are called mitochondria; they act like little power plants to drive the many activities of the gut.

An outbreak of ulcers can be treated by adding coarse fibre to the diet. Oats appear to be particularly effective. The inclusion of 10% whole oats even in pelleted diets is beneficial, although pellet quality will suffer. If oats are added, adjustments need to be made to the diet to account for the drop in energy. In some cases, long hay can be offered to affected pigs to increase the fibre level in their diet, but this is generally impractical in barns with liquid manure systems. A coarser grind of the total grain in the diet may also prove helpful. The topic of grinding is covered in more detail in Chapter 10.

The Small Intestine

The small intestine works in conjunction with a number of tissues to achieve its objectives of digestion and absorption of as much food as possible. For example, it accepts digestive enzymes from the pancreas to supplement those it manufactures itself. It gets bile from the liver to assist in the absorption of fats and fat soluble vitamins. Many hormones produced throughout the body regulate the activity of the small intestine in relation to feeding, appetite and other external signals. As well, there are internal stimuli, such as gut fill and the presence of certain materials in the gut which also help to regulate its activity. It is quite clear then that the small intestine does not work in isolation, but is influenced by many other tissues in the body. Once food enters the small intestine from the stomach, digestion speeds up and absorption begins. More enzymes are added to the digesta, as well as mucous, buffers and bile. Some of the enzymes are produced locally by the intestine; others arrive from the pancreas.

Specific enzymes have specific roles to play. Carbohydrates, such as starches and sugars, are broken down by the action of enzymes which are very specific with respect to the carbohydrates they will attack. Amylase breaks down starches such as those found in grains. Sucrase degrades sucrose (table sugar) and lactase degrades the 'milk sugar', lactose.

Proteins are digested by a totally different set of enzymes. Proteins must be broken down into amino acids before crossing the intestinal wall. Protein digestion begins in the stomach but becomes much more effective in the small intestine. Examples of protein-degrading enzymes include trypsin, chymotrypsin, elastase and carboxypeptidase. The protein-degrading (proteolytic) enzymes attack proteins at very specific locations in their structure.

Fats in the diet must also be digested before being absorbed. An enzyme called lipase, derived from the work lipid which is another name for fat, breaks fats into smaller parts which are then combined with bile salts to form a compound that can cross the intestinal barrier. Bile salts are produced in the liver and are an absolute necessity for proper fat digestion.

It can be seen that a very competent system has been devised to allow the pig to digest the various components in the diet. Failure of any part of this system will result in impaired utilization of food. It is a complex system, with details far beyond the scope of this book. It is important, though, to recognize that digestion is not a simple matter and that what and how we feed the pig, how we house it, how old it is and how healthy it is can all influence the final outcome of the digestive processes.

The structure of the small intestine is uniquely designed to accomplish its objectives of digestion and absorption of nutrients. The wall is heavily muscled which permits the intestine to expand and contract in a rhythmic manner to move material along its length and to assist in mixing enzymes, bile and other secretions into its contents. The process also ensures that material ready for absorption is brought into contact with the absorptive cells found along the intestine surface. The constant mixing motion is absolutely critical if the process of absorption is to be efficient.

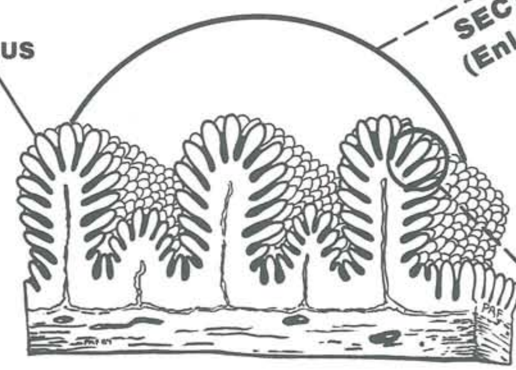
The small intestine is designed to maximize absorption. The surface consists of finer-like projections called villi which increase the surface area of the gut and thus increase its absorptive capacity. Along the villi are further projections, called microvilli which also increase surface area and thus, the absorptive capacity of the small intestine.

Another interesting feature of the small intestine is the way in which the absorptive cells grow. They are called enterocytes and are formed at the base of the villi and then migrate up along its surface as they mature. The maturation process is important because the more mature these cells are, the greater is their content of digestive enzymes. The migration of enterocytes along the surface of the villi from the base to the tip, ensures that the mature cells receive maximum exposure to the contents of the intestine; meanwhile, the immature cells located at the base of the villi are protected rom the physical forces of food moving along the length of the intestine. Once the enterocytes reach the tip of the villi, they are sloughed off into the lumen of the intestine, to be digested and absorbed. These sloughed off cells, together with enzymes secreted into the intestine, constitute what are called endogenous protein. This endogenous protein has been estimated to represent anywhere from 25 to 75% of the protein digested and absorbed by the gut. The diet makes up the remainder.

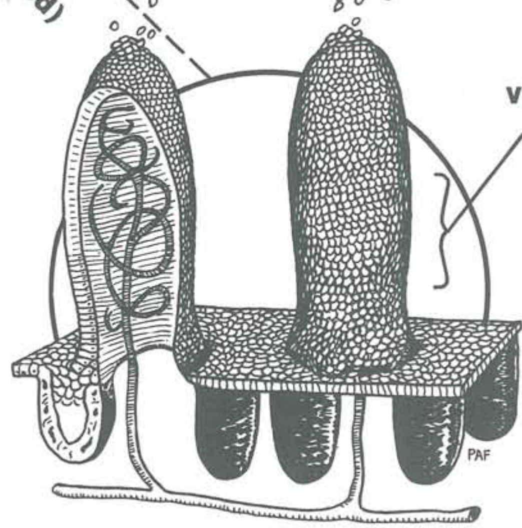
The cells have a very brief existence even under conditions of good health. The life expectancy of an enterocyte in a one week old piglet is only two to four days. Sometimes the enterocytes do not reach

THE SMALL INTESTINE OF THE PIG

Moving through the lumen, feed is digested and absorbed into the body of the pig. Muscles surround the intestinal tissue; their contraction moves the digesta along the tract and helps mix in digestive enzymes.



Folds in the intestine are lined with projections called **villi.** The villi increase the surface area, thus enhancing both digestion and absorption.



The individual villus consists of cells that form at the base and migrate to the tip, where they are sloughed off into the lumen of the intestine. As the cells migrate they mature, increasing their ability to break-down and absorb nutrients from the lumen of the gut. It takes a cell 2-5 days to move from the base to the tip. Each day, literally billions of cells are discarded along the length of the pig's gastrointestinal tract. The villi are also the site of absorption, where nutrients pass through the cells to enter the blood stream.

maturity, but are sloughed off into the intestinal lumen prematurely. As a result, the 'oldest' cells in the system are still immature. If this happens, the digestive ability of the small intestine is impaired due to the absence of mature cells and their rich source of digestive enzymes.

Several things have been shown to influence the lifespan of absorptive cells. Research suggests that one of the factors responsible for the post-weaning lag in the young pig is a reduction in the length of the villi. This results in a greater proportion of immature intestinal cells with reduced digestive capacity. Diet composition and feeding behaviour may also affect the lifespan of the cells. For example, even a few days off feed will lower the rate of cell turnover and impair the intestine's ability to produce new cells.

What does all this mean in the day-to-day feeding of pigs? A very relevant example is the post-weaning lag mentioned above. The stress of weaning with an associated drop in feed intake, appears to have a negative effect on the structure of the villi and thus, the function of the small intestine. Removing milk form the diet impairs clot formation and increases the flow of material from the stomach into the small intestine. The small intestine is unable to handle the material presented to it resulting in digestive upset. A further drop in feed intake compounds the problem. Poor sanitation which leads to increased stress from disease makes the situation even worse. Various feeding regimes designed to minimize this problem will be discussed in Chapter 5.

Another feature of the small intestine and the stomach which is relevant to practical nutrition is their overall capacity. Size plays an important role in determining the amount of food a pig can eat. It has been estimated that the capacity of the small intestine represents a major limiting factor in young, growing pigs and that among individual animals, the length of the intestine is correlated with lean tissue growth. As a result, young pigs are fed a very concentrated diet that maximizes the quantity of digestible nutrients per unit of feed and thus, the amount of nutrients consumed per day by the animal.

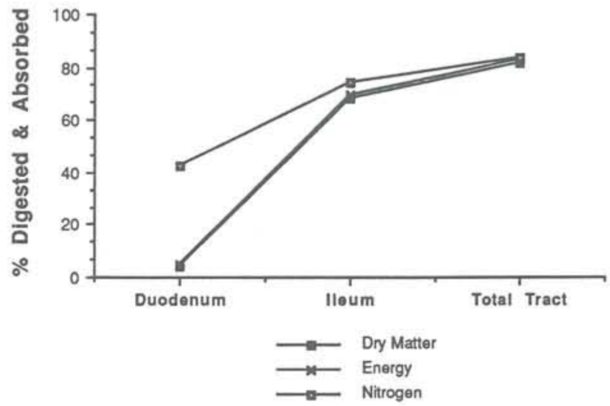


Figure 2-3. Nutrient Digestion Along the Gastrointestinal Tract of the Pig.

The Large Intestine

The large intestine plays an important role in the processes of digestion and absorption. Figure 2-2 shows how the digested portion of food increases as it passes along the intestinal tract. By the time the digesta leaves the first part of the small intestine called the duodenum, much of it remains to be absorbed. Even as the food passes throught the last segment of the small intestine called the ileum, digestion and absorption still occur.

The major role of the large intestine, which consists of the cecum and colon, is to absorb water and certain minerals called electrolytes. Bacteria in the large intestine break down undigested food and help to extract more nutrients, especially energy, from the feed ingredients. Complex carbohydrates, supplied by fibre (roughage) in the diet, are converted by the bacteria into volatile fatty acids. These volatile fatty acids can be absorbed and used as an energy source by the pig. The ability to utilize more fibrous ingredients increases in older animals. Sows for example, can utilize alfalfa hay more efficiently than weanlings.

The B-vitamins, as well as vitamin K, are produced by these same bacteria. It is not clear, though, to what extent the vitamins can be absorbed by the large intestine. If the vitamins are excreted in the feces and re-eaten, they will then contribute to the vitamin nutrition of the pig. Some people believe that pigs housed on fully-slatted floors which have less exposure to manure, have a higher requirement for dietary vitamins. There is very little scientific evidence to support this. The prudent approach is to ensure that the diet is properly supplemented with preformed vitamins to meet the requirements of the pig. In this way, the pig is not dependent on microbial fermentation to supply even a portion of its vitamin requirements.

Some of the information in Figure 2-2 must be interpreted with great care. It suggests that nitrogen, and thus protein, is absorbed by the large intestine. It is true that nitrogen is absorbed, but unfortunately, not as amino acids. Thus, if an essential amino acid is not absorb from a feed by the end of the small intestine, it will not be absorbed intact. The large intestine does not have the ability to absorb essential amino acids but rather absorbs nitrogen as a simpler compound called ammonia. Nutritionists who are measuring the proportion of lysine or other amino acids digested from a given feedstuff will collect digesta as it leaves the small intestine rather than collect the feces. This is done quite painlessly by surgically placing a collecting tube in the intestinal tract of the pig. If nutritionists use feces to determine amino acid digestibility, their results will be incorrect. The bacteria in the large intestine break down lysine and other amino acids and are also able to manufacture amino acids from non-protein nitrogen.

Summary

It appears that about 20% of the intestinal tissue turns over (is replaced with new tissue) every day! In the pancreas, up to 75% of the tissue is replaced daily. This compares with muscle which turns over at a rate of 2 to 3% per day. It has been estimated that 25% of the protein turnover in the total body occurs in the gastro-intestinal tract.

Studying the physiology of the stomach, intestines and related tissues in the pig provides extremely useful information on how the pig digests and absorbs feed, and how different conditions impair this activity. Simply stated, for best performance, the pig should be fed a diet that is suited to its digestive abilities. Since these abilities change with age, the better quality and more expensive ingredients should be used with the younger pig than with the adult sow or boar.

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