

MONOGASTRIC NUTRITION

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Summary

Some of the livestock kept for agricultural production are classified as monogastric animals, such as horses, pigs and poultry. They differ from the ruminant animals, such as cattle, sheep, goats and llamas, in that monogastric animals require a good source of protein in their diet and are limited in their capacity to ferment fiber for the provision of energy. The horse however, does obtain most of its energy through the fermentation of fiber, or complex carbohydrates in the hindgut, while pigs and poultry obtain energy from the digestion of simple carbohydrates in the small intestine. The horse is an herbivore while poultry and pigs are considered omnivores. The most important nutrient for all of these species is water, which must be potable and non-saline. Water for horses and pigs should be under 5,000 ppm total dissolved solids (TDS); however poultry and very young animals are more sensitive and water quality should be under 3,500 ppm TDS. Pigs, poultry and horses all require a good source of protein and amino acids, with

the more important amino acids being lysine, threonine and methionine. Young growing animals and pregnant or lactating females have higher protein requirements due to growth and the best sources of protein for all of these species are the oilseed meals such as soybean meal, canola meal as well as legumes. For energy, poultry and pigs are best fed cereals with such as wheat and corn, however barley contains β -glucans, which are undesirable for poultry. Horses are best fed fiber, or cellulose as energy sources, as supplied by fresh pastures, hays and pulps/pommaces. All of the monogastrics have requirements for fatty acids and fats, minerals and vitamins for optimal growth and performance. Each species has special considerations for nutrition and feeding management which are outlined in this chapter.

1. General Introduction

Monogastrics are classified as animals having one simple or single-chambered stomach, as opposed to ruminant animals, which are herbivores that have large, four-chambered stomachs where fiber is primarily fermented via resident microbes. Examples of ruminants are cows, sheep and deer and examples of monogastrics are humans, cats, dogs. The main agricultural species that are monogastrics are pigs, poultry and horses, however their digestive tracts are very unique to each species and they rely on very different feedstuffs. For example, the horse is an herbivore and its diet is largely made of forages such as grasses and hays. It relies heavily on the microbes in its hindgut to ferment fiber for the provision of energy. In contrast, pigs and poultry have a very limited capacity for fermentation in the hindgut and thus rely on simple carbohydrates as a primary source of energy, and they are also considered omnivores. All monogastric animals need to be provided with a good source of protein and amino acids from the diet, which is different to the ruminant. This chapter has been divided to discuss pigs, poultry and horses separately as their digestive tracts, nutrient requirements and appropriate feedstuffs are unique to each species.

2. Pigs

Pigs are omnivorous scavengers that have the ability to use a huge variety of feedstuffs for nourishment. This was exploited by the domestication of pigs approximately 5000 years ago. Pigs originally were fed wastes from food production and/or left to search for feed in addition to that offered by the owner to provide a readily available source of meat. While such a husbandry system may still be possible, pigs are now largely kept in purpose-built facilities where feed as well as environment for the pigs can be controlled. Such facilities require a more elaborate approach to feeding, but also allow the pigs to express their huge potential for growth. This review of pig nutrition focuses on the nutrition of pigs kept in intensive facilities.

2.1. Nutrient Requirements of Pigs

Physiological requirement is the need to ingest nutrients that cannot be synthesized by the animals' metabolism. Without supply of these essential nutrients, the metabolism of the animal does not function with the consequence of various deficiency symptoms which may include death of the animal. Nutritional requirement, by comparison, refers to the amount of nutrients needed to achieve a desired level of performance.

2.1.1. Essential Nutrients

Pigs need water, amino acids and fatty acids, macro- and micro minerals and vitamins. Water may be the most crucial 'nutrient', and is best made available to pigs at all times. Water for pigs should ideally be suitable for human consumption, but needs to be free from pathogens, and contain not more than 5000 ppm of total dissolved solids. Failure to fulfill these minimum quality criteria may cause sickness or the pigs' refusal to drink, if the dissolved solids content of water is too high.

Essential amino acids are listed in Table 1. Non-essential amino acids can be synthesized in sufficient amounts by the pig, given suitable precursors. It should be noted that pigs need a sufficient nitrogen intake to be able to synthesize non-essential amino acids. Conditionally essential amino acids can be synthesized in sufficient amounts under some circumstances. Arginine and proline are non-essential for pregnant sows, but can not be synthesized sufficiently by the baby pig. Cysteine and tyrosine can be synthesized if the diet contains enough methionine or phenylalanine, respectively. Arachidonic acid can be synthesized from linoleic acid, while linolenic acid can serve as a precursor for omega-3 fatty acids.

Apart from the essential minerals listed in Table 1, pigs may require ultra-trace minerals, namely chromium, molybdenum, boron, nickel, silicium, vanadium and arsenic. However, the requirement for these minerals is so low that deficiencies can only be achieved with special, purified diets. The lipid- and water soluble vitamins needed by pigs are listed in Table 1. Pigs do not require vitamin C.

Amino acids			Fatty acids	Minerals	Vitamins
Essential	Non-essential	Conditionally essential			
Histidine	Alanine	Arginine	Linoleic acid	Calcium	Vitamin A
Isoleucine	Aspartic acid	Cysteine	Linolenic acid	Phosphorus	Vitamin D
Leucine	Asparagine	Proline	Arachidonic acid	Sodium	Vitamin E
Lysine	Glutamic acid	Tyrosine	Omega-3 and omega-6 fatty acids	Chlorine	Vitamin K
Methionine	Glutamine			Potassium	Biotin
Phenylalanine	Glycine			Magnesium	Choline
Threonine	Serine			Sulfur	Folic acid
Tryptophan				Iron	Niacin
Valine				Zinc	Pantothenic acid
				Manganese	Riboflavin
				Copper	Thiamin
				Cobalt	Vitamin B ₆
				Iodine	Vitamin B ₁₂
				Selenium	

Table 1. Essential nutrients for pigs

2.1.2. Estimates of Nutritional Requirements

Pigs require nutrients as amounts per day to support a certain level of performance. If the nutrients required are not supplied in adequate amounts, growth performance will suffer or the pig will mobilize body reserves to support pregnancy or milk production. Although sows have the ability to compensate for nutrient shortages to a certain degree or period of time, prolonged or severely inadequate intake of nutrients will be detrimental to the sows' body condition and subsequent performance.

Nutritional requirements are stated either as dietary contents or daily intakes, or are calculated using the factorial method. In this method, requirements are apportioned to different functions, e.g. maintenance, growth, maternal and fetal growth and milk production. This partitioning is based on analysis of empirical data, and not necessarily based on physiological principles. For example, maintenance requirements – the nutrients required to maintain a pig's body weight and body composition – can not be entirely separated from requirements for growth. Physiological processes are upregulated to achieve growth, and will not immediately return to maintenance levels if nutrient intake becomes inadequate to achieve growth.

NRC (1998) compiled the available data on nutrient requirements into a model to predict nutrient requirements for growing, gestating and lactating pigs. Factorial estimates of requirement are used to predict amino acid or energy requirements of pigs, while the requirements for most minerals and vitamins are estimated according to the pig's body weight or physiological state, e.g. gestation or lactation. For some essential nutrients there are insufficient data to derive predictions based on body weight or physiological state, so that only blanket values are given.

2.1.3. Amino Acid Requirements

The NRC (1998) model calculates lysine requirements according to the factorial method, and derives the requirements for other amino acids using the ideal protein concept. Lysine is chosen as the key amino acid because in cereal-based diets – most commonly used in swine nutrition – lysine usually is the limiting amino acid. An ideal protein supplies amino acids so that none is limiting for the animal, and none is supplied in excess. Ideal proteins (Table 2) differ according to their use, i.e. an ideal protein for maintenance has a different amino acid pattern than an ideal protein for body protein deposition or for milk production.

Amino acid	Maintenance (mg/kg ^{0.75} body weight)	Protein deposition (g/100g body protein deposition)	Milk production (g/kg litter gain)
Lysine	36	12.2	22
Relative (%) to lysine:			
Arginine	-200	48	66
Histidine	32	32	40
Isoleucine	75	54	55
Leucine	70	102	115
Methionine	28	27	26

Cysteine	123	55	45
Phenylalanine	50	60	55
Tyrosine	121	93	112
Threonine	151	60	58
Tryptophan	26	18	18
Valine	67	68	85

Table 2. Lysine requirements and ideal ratios to lysine for different functions (NRC 1998)

To determine lysine requirements, all applicable factors are added up. A growing pig requires $36 \text{ mg/kg}^{0.75}$ body weight (*BW*) for maintenance, and 12.2 g true ileal digestible lysine to deposit 100 g of body protein. The requirement for lysine can be calculated for any combination body weight and protein deposition. Requirements for lysine in gestation and lactation are calculated analogously. In gestation, maintenance requirements and requirement for protein gain (12.9 g/100 g protein gain) are added. For this calculation, it is assumed that protein gain remains constant throughout gestation, and that the requirement for protein gain is the same for maternal and fetal growth. In lactation, the requirements for maintenance and milk production are added. A complication is that sows are capable to mobilize body protein to supplement inadequate protein (amino acid) intake with feed. However, supplying adequate amino acids with feed is entirely possible, so that body protein mobilization to supply amino acids for milk synthesis can largely be avoided.

Once the lysine requirements are determined, the requirements for other amino acids can be calculated by applying the ideal ratios shown in Table 2. Under practical feeding conditions using cereal grain-based rations, only lysine, threonine and methionine + cysteine are considered when determining requirements because such rations supply other amino acids in adequate amounts. However, when using feedstuffs with very different amino acid contents, other amino acids may need to be considered.

Amino acid requirements are commonly expressed as ‘true ileal digestible amino acids’. This takes into account that not all amino acids present in feed can be digested by the animal, and that some amino acids are lost during digestion of feed, be it as secretion of enzymes or as cells sloughed off the small intestinal wall. It also takes into account that there is no amino acid absorption in the large intestine, hence the declaration as ‘ileal’. Amino acid requirements and contents can also be expressed on a total amino acid based, which does not take into account the digestibility of amino acids. Values for requirements and feed contents on a total amino acid base are approximately 15% to 25% greater than true ileal digestible values.

2.1.4. Energy Requirements

Energy is derived from the oxidation of nutrients, and is commonly expressed as digestible (DE), metabolizable (ME) or net energy (NE). DE is the energy in feed minus energy in feces, both determined by quantitative combustion. ME is digestible energy minus energy in urine and in methane, while NE is ME minus heat increment, which is the energy (heat) released when metabolizing nutrients. Most common in use are DE

and ME, although currently there is a move towards NE, which is widely regarded as the most accurate system for describing dietary energy. The following description of factorial estimates of energy refers to ME, but the principles are equally applicable for digestible and net energy.

Factorial estimates of energy requirement follow the same principle as estimates for amino acid requirement, adding up the factors 'maintenance', 'growth' and 'milk production'. Maintenance requirements are estimated as 444 to 458 kJ/kg^{0.75} BW (ARC 1981, NRC 1998), and apply for all ages of pigs. Requirements for growth are separated into protein growth requiring 44 kJ/g protein gain, and lipid growth, requiring 53.5 kJ/g lipid gain (ARC 1981). Pigs need to deposit a minimum amount of lipid per unit protein deposition. If the energy intake of a pig is insufficient to support maintenance as well as protein plus the associated minimum lipid gain, protein deposition will be reduced. Conversely, if energy intake exceeds to requirement for maintenance and protein plus minimum lipid gain, the excess energy will be used exclusively for lipid deposition. Energy requirement per fetus is 0.161 MJ ME/d. Energy requirement for milk production is dependent on litter growth rate and number of piglets (NRC 1998):

$$\text{Milk (MJ ME/d)} = (20.3 \times \text{litter gain [kg/d]} - 0.377 \times \text{number of piglets}) / 0.72$$

where 0.72 is the energetic efficiency of utilizing feed ME for milk production. Lactating sows may not be able to ingest sufficient energy to support their energy requirement. In this case, the sow will mobilize body reserves to support milk production. Energy mobilized from the sow's body is utilized with greater efficiency (88%) than feed energy. Mobilized body protein contributes 23.4 kJ/g, mobilized body fat 39.3 kJ/g to the total energy available.

These energy values are applicable when pigs are kept under thermoneutral conditions. If the temperature drops below the lower critical temperature, pigs need additional energy to maintain body temperature. The estimate for gestating sows (200 kg) is 1.05 MJ ME per degree below 20 °C, while for lactating sows, an additional 1.3 MJ ME is needed per degree below 20 °C. There are no estimates for growing pigs.

2.1.5. Mineral and Vitamin Requirements

Requirements for mineral and vitamins in growing pigs are estimated according to BW, unless there are insufficient data. For gestating or lactating sows, estimates of requirement are given without consideration of body weight or performance. In practical feed formulation, only Ca, P and possibly Na are considered. The remaining macro- and micro-minerals and vitamins are either present in sufficient amounts in the base ingredients, or are supplied by mineral and/or vitamin premixes.

Calcium is not present in sufficient amounts in cereal grain-legume seed diets. It is usually supplemented by addition of limestone to diets. Total P is present in (almost) adequate amounts in cereal grain-legume seed diets. However, P in these diets occurs partly as phytate, which is poorly available because pigs lack phytase. Therefore, phosphorus is either supplemented as mono- or di-calcium phosphate or meat and bone meal, or is made available by inclusion of exogenous phytase in diets. Ca and P should

be supplied in certain ratios; on a total basis, the Ca:P ratio should be between 1:1 and 1.25:1, on an available P basis, the Ca:P ratio should be between 2:1 and 3:1. The sodium requirement of pigs can be met by inclusion of 0.25% to 0.5% salt in plant-based diets.

2.2. Feed Intake of Pigs

Requirements of pigs are expressed as amounts per day, but rations are calculated on a content basis (% , g/kg, ppm etc.). Therefore, it is necessary to know the feed intake of pigs for diet formulation. Pigs are usually offered feed ad libitum, with the exception of gestating sows that are fed restrictively.

The voluntary feed intake of pigs increases with *BW*. Voluntary feed intake is limited by gut-fill in younger pigs and possibly lactating sows. As pigs grow, this limitation is replaced by metabolic limitation, i.e. to supply energy appropriate to the pigs' body weight and performance. This means that pigs over 30 to 40 kg body weight can increase their feed consumption to compensate for low dietary energy concentration, and can decrease their consumption if offered a high-energy diet. Therefore, feed intake of growing pigs can be estimated according to digestible energy intake (MJ/d, NRC 1998):

$$5.23 + 0.787 \times BW - 0.00586 \times BW^2 + 0.0000184 \times BW^3$$

This represents more or less the maximum intake that may be observed with pigs. It should be noted, that genotype and gender has major impact on the voluntary feed intake, i.e. castrated males eat more than female or entire male pigs, and leaner genotypes usually eat less than genotypes that deposit more fat. Also, the ability to compensate for feeds with diverging energy contents is not entirely affective. Moderate addition of fat to diets can increase energy intake, while high-fiber diets may reduce energy intake. It is therefore best to determine the feed intake of pigs on farm so that diets can be formulated with the appropriate contents of nutrients.

Gestating sows are fed restrictively to avoid excessive fat deposition during gestation, which will impair feed intake during the subsequent lactation. Feed allowances are allocated to supply energy according to the sows' *BW* and condition at breeding and the expected *BW* gain. Smaller sows have lower maintenance requirements, hence receive less feed. Sows in poor body condition, e.g. low backfat or large weight loss in the preceding lactation, receive more feed than sows in good body condition. Feed allowances should be re-evaluated at least once, better twice during pregnancy to assure that target *BW* and conditions are met at farrowing. Generally, feed allowances for gestating sows are between 2 and 3 kg/d when fed a diet containing approximately 12 MJ ME/kg.

Lactating sows are subjected to a step-up feeding regimen that increases feed allowances gradually until ad-libitum intake is achieved around day 7 of lactation. The step-up feeding greatly reduces the risk of metabolic diseases immediately after farrowing. Feed allowances start with approximately 3 kg/d on the day after farrowing, and are increased by 1 kg/d if the sow eats her allowance. Voluntary average lactation

feed intake of sows increases up to the 4th parity, from 5 – 6 kg/d in primiparous sows up to 7 – 8 kg in older sows.

2.2.1. Feeding Piglets

Feeding piglets needs to take into account the development of voluntary feed intake and digestive capacity. Piglets start to show interest in solid feed at 2 weeks of age earliest, and usually start eating small amounts of solid feed around 3 weeks of age when the piglets' need for nutrients starts to exceed the supply from sows' milk. Offering creep feed before 3 weeks of age may not help piglets during the transition from milk-feeding to solid feeding, but certainly is necessary when weaning at a later age, e.g. 4 weeks old. Creep feed contains a high proportion of milk proteins and lactose, but also should contain other carbohydrate sources to induce amylase and maltase secretion and activity. Fat inclusion should be limited; if added fats with short-chain fatty acids such as coconut oil should be preferred. Such diets should contain at least 1.5% total lysine, 13.5 MJ ME/kg, 0.9% Ca and 0.5% available P and be fed until one or 2 days after weaning. After an initial set-back at weaning lasting 1 to 3 days, the piglets' feed intake and digestive capacity increases rapidly, so that the very expensive creep diet and be replaced by successively less complex diets with reduced nutrient contents. The aim for these diets is to gradually introduce the feedstuffs used in the growing-finishing period. When pigs reach about 20 kg *BW*, they are regarded as enzymatically competent, and can be fed regular feedstuffs. Such a phase-feeding regimen usually comprises 2 to 4 diets until the end of the nursery phase at approximately 25 kg *BW*. The last of these phase feeding diets should contain 1 % total lysine, 13 MJ ME/kg, 0.7% Ca and 0.32% available phosphorus.

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Biographical Sketches

Susan Novak was born in Edmonton, Alberta. She completed a B.Sc. degree in animal science in 1995, and Ph.D. in reproductive physiology in 2000, both at the University of Alberta in Edmonton, Alberta. She finished a post-doctoral fellowship in 2002 at Université Laval in Québec where she studied in vitro reproductive technologies in the pig. Since September 2007, she is with the Swine Reproduction-Development Program at the University of Alberta, Edmonton, Alberta as a Research Scientist.

Her main research interests are studying the nutritionally mediated effects on embryonic and fetal development in pig utilizing high-throughput technologies such as proteomics and microarrays to study gene and protein expression. Following her post-doctoral fellowship, she joined Alberta Agriculture, Food and Rural Development as an equine research scientist, aiming to improve reproductive technologies in horses. As the equine research scientist, she studied markers of stallion fertility using proteomics techniques and she also taught Equine Physiology and Nutrition at the University of Alberta. She often gave equine nutrition seminars to the industry in Alberta and was an invited speaker at the Horse Breeders and Owners Conference in 2007.

Dr. Novak is a member of the Society for the Study of Reproduction from 1999- present and a past member of the Equine Science Society and the International Embryo Transfer Society.

Soenke Moehn holds a Diplomagraringenieur 1989 and Doctorate of Agricultural Sciences (1994) from the University of Hohenheim, Stuttgart, Germany. From 1994 - 1998 he was a post-doctoral fellow at the Department of Animal and Poultry Science at University of Guelph, Guelph, Ontario. Since 1998 he has been a Research Associate at the Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta; Dr. Moehn is member of the American Society of Animal Science

Doug Korver received his B. Sc. Agriculture from the University of Saskatchewan in 1990. In 1993, he received an M. Sc. in Animal Science from the University of Delaware, and a Ph. D. in Nutrition from the University of California, Davis in 1997. He is currently an Associate Professor of Poultry Nutrition at the University of Alberta in Edmonton, Alberta, Canada. His areas of research include feed ingredients, nutrition-immune function interactions and bone metabolism in poultry. He is the author or co-author of over 30 peer-reviewed papers and 56 abstracts presented at scientific meetings. He has presented invited talks at scientific and industry meetings in 10 countries on 4 continents. Dr. Korver is a member of the Poultry Science Association, the World's Poultry Science Association and the Canadian Society of Animal Science.