NUTRITIONAL PATHOLOGY IN RABBITS: CURRENT AND FUTURE PERSPECTIVES

Deborah A. McWilliams, MSc

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Introduction

Nutritional pathology, or clinical nutrition, is a discipline that investigates nutritional origins of disease processes and the use of nutrients as pharmacologics. It is a discipline that recognizes the interaction and synergy of nutritional factors with an organism's physiology, psychology and environment. The purpose of this paper is to present current research and production information on nutritional pathology for rabbit growers that indicate prospective trends for the future of the grower rabbit industry.

Since the beginning of modern commercial rabbit production, the average morbidity and mortality rate has not dropped because, as health problems have been solved, health problems have developed. For example, before 1970, pasteurellosis, myxomotosis, coccidiosis and mucoid enteritis were primary concerns of commercial rabbit growers. Of those four health problems, only mucoid enteritis remains uncontrolled by husbandry, vaccine or feed additive today. However, after 1970, other health problems developed for commercial rabbit growers. These problems include colibacillosis (enteric colibacillosis), cecal impaction, enterocolitis and viral hemorrhagic disease (VHD). VHD can be prevented by vaccination, but the other problems remain a challenge in the rabbit industry.

Nutrition is an important factor in most of the current rabbit disease challenges. Rabbits have gut associated lymphoid tissue (GALT) that recognize foreign antigens (immune challenges) in ingested food. Fifty percent of a rabbit's lymphoid tissue is GALT and, in the rabbit, it is found in Peyer's patches, in the functional lymphoid appendix and in the sacculus rotundus. The ability of gut mucosal immune functions is dependent on adequate nutrition for nutrient absorption and replacement of gut cell loss inherent in effective GALT functions.

Nutrition is also an important factor for a rabbit's ability to cope with environmental and psychological stressors such as heat, cold and inappropriate husbandry practices. Adrenal glands, in the rabbit, control cecotrophy (ingestion of soft feces) and stress affects adrenal gland functioning. For example, increased stress results in increased adrenal activity that will slow or stop digestive processes important to cecotrophy. Cecotrophy provides a rabbit with vitamins, protein and volatile fatty acids (VFA's) that are essential to the nutritional status and the health of a rabbit. Research indicates that altering some dietary constituents in a rabbit's ration may compensate for the increased metabolic demand caused by stress.

In addition to a presentation of current research and production information on nutritional pathology for rabbit growers, several appendices are included with this paper. These appendices present information on nutrition and current research on the recommended nutritional indices for grower rabbits.

Stressed Rabbits, Symbiots and Opportunistic Pathogens

Stress, bacteria and protozoa are factors in the health of grower rabbits. Bacteria and protozoa can have a positive and a negative effect on rabbit health.

Stress. Stressors for an animal can be psychological and/or physical and the state of each will affect the state of the other. These stressors include heat, cold, housing, handling, nutrition, light and dark cycles and interaction – or lack of interaction – with conspecifics. Stress can also be "good stress" (e.g., exercise) or "bad stress" (e.g., fear).

"Bad stress" often results in a negative effect on the immune system that may result in an increased incidence of diseases like coccidiosis and mucoid enteritis (ME). The acquired immunity of stressed rabbits is weakened by stress and the effects are immunodepressive.

Heat stress results when the environmental temperature rises and the animal cannot physically compensate for the increased temperature. Heat-stressed rabbits often decrease, or stop, eating feed and this may result in weight loss, a slowed digestive process and/or diarrhea. Research indicates that heat-stress can be moderated if rabbits are provided with cold drinking water (not warm or room-temperature drinking water). For example, by providing cold water for pregnant does and fatteners, their weaning weight increased by 2.1% and the commercial weight at 67 days was improved by 4.8% (97g) because of an increase in feed ingestion despite the high environmental temperatures.

Trichobezars (hairballs, wool block) are masses of hair and ingesta in the stomach of mature rabbits on low fibre diets or on diets deficient in copper, protein or magnesium. Rabbits with trichobezars develop anorexia, become lethargic, lose weight and eventually stop producing cecotrophs and hard pellets. Trichobezars can also be caused by stress (stress trichobezoars) because of stress-associated hormonal secretions that slow digestive processes. Stressed rabbits may also "over-groom" or "barber" themselves or conspecifics. The ingestion of large amounts hair, combined with slower digestive processes, results in the formation of hairballs.

Opportunistic Symbiots and Pathogens. The gastrointestinal tract (GIT) of rabbits is both dependent on symbiotic relationships with bacteria and protozoa and attacked by bacteria and protozoa. Normal cecal contents in the rabbit include mostly bacteriodes (gram negative cellulolytic anaerobes) with small amounts of Clostridium sp, *Escheria coli* (*E.coli*) and *Streptococcus faecalis*. Symbiotic relationships with the bacteriodes are necessary to assist in the digestion of food, especially with a high fibre diet essential to maintaining the correct stomach and cecal pH of a rabbit. For example, a rabbit on a low fibre diet develops a change in GIT pH that will kill symbiotic bacteria, and the loss of the bacteria may result in an increase in pathogenic organisms like *Clostridia sp*. and *E. coli* that cause disease states in rabbits. Other opportunistic pathogens include coccidia like *Eimeria perforans (E. perforans), E. magna E. piriformis, E. intestinalis, E. flavescens, E. irresidua* and *E. media*. *E. coecicola* and *E. exigua* are also intestinal coccida but are not pathogenic.

The rabbit stomach normally has a very low (acidic) pH (1 to 2) that effectively kills pathogenic microorganisms. Weanling rabbits have a stomach pH of 5 to 6.5 and weanling diarrhea develops because this stomach pH is not acidic enough to destroy opportunistic pathogens. Weanlings, however, must go through this period of a higher stomach pH to allow the growth of symbiotic microbial populations in the gut.

Adequate fibre is an important nutritional factor in diseases caused by opportunistic pathogens. For example, 53% of rabbits on a low fibre diet developed diarrhea caused by *E. coli* compared to 22% of rabbits on a diet with normal fibre levels. There was also higher mortality in the fibre deficient group compared to the normal fibre level group. In the low fibre diet group, 33.3% of the rabbits died compared to 17.6% of the rabbits on a normal fibre level diet.

Nutritional Pathology Issues in the Grower Rabbit Industry

The primary nutritional pathologies reported in the current research literature include cecal impaction (and resultant enterotoxemia), colibacillosis, and ME. Each of these include diarrhea (watery feces) that results in dehydration and loss of nutrients. In rabbits, diarrhea can also be caused by stress (transportation, new hutch or cage, new people or animals, new sounds, time changes), lack of dietary crude fibre, high dietary protein and from mold.

Cecal Impaction

Normal functioning of the rabbit cecum is dependent on dietary fibre. Without sufficient dietary fibre, the proximal colon absorbs too much liquid and this prevents digesta particles refluxing back to the cecum. This results in a loss of nourishment for the normal bacteria in the cecum and allows growth of opportunistic pathogens.

Cecal impaction results when a decrease in dietary fibre increases retention time and there is a digesta build-up in cecum. The accumulated digesta is retained and a prolonged fermentation results that produces tympany (bloat). The pH of the cecum is also altered and destroys symbiotic bacteria and allows the growth of opportunistic pathogens like *Clostridium spiriforme* (*Clostridium spiriforme* proliferation) that result in enterotoxemia (carbohydrate overload of the hindgut or starch overload theory).

Obese rabbits, often on high carbohydrate diets, often develop enterotoxemia because the excess carbohydrates in the cecum change the normal acidic pH (1 to 2) to an alkaline pH (6+) favourable to the development of *Clostridia sp*. and *E. coli*. Research indicates that adding probiotics to the rabbits' drinking water may prevent the development of enterotoxemia.

Colibacillosis

Dietary fibre is again an important factor. Colibacillosis develops when there is a deficiency in dietary fibre and the gut pH is altered. It consists of mild to severe yellow diarrhea, anorexia and fever. Colibacillosis is a form of enteritis caused when *E. coli* multiply in the altered gut environment. Colibacillosis is often seen with intestinal coccidiosis and the two pathogens produce a virulent synergy and are more lethal together than alone.

Mucoid Enteritis (ME)

ME is also called mucoid enteropathy, epizootic enterocolitis, epizootic rabbit enterocolitis (ERE) and enteritis. ME is not considered to be a specific disease, but it is considered to be a syndrome response GIT impaction. Gram-negative bacterium, however, are associated with the syndrome. It is a pervasive problem in the grower rabbit industry and estimates are that 95% of breeding colonies have been affected. The syndrome is primarily found in growing rabbits between three and ten weeks of age and in lactating does. Depressing the immune systems of specific pathogen free (SPF) in research colonies is sufficient to produce the syndrome.

ME can be preceded by any sudden change in diet, overfeeding, high dietary carbohydrates, starches, low dietary fibre or stress. Dietary fibre is again an important factor. Rabbits with a dietary fibre of 18% to 20% of diet (10% of it as indigestible fibre) are least likely to develop ME.

The mortality of ME can range from 30% to 80% and clinical symptoms include depression, decreased feed intake, excessive thirst, abdominal distention, mucoid pellets and diarrhea. A post mortem usually finds a stomach distended from fluids and gas and mucus plugs in the small intestine and/or colon. The contents in the cecum are dessicated. Rabbits who survive ME develop antibodies to the syndrome and may become more resistant to ME.

Nutritional factors in ME are dietary excess protein (over 18%) and insufficient dietary fibre (under 10% crude fibre). For example, ME has been reproduced using intestinal samples from infected animals and it has also been reproduced from contaminated foods, contact with infected animals and contact with contaminated equipment (cages, feeders). The organism is robust and can survive temperatures as low as –20 degrees Celsius. Disinfection of all equipment, cages and materials, single batch management and sanitary isolation are essential to controlling the disease. Use of antibiotics will reduce symptoms, but the symptoms reappear when antibiotics are terminated.

The lowest mortality from ME was found in rabbits on a low energy (2350 kcal and 16% protein), high fibre (18% crude) diet.

APPENDIX A
Review of the Rabbit GIT and Current Applicable Research

Rabbits chew with 120 jaw movements per minute and food is broken into minute particles. Cecotropes, however, are consumed whole and remain intact in the stomach for several hours because the mucus-like membranes around the cecotropes remain intact for six hours after ingestion.

The rabbit is both a foregut and hindgut fermenter. Its stomach is a storage organ from which ingesta moves into the small intestine about three to six hours after eating. It is a storage organ (foregut fermenter) because the normal rabbit stomach is never completely empty and will be half full even after a 24 hour fast.

The rabbit small intestine and its three functional areas (duodenum, jejunum and ileum) is a major source of digestion and absorption. Acid material from the stomach is neutralized and mixed by muscular action with bile and pancreatic secretions. The major components of bile are bile acids (bile salts) and bile pigments. Bile acids are important for fat and vitamin absorption. Bile pigments are converted by microbial action into several compounds called urobilinogens that colour feces and urine. In the rabbit, for example, a reddish-orange colour to the urine might be associated with bile pigments. The pancreas is the source of major digestive enzymes and alkaline secretions to neutralize stomach acid. Volatile fatty acids (VFAs) are the primary substance created and absorbed in the intestines.

As a hindgut fermenter, the digestive strategy of the rabbit is to eliminate fibre from the gut as rapidly as possible and use digestive processes for the nonfibre components. Muscular contractions in the colon separate fibre particles from nonfibre feed components. Then, peristaltic contractions move the fibre particles through the colon for excretion as hard feces. An antiperistaltic action moves fluids and small particles into the cecum where they are fermented for two to twelve hours. The fermentation process involves symbiotic bacteria (bacterial enzymes) and the product of this fermentation is moved into the colon.

If the cecal contents enter the colon in the morning, pellets are formed by colon contractions and enveloped in mucus and become cecotrophs (soft pellets) that are excreted and are ingested about one hour after formation. By the end of the morning, about ¾ of the stomach contents are cecotrophs and are digested.

Cecotrophs consist of food residues and bacteria with high-value proteins (bacterial proteins). As a food source, cecotrophs provide watersoluble vitamins like B vitamins necessary for metabolic activity (energy use, or use of nutrients) and necessary for the effective functioning of red blood cells (oxygen transport). Cecotrophs also have vitamin K coagulation factors. The B vitamins include B1, B2, B6, B12, and pantothenic acid.

The cecotrophs form eight to twelve hours after the last meal of rationed animals or after the peak intake of ad lib animals. Cecal contents that enter the colon later in the day, or night, become hard pellets and are excreted as waste. Any remaining liquid and small particles (< 0.1mm) are returned to the cecum.

A major importance of ingesting cecotrophs is related to protein reutilization. Cecotrophs contribute to dietary crude protein and the highest available crude protein occurs in cecotrophs formed by rabbits on low digestibility by-products. Some research indicates that cecotrophs are a good source of essential amino acids like the sulphur containing amino acids (e.g., methionine) and lysine and threonine. The proportion of microbial protein with respect to total protein of soft feces varies with a rabbit's diet. Cecotrophy could overcome poor quality protein or low dietary vitamins in normal rearing conditions, but not in intensive rearing (meat production).

Young rabbits, before eight weeks of age, have a sterile hindgut because of the antibacterial action of rabbit milk. They also have a high stomach pH (alkaline or 5+) that does not neutralize ingested bacteria so bacteria is allowed to colonize the cecum. A young rabbit should have sufficient intestinal and cecal bacteria for digestion about two weeks after weaning. Weaning stress, physical and psychological, can be reduced by putting the doe and her kits on grower ration at 18 days. This method often reduces the incidence of mastitis because the doe completely dries before the next litter. The doe is put back on breeder ration when the kits are weaned.

Before eight weeks of age, young rabbits cannot digest starch because their pancreas is immature and pancreatic enzymes normally digest starch in the small intestine. Prior to eight weeks, starch moves undigested into the cecum where it can be fermented by Clostridium spiriforme.

APPENDIX B
Current Rabbit Nutrition Recommendations: Digestible Energy, Crude Protein, Amino Acids

Table 1. Recommended Digestible Energy, Crude Protein and Amino Acids for Grower Rabbit of Different Ages and Reproductive Status (based on a feed of 89% Dry Matter - DM)

Component	Growing Rabbits (4 to 12 weeks)	Lactating Does and kits before weaning	Pregnant Doe	Males	Fatteners and non-pregnant does
Digestible energy (DE)	2500 Kcal/kg	2600 Kcal/kg	2500 Kcal/kg	2100 - 2200 Kcal/kg	2500 Kcal/kg
Crude protein (CP)	15%-18%	16% - 20%	15% - 20%	12%- 15%	16-17%
Amino Acids:					
Methionine and cystine	0.6%	0.6%	*	*	0.6%
Lysine	0.65%	0.75%	*	*	0.7%
Arginine	0.9%	0.8%	*	*	0.9%
Threonine	0.55%	0.7%	*	*	0.6%
Tryptophane	0.18%	0.22%	*	*	0.2%
Histidine	0.35%	0.43%	*	*	0.4%
Isoleucine	0.6%	0.7%	*	*	0.65%
Phenylalanine + tyrosine	1.2%	1.4%	*	*	1.25%
Valine	0.7%	0.85%	*	*	0.8%
Leucine	1.05%	1.25%	*	*	1.2%

*indicates dietary levels not established.

Crude Protein: Crude protein is a measure of the nitrogen content and is used to estimate amino acids. A protein is formed of amino acids and all amino acids contain nitrogen. Amino acids are approximately 16% nitrogen and other dietary factors may contain nitrogen. The major digestible fraction of dietary crude protein is digested before ingesta reaches the cecum. Cecotrophs contain bacterial proteins (protein produced by bacteria).

Hay: There are large variations in essential amino acid digestibilities for hays depending growth conditions and time of harvest. There are also various kinds of hay, but grass hay is best for both a protein and fibre component of a rabbit's diet. Alfalfa is often included in commercial rations and should not be used as a supplement.

Table 2. Approximate Protein, Fibre and Calcium Compositions of Some Hay

TYPE	PROTEIN	FIBRE	CALCIUM
Alfalfa	16%	28%	1.5%
Grass hay	14%	31%	0.4%
Timothy	8%	30%	0.5%
Wheat straw	3%	35%	0.2%

Plant Proteins: There are two types of plant proteins: seed proteins and leaf proteins. For legumes and oil seeds (seed proteins), soluble proteins like albumins and globulins are found in high proportions. Leaf proteins (insoluble proteins) are found in the cell cytoplasm of the leaves of forage plants. The major proportion of leaf proteins are separated from the cell wall by a membrane and is not as digestible as seed proteins unless the animal's GIT can digest the membrane. Plant protein values can be limited by antinutritive factors like trypsin inhibitors, lectins, tannins and fibrous material if the plant is not processed.

Protein: A protein is an enzyme and it is an essential component of animal tissue. For example, blood proteins transport nutrients and regulate fluid balance, cell membranes contain proteins and, the immune system is based on proteinaceous antibodies. Hormones are also proteins or protein derivatives.

Essential proteins are isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. They are called essential because their carbon skeleton cannot be synthesized by some animals. The nutritive value of a protein is determined by its amino acid composition (chains of) and its digestibility (the proportion of ingested protein digested in the gut and absorbed as free amino acids). In rabbits, the main factors in protein digestibility are chemical structure, property (insoluble proteins are more resistant to digestion) and accessibility to enzyme activity.

APPENDIX C
Current Rabbit Nutrition Recommendations: Fibre and Fats

Table 3. Recommended Fibre and Fat Compositions for Grower Rabbit of Different Ages and Reproductive Status (Feed is 89% dry matter - DM)

COMPONENT	GROWING RABBITS (4 TO 12 WEEKS)	LACTATING DOES AND KITS BEFORE WEANING	PREGNANT DOE	MALES	FATTENERS AND NON-PREGNANT DOES
Crude Fibre	10%-16%	10%-14%	10%-14%	14-20%	14%-16%
Fats	2%-4%	3%-5.5%	3% - 5.5%	1% - 3.5%	2%-4%

FIBRE

Crude Fibre (Acid detergent fibre; ADF): Crude fibre is often called fibre or roughage. It is a mixture of cellulose, lignin, cutin and suberin. The digestibility of crude fibre varies from 60% to 80%. There is nonfibrous (soluble) and fibrous (insoluble) fibre. Nonfibrous includes starches and sugars that are quickly metabolized. Fibrous refers to plant fibre that is not as digestible or quickly metabolized.

Fibre degradation in the rabbit GIT depends on microbial activity, digesta retention time in the cecum and fibre chemical composition. Fibre degradation is not significantly affected by dietary level of fibre because the quantity of fibre **entering** the cecum is not a limiting factor for the microbial fermentation processes. The dietary level of fibre **is** important to the rabbit GIT functions. Digesta retention time in the cecum is normally relatively short and predominately allows for degradation of more easily digestible fibre fractions like pectins or hemicelluloses (soluble fibres). Retention time in the cecum, however, will increase proportionally to the reduction of the dietary fibre intake because the cecum attempts to compensate for the fibre deficit. An increase in dietary fibre increases the rate of passage (decreases retention time) in the GIT (cecum included).

The formation of cecotrophs require fibre to prevent ingesta becoming mostly liquid and pushed back into cecum. This would create a cecal bacterial imbalance and would result in a loss of nutrients. On a low fibre diet, 9.4% of dry matter (DM) intake became cecotrophs. On a diet higher in fibre, 11.7% of dry matter (DM) became cecotrophs.

For rabbits, high fibre, low protein diets encourage cecotrophy and prevent obesity. High fibre diets also take time to eat (provide occupation) and reduces boredom and stress. The recommended dietary fibre levels are 18% to 20% of the diet and 10% of it should be crude indigestible fibre (fibrous or insoluble). Many feeds will only have 5.7% to 14% fibre and hay should be included as a supplement to many feeds.

Research on fibre indicates that a high fibre diet results in 70g more live weight at 49 days and at 72 days compared to rabbits on low fibre diets. This is because the animals were less likely to develop nutritional pathologies and more nutrients were available by digestive processes. An increase of dietary level of fibre also increases feed intake and soft feces production (cecotrophe) that increases the available protein and allows higher weight gain.

Research also indicates that **excessive** dietary fibre alters the digestible energy content of the feed. If the result is a dietary protein level higher than the digestible energy (DE), there will be an energy deficit and a protein surplus. The effect of a protein excess is to promote the excessive growth of proteolytic digestive flora that produces ammonia and creates further GIT imbalances. For growing rabbits, more than 16% fibre reduces digestible proteins and will create an energy deficit.

Dietary Fibre: In animal nutrition, dietary fibre refers to the total amount of non-starch polysaccharides (NSP) and lignins (compounds hydrolysed only by bacterial enzymes). Or, in other words, it is the total soluble and insoluble dietary fibre. The dietary fibre in commercial rabbit feed may range from 150 to 500 g per kg feed. Determining the fibre content of a compound feed or raw material is highly variable depending on the analytical method of estimation.

Pectic substances are a soluble fibre and is found in young tissues of dicotyledonous plants such as legume seeds (soybean, pea, faba bean, white lupin) and in fruits and pulps. These pectic substances includes several classes of polymers including pectins (rhamnogalacturonan, arabinose, galactose) and neutral polysaccharides (arabinans, galactans,saccharides).

Cellulose, an insoluble fibre, is the most abundant polymer on earth. It is only degradable in strong acid solutions (e.g., 72% sulphuric acid). Levels of cellulose vary from 400g to 500 g DM per kg in the hulls of legumes and oilseeds; 30 to 150 g per kg DM in oilseeds or legume seeds; 100 to 300 kg DM in forages and beet pulps; and, 10 to 50 g in cereals except for oats which is 100g per kg DM.

Hemicellulose refers to xylose, mannose and glucose bonded with cellulose. Hemicellulose is found in the primary cell wall of dicotyledonous plants (vegetables, seeds). The level of hemicellulose s about 100 to 250 g/kg DM in forages and agro-industrial by-products (brans, oilseeds, legume seeds, hulls, pulp) and 20 to 200 g/kg DM of grains and roots.

Particle size: A factor in the fibre requirements of rabbits is related to the effect of large size fibre particles on the passage rate through the gut. Research indicates that the most effective fibre fraction to promote transit time in the rabbit is longer than 0.3mm. For example, cellulose tends to produce larger and thinner particles than lignin. Particles of different size in the same feed means the fibre composition is not homogenous among the particles of different size. For example, the larger particle size, the more lignin. Lignin (fibrous or insoluble) is a non-saccharidic polymer of the cell wall that excludes water and makes the cell wall more rigid and resistant to various agents like bacterial enzymes. Feed manufacturing also reduces fibre particle in successive millings even when using sieves of the same diameter.

FATS

Lipids (Fat): Lipids (fats) refer to triglycerides. Triglycerides are the only lipid of nutritional importance because they are the highest energy-yielding component of feed (2.25x more than protein or carbohydrates). The nutritive properties of triglycerides depend on the fatty acid characteristic (a chemical nature: the number of carbon atoms and the number and position of unsaturated (double) bonds). For example, essential fatty acids are:

a) **C18:3,n-3 (linolenic acid):** Needed for the synthesis of C20:5,n-3 (eicosapentaenoic acid) which is a precursor for several compounds essential for heart, retina, brain functions and immune functions.
b) **C18:2,n-6 (linoleic acid):** Essential for the synthesis of arachidonic acid (C20:4,n-6) which is a precursor of prostaglandins and prostacyclins (reproductive function) and thromboxanes (homeostasis function).

The essential fatty acids required by rabbits are small amounts of n-3 and n-6 that are normally included in compound feeds.

Fat digestion, in the rabbit, occurs only in the small intestine where emulsification occurs by bile salts secreted by the liver and pancreatic lipase. The result is free fatty acids (directly absorbed into blood) and medium- to long-chain fatty acids and monoglycerides that are absorbed by microvilli in the duodenum and jejunum. Fat absorption is a passive (non-energy consuming). Some of the long-chain fatty acids can be directly incorporated into fat tissue meaning dietary fat can significantly affect the fat component of the rabbit carcass.

Research indicates that the use of high fat diets for does could improve the DE intake and milk yield of lactating rabbits and increase litter weight. Results indicate that a high fat diet for does will not affect body condition.

Volatile fatty acids (VFAs): VFAs are the main product of carbohydrate microbial fermentation and, in the rabbit, VFAs are rapidly absorbed in the hindgut and provide an important source of energy for the rabbit.

APPENDIX D
Current Rabbit Nutrition Recommendations: Minerals

Table 4. Recommended Dietary Mineral Concentrations for Grower Rabbits of Different Ages and Reproductive Status (Feed is 89% dry matter - DM)

MINERAL	GROWING RABBITS (4 TO 12 WEEKS)	LACTATING DOES AND KITS BEFORE WEANING	PREGNANT DOE	MALES	FATTENERS AND NON-PREGNANT DOES
Calcium	0.4%	1.10%	0.80%	0.40%	1.10%
Phosphorus	0.3%	0.5%-0.8%	0.37%-0.5%	0.3%	0.3% - 0.8%
Potassium	0.6%	0.9%	0.9%	*	0.9%
Sodium	0.3%	0.3%	0.3%	*	0.3%
Chlorine	0.3%	0.3%	0.3%	*	0.3%
Magnesium	0.03%	0.04%	0.04%	*	0.04%
Sulphur	0.04%	*	*	*	0.04%
Cobalt	0.1 ppm	0.1 ppm	*	*	0.1 ppm
Copper	5.0 ppm	5.0 ppm	*	*	5.0 ppm
Zinc	50.0 ppm	70.0 ppm	70.0 ppm	*	70.0 ppm
Iron	50.0 ppm	100.0 ppm	50.0 ppm	50.0ppm	100.0 ppm
Manganese	8.5 ppm	2.5 ppm	2.5 ppm	2.5ppm	8.5 ppm
Iodine	0.2 ppm	0.2 ppm	0.2 ppm	0.2ppm	0.2 ppm
Fluorine	0.5 ppm	*	*	*	0.5 ppm

ppm = parts per million; a measure of concentration; 1 in 1,000,000 or mg/liter
*indicates dietary levels not established.

Calcium (Ca): The rabbit has two important differences in calcium metabolism than other mammals:

1. Ca is absorbed in direct proportion to its concentration in the diet regardless of metabolic needs. This means blood levels of Ca will rise with increasing dietary intakes of Ca. In other mammals, plasma calcium is regulated by dietary vitamin D and parathyroid hormone.
2. Rabbits excrete excess Ca through the urine (kidneys). The continuous filtration of excess Ca by the kidneys may form crystals and bladder and kidney stones that might damage the organs and result in red pigmentation in the urine. Long-term feeding of excess Ca (> 40g/kg DM) may calcify soft tissues.

Does in late gestation and early in lactation may have a drop in plasma Ca, P and magnesium (Mg) levels and will develop milk fever (hypocalcemia). The symptoms are loss of appetite, tetany, muscle tremors and ear flapping. Prolonged Ca deficiencies will result in osteoporosis. A prolonged excess in Ca will impair zinc (Zn) and P absorption in the rabbit.

Chromium: Research indicates that chromium supplementation does not induce any significant differences in daily weight gain, feed to gain ratio, hot carcass weight, dress-out percentage or meat/bone ratio. Chromium supplementation, however, did increase perirenal fat because chromium modifies lipid anabolism.

Copper: Copper exists in rabbit feed as cupric sulphate at 4 to 30 mg/kg. It is important in reducing enteritis and increasing weight gain in young stock.

Macrominerals: Macrominerals are needed by rabbits in relatively large amounts for the growth and maintenance of bone structure, muscle contractions, cellular nutrient absorption and salt balance. The macrominerals for rabbits are calcium, phosphorous, magnesium, potassium, sodium and chlorine.

Magnesium (Mg): In rabbits, an Mg deficiency results in poor growth, alopecia, hyperexcitability, convulsions, loss of fur texture and fur chewing. Any dietary excess of Mg is excreted through the urine. Mg is usually available in sufficient quantities in commercial rabbit feeds.

Microminerals: The essential microminerals (trace minerals) are needed by rabbits in amounts relatively small compared to macrominerals. They are used as part of, or activators for, enzymes. These microminerals include copper, iodine, iron, manganese, and zinc.

Mineral: A mineral is an inorganic substance.

Phosphorus (P): For rabbits, dietary phosphorous does not affect growth rate or the feed conversion ratio. However, diets low in Ca and P will cause rickets in young rabbits. In adult rabbits, low dietary Ca and P can cause osteomalacia, lack of fertility and abnormal behaviour.

Sodium (Na): Na regulates cellular pH and osmotic pressure and concentrates in plasma outside of cells. Although Na requirements for rabbits have not been established, research does indicate that excess Na in the form of salt can stunt growth.

APPENDIX E
Current Rabbit Nutrition Recommendations: Vitamins

Table 5. Recommended Dietary Vitamin Concentrations for Grower Rabbits of Different Ages and Reproductive Status (Feed is 89% DM)

VITAMIN	UNIT	GROWING RABBITS (4 TO 12 WEEKS)	LACTATING DOES AND KITS BEFORE WEANING	PREGNANT DOE	MALES	FATTENERS AND NON-PREGNANT DOES
A (or beta-carotene 30 ppm)	UI/kg**	6,000	12,000	12,000	6,000	10,000
D	UI/kg	800-1,000	800-1,000	800-1,000	800-1,000	800-1,000
E	ppm	50	50	50	50	50
E	Mg/kg	50	50	50	50	50
K	ppm	0	2	2	0	2
C	Ppm***	0	0	0	0	0
B1	ppm	2	*	0	0	2
B2	ppm	6	*	0	0	4
B6	ppm	2	*	0	0	2
B12	ppm	0.01	0	0	0	0.01
Folic acid	ppm	5	*	0	0	5
Pantothenic acid	ppm	20	*	0	0	20
Niacin	ppm	50	*	*		50
Biotin	ppm	0.2	*	*		0.2

*indicates dietary levels not established
**UI/kg = International Units (IU) per kilogram. It is the quantity of a biologic (e.g., a vitamin) that produces a biological effect and is agreed upon by international standards. IU refers to the potency of a biologic based on weight. Weights of biologics differ. For example, 1,000 IU of vitamin C has a different weight that 1,000 IU of vitamin A and these weights may differ among manufacturers.
***ppm = parts per million; a measure of concentration; 1 in 1,000,000 or mg/liter

Fat Soluble Vitamins: Fat soluble vitamins include vitamins A, D, E and K. Fat soluble means that dietary excesses are stored in fat cells and prolonged dietary excesses can result in toxic levels of the vitamin. Vitamins A, D and E are in pelleted rations but have a shelf-life of only three months.

Vitamin A: Vitamin A is important for reproductive performance and coat quality. A deficiency in vitamin A (hypovitaminosis A) can result in reduced fertility, congenital abnormalities, fetal resorption, abortion and thin, weak newborn kits. It can also cause lesions on the cornea and conjunctiva.

Hypervitaminosis A can result in reduced fertility, congenital abnormalities, fetal resorption, abortion and thin, weak newborn kits. In addition, it may cause perinatal mortality and congenital defects like hydrocephalus. Alfalfa is usually high in vitamin A and, if fed with pellets, may cause hypervitaminosis A.

Vitamin C: Research indicates that dietary supplementation of vitamin C at 25 to 30 mg per rabbit per day can help with stress situations including heat stress. Italian rabbitries successfully used vitamin C at 250mg/L in the drinking water for the first two weeks after weaning to reduce the affects of weaning stress. Vitamin C supplementation has also been found to reduce the virulency of respiratory disorders in rabbits and and it may prevent enterotoxemia by inhibiting toxin production if supplemented at 50 to 100 mg/kg daily per rabbit.

Dietary supplementation of vitamin C at 2g/kg did not affect body weight or the semen quality of male 22 weeks old rabbits.

Vitamin D: Rabbits are very sensitive to vitamin D toxicosis and adults are more susceptible than younger rabbits. Hypervitaminosis D causes anorexia, weight loss and infertility. It also increases Ca absorption in the intestine, increased renal tubular resorption, increased bone resorption and, soft tissue mineralization.

Vitamin E: Vitamin E is important for removing oxidizing agents from cell membranes. This improves cellular function and longevity. Hypovitaminosis E can result in reproductive failure and myopathy (muscular dystrophy and hind leg paralysis in young rabbits) from increased blood creatine phospokinase that damages muscle. Symptoms of hypovitaminosis E will develop if the dietary level for rabbits is less than 16 mg/kg per rabbit daily. Hepatic coccidiosis will deplete an animal's levels of vitamins A and E.

Dietary supplementation of vitamin E at 440 mg/kg of a ration did not affect body weight and semen quality of male 22 week old rabbits.

Vitamin K: In rabbits, an excess of vitamin K (hypervitaminosis K) can cause nephritis if supplemented at a level of 8g/Kg. Hypovitaminosis K, a deficiency in dietary vitamin K, can result in muscle weakness, paralysis and respiratory distress. Feed ingredients like soybean meal, Lucerne hay and molasses are rich in vitamin K

Vitamins: Vitamins are organic and are composed of carbon and hydrogen. Vitamins have important roles in metabolism.

Watersoluble Vitamins: Watersoluble vitamins are B and C. Water soluble means that dietary excesses are excreted in the urine.

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***Excellent reference books.**