Classical Horse Training

Combining art with science to achieve balance and harmony

BASIC NUTRITION & EXERCISE PHYSIOLOGY

''the horse as an superior athlete''

MANUAL

Foreword

This document is the result of many years of research and personal experience worldwide. I sincerely hope that it will be useful to your personal learning experience and contribute to your personal training and development. I wish you a lot of fun and lightbulb moments diving into these materials.

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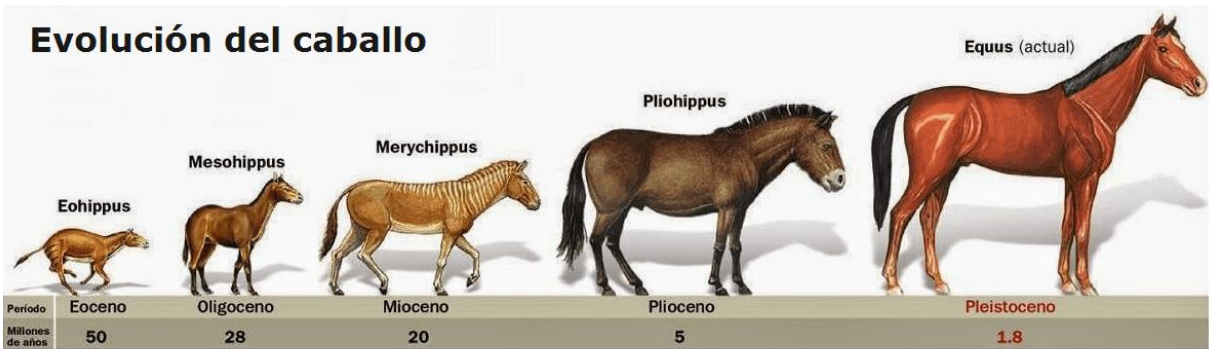
INTRODUCTION

Horses have been critical to mankind for as long as we can remember. Society as we know it has been shaped on horseback. It is due to their superior athletic capability that they enabled us to travel long distances, to help ploughing our fields and to conquer land. Today, their athletic potential is mainly used for purposes of leisure activity or (top)sport. This change in use throughout history has led to various physiologic adaptations that allow the horse to function optimally within its environment. As a result, horses have changed from more worker type of animals into lean and slim looking athletes.



Considering the horse as an athlete falls within the study of physiology. But what is physiology really? According to the dictionary, physiology can be defined as:

> *''The scientific study of function and mechanisms in a living system. As a sub-discipline of biology, physiology focuses on how organisms, organ systems, individual organs, cells and biomolecules carry out the chemical and physical functions in a living system.''*

Thus, where equine biomechanics is concerned with the study of movement and the forces and torque that cause this movement, the field of equine physiology is concerned with studying the horse more in terms of internal and cellular processes that enable activities – such as muscle contraction and brain function – in the horse.

In terms of training, the horse shows some unique physiologic adaptations to exercise which makes it difficult to apply findings from human physiology directly to the horse. This raises the question: *can horses be trained on the basic of the principles by human athletes?*

Furthermore, the study of physiology includes equine energetics, which looks at the energy needs and metabolisms of the horse as well as how to optimize energy levels and thus performance. Since the horse acquires potential energy sources through its diet, the study of physiology is closely related to nutrition. I will therefore divide this manual into two separate, but closely related sections:

- Part 1: Basic Equine Nutrition
- Part 2: Basic Exercise Physiology

In the first section I will elaborate on the nutrient requirements of horses. In the second part I will elaborate on the physiological processes in the horse that enable performance and connect the dots on the role of nutrition in these processes.

Altogether, this manual aims to explain on the basic physiologic processes inside your horse. It will give you an even deeper understanding of your horse inside out as well as the knowledge to optimize your training and how to reach your goals.

PART 1: BASIC EQUINE NUTRITION

Studying equine nutrition in relation to overall health as well as performance is quite complex. Especially the latter topic is subjected to limitations:

> *''Scientific data on the relationship between nutrition and equine performance has occupied the attention of many researches in recent years; however, it is difficult to design controlled experiments that only isolate nutritional influences on performance. Subtle, yet important effects of nutritional alterations may go undetected, partly because the power of statistical studies is limited by the small numbers of horses often used in experiments.''* – Hintz 1994

Although science has greatly evolved, the field of nutrition still remains complicated. However, since the horse spends the majority of its time eating, a basic understanding of nutrition is key to all horse carers.

In short, a proper feeding schedule needs to balance three key elements:

- Nutrients
- Rations
- Timing

First of all, the horse's nutrient requirements need to be met to avoid deficiencies or toxicities with all consequences thereof. With so many different opinions and feed choices available today, many people find themselves wondering what nutrition a horse needs for good health and optimal performance. To help you see the '*trees through the forest'*, I will share insights that have received most consensus from scientific and empirical research.

Second, the portion sizes need to be considered to control and/or optimize the horse's calorie intake. It might be helpful to measure your rations either with a food weighting scale or a simple measure cup.

The most important principle regarding ratio is that you need to feed according to (desired) bodyweight and workload. For example, an average 500kg horse in hard work will burn nearly twice as many calories a day as a horse who weighs the same but is ridden lightly twice a week.

Third, timing also play a role. Using logic, it is not desired to feed a heavy meal just before exercise. On the opposite, the horse also doesn't have sufficient energy when it is asked to perform on a completely empty stomach. Especially on multiple day events the timing of feeding is important in order to replenish depleted energy sources such as glycogen so the horse can start with full energy reserves the next day.

In the coming chapters I will explain all the nutrients your horse needs for basic functioning and how to select products that meet these requirements. It is required by law that horse feed manufacturers put the nutritional composition of the product (apart from hay) on a ''feed tag'' which is either attached to or printed directly on the package. This information can be used to determine whether your horse's nutritional requirements are being met by the products you are using. As such, I will help you to understand how to read the feeding tags so that you can make an informed decision. Later on, I will also elaborate on dietary considerations in relation to performance.

Finally, before getting into it, I want to stress out that is always advised to call upon a specialized equine nutritionist or herbalist to assist you in your choices.

Now let’s go!!

NUTRIENT CATEGORIES

When feeding horses, it is important to recognize the six basic nutrient categories that must be met:

- Water
- Carbohydrates
- Fat
- Protein
- Vitamins
- Minerals

The first three categories of *carbohydrates, fat and protein* make up for what is commonly referred to as the **macronutrients** that supply the body with energy. For this reason, the body requires these nutrients in relatively large amounts.

Micronutrients on the other hand consists of *vitamins and minerals* and are not needed in the same quality as macros, but are still equally important. Micronutrients work in tandem with macronutrients to keep the body functioning and are crucial in order to maintain energy levels, metabolism, cellular functions, and physical and mental well-being.

In the coming chapters, I will elaborate on each of these nutrients and the horse's needs.

MACRONUTRIENTS

WATER

It is fair to say that water is the most important nutrient as horses can't live long without it. Water is extremely important in the digestive process to avoid colic, dehydration and other life threatening conditions. A horse deprived of water might only live 3-6(!) days.

An average 500kg horse drinks somewhere between 30-50 litres of water a day. This could increase depending on temperature and workload. Pregnant mares also need more water for milk production.

The two main reasons why a horse needs so much water are:

- Physiology of the digestive tract
- Temperature regulation

The high fiber diet of horses needs water to help keep the fibre moving through the system. A lack of water can result in colic.

Second, horses use the process of sweating to cool down. This requires large amounts of water. A lack of water could result in dehydration and are unable to control their internal temperature to normal levels.

A horse always needs free access to clean water. If water is contaminated with dirt, algae or faeces they could potentially become ill. Remember that a horse cannot vomit. As such, once the water is ingested it needs to pass right through the system – no matter how bad the quality is.
As such, always provide your horse with unlimited access to free water. Clean your water buckets regularly and add salt in warmer temperatures.

CARBOHYDRATES

Carbohydrates will most likely make up the largest part of the horse's diet. They serve as a main fuel source that gives the horse energy and assists in regulating its body temperature. Although fat produces about twice as much energy as carbohydrates, the body cannot use it without the presence of oxygen produced by aerobic work i.e. endurance type of work. This leaves carbohydrates – in particular, sugar and starch as glycogen – as the source of immediately available energy for anaerobic work i.e. speed like activities, when the body can't use fat.

Metabolically speaking, using glycogen is the quickest and most efficient way to fuel muscle contraction, and blood glucose is the quickest energy for all essential energy needs such as respiration, digestion and brain function. More importantly, the body doesn't require oxygen to use glycogen for energy.

Carbohydrates can be divided into two groups:

- Structural
- Non-Structural

Structural carbohydrates consists of fibre and are mostly ingested through the roughage that the horse eats, i.e. hay and/or grass. Fibre is made up of complex carbohydrates and the horse's digestive system needs it to function properly. Following digestion in the stomach and small intestine, the digestive material enters the large intestine – consisting of the cecum and colon [hindgut]. The hindgut contains a delicate balance of proper population of microorganisms [bacteria and protozoa] that are capable of breaking fibres down into an energy source that the horse can absorb. This explains why horses get so much nutritional value from hay and grass.

Feed	Calories Per Pound
Green Pasture	245
Orchard Grass Hay	872
Alfalfa Hay	977
Timothy Hay	804
Alfalfa Pellets	970
Corn	1,536
Premium Oats	1,250
Beet Pulp	1,059

Besides contributing to daily energy requirements, fiber supports a healthy microbial population in the hindgut and helps prevent colic, gastric ulcers, hindgut acidosis, and unwanted behaviours such as cribbing or stall-walking. However, researchers have yet to quantify a specific fiber requirement for horses.

Although a specific fiber requirement has not yet been established, ideally the horse should be fed between 1.5-2.5% of its body weight in forage per day. For an average 500kg horse at rest this would be a minimum of 7,5-10 kg dry matter per day. When the horse has to perform heavy exercise, it could increase to 12,5kg of dry matter per day. Apart from exercise, the horse's requirements are also dependent on the yearly seasons. For example, during winter months, a horse naturally should become more skimpy. Although today it is quite popular to promote 24/7 access to forage, it needs to mentioned that horses in the wild do not have this luxury. On the contrary, they often need to travel quite some distances to get to the next food source. As such, not all horses do well on 24/7 access. For some, this can even lead to obesity. As long as the feeding intervals do not extend beyond 3-5 hours to prevent acidity, rationing of forage could help to maintain your horse's ideal bodyweight.

In case the horse doesn't have sufficient access to forage, or when extra calorie or fiber intake is desired you can choose to add by-product fiber sources to the diet. Manufactured fiber sources include *beet pulp, bran and grain hulls.* Beet pulp is very popular due to its digestibility and palatability. Several studies have shown that a horse can consume up to 55% of beet pulp in the diet without negative effects. However, since the digestibility of beet pulp is much higher than most grass hays, you should take into account that the diet has to be sufficiently balanced when adding beet pulp to the diet.

Beet pulp is higher in calcium and as such could also be used to balance traditional grains that tend to be low in calcium and high in phosphorus levels (see chapter on minerals). Furthermore, beet pulp has a lower level of potassium than most grass hays and thus is a safe feed for horses with HYPP.

However, keep in mind that beet pulp is a fortified feed. Therefore, supplementation of vitamins and minerals is needed to balance the diet.

Apart from beet pulp, brans are another option but less desirable due to their high phosphorus concentrations. Furthermore, they contain a lot of fat which is not beneficial for all horses.

Altogether, it is important to remember that these fiber by products are only fermentable fiber sources and thus they should be fed alongside hay. Thus, these products can be used to stretch forage rather than replace it.

Table 1. Nutritional composition of selected feedstuffs
(All values on a 100% dry matter basis)

Item	Beet Pulp	Legume hay	Grass hay	Oats
Dry matter, %	91.6	90.9	92.0	90.1
Crude protein, %	9.4	21.3	10.9	12.6
Starch, %	1.1	1.8	2.1	43.5
Non structural carbohydrates, %	11.8	11.0	12.9	48.7
Acid detergent fiber, %	26.1	30.5	39.0	13.3
Neutral detergent fiber, %	41.7	38.8	62.9	27.1
Energy, Mcal/lb	1.199	1.193	0.909	1.521
Calcium, %	0.96	1.52	0.51	0.12
Phosphorus, %	0.09	0.27	0.24	0.39

Source: Equi-Analytical Laboratories, http://www.equi-analytical.com/CommonFeedProfiles/default.asp

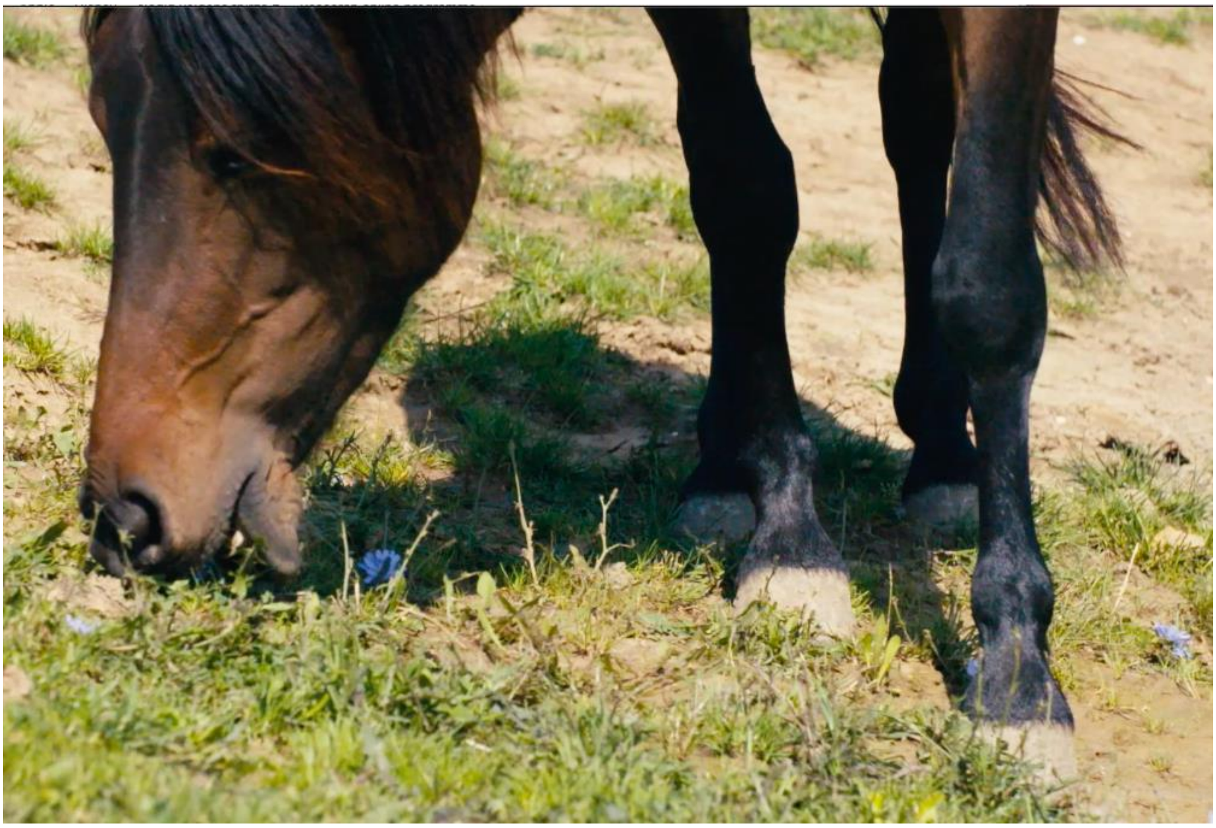
Non-structural carbohydrates consists of simple sugars, starches and fructan. Much has been written about sugar levels in feeds and roughage as they play an important role in equine health. Hence, we need to dive in a little bit deeper.

The first two non-structural carbohydrates of **simple sugars and starches** are mostly found in grains and provide a more concentrated form of energy than structural carbohydrates. They are easily digested and absorbed in the upper intestinal tract.

Although most horse owners somewhat fear sugars and starches, it must be said that they are in essence not all bad. In fact, they are necessary to a certain extent for proper brain and muscle function. Sugar and starch are stored as muscle glycogen which provides an important energy source for anaerobic work (to be explained later) – when the horse can't use fat. When exercise intensity increases, the horse relies on glycogen and thus starches and sugars to provide a vast fuel source. Furthermore, sugars and starch are just as important after exercise in replenishing muscle glycogen levels.

Unfortunately, daily requirements for sugars and starches in the horse have not yet been established. Furthermore, sugar and starch content can vary greatly between grasses and hays and almost all processed feeds contain 'hidden' sugars. Just as in humans, an overload of sugars has been linked to many health concerns in horses and thus sugar and starch intake should be closely monitored. I will explain this more into depth in the next section, but first we also need to consider fructan, which is a bit of a different story.

Fructan is a type of carbohydrate that plants accumulate and store for energy. Fructan is commonly found in certain types of grasses and hays, and the content varies immensely. It usually can be found in high levels in cool-season grasses such as timothy, orchard grass, brome and ryegrass.



Fructan is a bit different because although it is a non-structural carbohydrate like simple sugars and starches, it needs to be fermented in the hindgut like fibers and complex carbohydrates. As such, fermentation of fructan involves a longer process than simple sugars and starch and relies on a delicate balance of proper population of microorganisms in the hindgut.

The exact process of digestion has already been explained in the manual Basic Anatomy. However, I want to quickly stress again that there are huge differences in function between the fore- and hindgut. The majority of digestion and absorption of simple sugars and starch – as well as protein and fats – take place in the foregut through the process of enzymatic action. The hindgut – where feed has to spend most of its time - is mainly designed for fermentation processes in which fibre and complex carbohydrates are broken down into volatile fatty acids that the body can use for metabolism.

But the microorganisms in the hindgut responsible for fermentation are sensitive to changes in diet (and also antibiotics!). An overload of sugars, starches or fructan can upset the normal population of microflora through increasing the pH value and thereby changing the environment within the hindgut.

Let me explain this a bit more in depth. The **pH value** describes the acidity in the horse's body. An optimal pH value is a condition that must be met in order for all organs and organ systems to function optimally. The kidneys ensure the correct acid / base balance in the horse's body. A low pH means a high acidity and a high pH means a low acidity. A horse can handle a high pH better than a low pH value. The ideal pH value lies between 7-7.3.

Food either has an acid-forming or base-forming charge. In nature, a horse eats few acidifying foods. Crude grass, herbs, stems, vegetables etc. are all base-forming. The acid-forming foods are in the corner of processed foods that contain high levels of sugars, starches and fructan like silage, grains, muesli and pellets. Furthermore, most domesticate horses are kept on pastures that are heavily modified and thus contain high levels of sugars, starches and fructan which heightens the acidity in the horse's body and thus lowers the pH value. A low pH negatively effects the following:

- Bone density and muscle load
- Course of Metabolism
- Immune System
- Microflora hindgut

The skeleton is the largest base reservoir (calcium and magnesium) followed by muscle. As such, a decrease in pH negatively affects **bone density, muscle load and recovery.**

The pH value also determines the correct course of the **metabolism**, the absorption of nutrients and the production of vitamins (including B,C and K) and proteins. In addition, it affects the activity and efficacy of enzymes.

The immune system decreases because the intestinal wall can produce less hormone and the production of IgA's (immunoglobins – a type of antibody in the first line defence) decreases. The second line of defence take overs and produces IgE's that prove allergic reactions. The horse become sensitive to pathogens – both external and internal.

Finally, a decreased pH causes a **disrupted intestinal flora.** There are roughly three major groups of bacteria in the horse's hindgut:

- Fibrolytic bacteria
- Starch and sugar fermenters
- Lactate utilising bacteria

When the horse's diet consists of high fibre but low starch and sugar levels, the fybrolytic bacteria dominate the hindgut microorganism population. These bacteria keep the pH at a stable level.

However, when all of a sudden large amounts of starch or sugars like fructan are dumped

in the hindgut, the *''starch and sugar fermenting bacteria (which produce lactic acid) essentially have a party and go to town rapidly fermenting their newly arrived favourite foods.''* They increase in numbers and lactic acid accumulates, lowering the pH in the hindgut. If sugars and starches continue to arrive the pH value can drop so low that fybrolytic bacteria, who don't like acidic environments, will begin to die off.
There is however a safety catch in the form of lactate utilising bacteria in play. These bacteria convert the lactic acid being produced into volatile fatty acids that be absorbed by the horse and used for calories. In doing so, these bacteria balance the pH towards a more neutral level and can prevent the negative consequences of an acidic hindgut.

So end good all good you might think. Then why the fuzz? Well, the safety catch doesn't always work. It is suggested there are individual differences in the response of bacterial populations in horses under the same conditions. For example, a study in 2013 stated that:

> *''Starch reaches the hindgut resulting in enrichment of lactic acid bacteria, lactate accumulation, and acidification of the gut contents. Bacterial products enter the bloodstream and precipitate systemic inflammation. Hindgut lactate levels are normally low because specific bacterial groups convert lactate to short chain fatty acids. Why this mechanism fails when lactate levels rapidly rise, and why some hindgut communities can recover is unknown (…)*
>
> *''We report that patterns of change in short chain fatty acid levels and pH in our in vitro system are similar to those seen in in vivo laminitis induction models. Community differences between microcosms with disparate abilities to clear excess lactate suggest profiles conferring resistance of starch-induction conditions.''* – Biddle et al.

Furthermore, the increase of sugar and starch fermenters and their production of lactic acid can be too fast for the lactate utilising bacteria to proliferate enough to prevent a lower pH.

When the safety catch fails, a disturbed population in the hindgut can cause a cascade of problems such as:

- Ulcers
- Cushing's disease
- Equine Metabolic Syndrome
- Hoof Abscesses
- Laminitis
- Colic
- Organ dysfunction
- Vitamin & Mineral deficiencies
- Degenerative bone conditions
- Muscle dysfunction
- Polysaccharide storage myopathy
- Exertional rhabdomyolysis (ER)

Wood chewing may be a sign of hindgut acidosis

That is a pretty long list of nasty stuff isn't it? This is why it is important to closely monitor your horse's intake on sugar, starches and fructan. To rebalance a lowered pH in the body, the kidneys need more basic-forming body stores. To balance your horse's pH and maintain a healthy bacterial flora in your horse's hindgut you could easily consider the following:

- Test your pasture (lab analysis) to know its exact contents
- Feed lots of fibre from low sugar / fructan pasture or hay
- Limit grazing to the early hours of the morning
- Avoid grains based meals or at least feed in small portions
- Make sure additional calories sources are low sugar / starch
- Consider fat as an alternative energy source
- Feed a balancer for vitamins & minerals

Remember it is inaccurate to describe low-sugar feeds as "low-carbohydrate" feeds because there is no horse feed that is low in "carbs." The fiber in forages is carbohydrate in nature.

Because of the importance of healthy bacteria in your horse's hindgut, it truly makes sense to pay a lot of attention on how your feed is affecting micro flora. Happy hindgut, happy horse!

PROTEIN

Protein is another macronutrient. It is needed for body growth and maintenance. Proteins are broken down in the small intestine into amino acids that are recombined to make proteins in that body that are needed to build good quality hoof, hair, skin, organ tissues, muscles, eyes, blood and bones. Furthermore, protein is also a crucial part of enzymes and hormones and thus an absolute essential nutrient in the horse's diet.

Proteins are long chains composed of small molecules called **amino acids**. Think of amino acids as train carriages that joint together to from a *'protein train'*. Amino acids are organic compounds containing carbon, oxygen, hydrogen, nitrogen and sulphur.

There are about 21 amino acids that can be sequenced in almost limitless combinations to form protein. They can be roughly divided into three groups concerning nutritional importance:

- Non-essential
- Conditionally essential
- Essential

Up to 12 amino acids are non-essential in the sense they do not have to be supplied in the diet as the they can be manufactured by the horse's body itself.

However, under certain conditions like growth, illness or injury, 6 of these amino acids must also be supplied through the diet.

The 9 remaining essential amino acids must be supplied by the diet since it cannot be manufactured by the horse's body.

The amount of protein that the body can synthesize is limited by the amino acids that basically run out of supply first and limit the horse's ability to grow, reproduce, perform or build muscle. The three most limiting acids in the equine diet are:

- Lysine
- Threonine
- Methionine

A common misconception is that higher protein is associated with higher energy. In reality, proteins are the most difficult energy source for the horse to digest and convert to usable energy.

The most important thing about feeding protein is that focus should be mostly on improving protein quality without increasing the protein amount. Protein quality is determined by how well a particular protein meets a horse's requirement for amino acids, and especially the essential amino acids. A high quality protein will contain amino acids in very similar proportion to the amino acids the horse needs. Low quality proteins will either be too low in some of the essential amino acids, or they will contain amino acids not available for absorption and thus making it unable to meet the horse's needs.

Protein requirements for horses vary depending on age and workload. In general, growing horses need a higher percentage of protein than mature horses. A growing horse generally needs between 12-18% crude protein in its diet, whereas a mature horse will usually do fine within a range of 8-12% depending on the workload.

The protein requirements for a mature horse in good condition that either is not in work or only in light work is generally easily met by average to good grass and/or hay.

Horses need more protein when tissue is being laid down for growth – such as young horses and gestating and lactating mares. However, horses that are in intense training also need more protein since they are developing muscle tissue, but even for these horses a 12% protein feed is usually sufficient.

Feeding horses higher levels of protein than they need results in the breakdown of excess protein via urine, which is quickly converted to ammonia. This is generally not desirable, especially for stabled horses as excess ammonia can lead to respiratory issues.

Different feeds contain different levels of protein quality. It is important to recognize that roughage provides a good source of protein. As such, you can select the hay that will help meet your horse's protein requirements. In general, legume hays (alfalfa, clover, Lucerne) are higher in protein than grass hays (Bermuda or timothy). Good quality legume hays can have roughly 18-22% crude protein, whereas good quality grass hay usually contains between 10-16%.

When a horse needs to put on weight, adding legume hays is recommended. When the goal is weight loss, you need to decrease the amount of dietary energy the horse is taking in, without robbing it completely of essential nutrients. As such, it is advised to cut down on legume hays and stay between roughly between 12-15% of protein. When the horse has lost fat and start to build muscle mass and increase performance, a mix between grass and legume hays might be ideal.

Nutrient Content of 4 Commonly Used Hays

Anaylsis on Dry Matter Basis	Type of Hay			
	Legume Hay (alfalfa or clover)	Mixed Hay (some legume, mostly grass)	Grass Hay	Bermudagrass Hay
Avg DE Mcal/lb Range	1.19 1.06 to 1.32	0.93 .84 to 1.03	0.91 .81 to 1.00	0.94 .87 to 1.01
Avg CF% Range	2.43 2.02 to 2.83	2.62 1.87 to 3.36	2.52 1.76 to 3.29	1.88 1.49 to 2.27
Avg NSC% Range	11 8.7 to 13.25	12.28 8.1 to 16.4	12.85 8.03 to 17.6	13 9.5 to 17.3
Avg RFV Range	159 132 to 186	93 75 to 112	88 72 to 105	86 76 to 95
Avg CP% Range	21 18.5 to 23.9	12 8.3 to 16.2	10 6.9 to 14.6	10 8.1 to 13.5
Avg Ca% Range	1.5 0 to 4.1	0.67 .39 to .96	0.5 .27 to .73	0.49 .38 to .60
Avg P% Range	0.27 .22 to .32	0.26 .18 to .34	0.23 .14 to .32	0.19 .14 to .25

Source: "Interactive common feed profile" from Equi-Analytical Laboratories in Ithaca, New York, 1-877-819-4110, equi-analytical.com

When you do feel your horse needs more protein and is not getting enough out of its roughage, choose a supplement wisely. Check feed labels for the percentage of content of the most limiting amino acids of lysine, threonine and methionine. Also check for the type of feed. Grains such as oats, corn and barley contain lower quality protein than legumes such as soybean, lupins and beans. Of the most commonly used protein ingredient in horse feed, heat treated cottonseed meal has the lowest quality of protein of all.

In conclusion, be aware that ‘*proteins aren’t proteins’*. Depending on the composition of essential amino acids, some proteins are high in quality to meet the horse’s needs whereas other are low and fall short. Not all horses require high quality protein, but for growing horses or those that are working hard and need to build and maintain muscle mass, protein is an important building block determining equine performance.

FAT

Fat is an excellent and easily digestible source of energy. It has twice as many calories than carbohydrates or protein. As such, it is the body’s most rich energy source. Furthermore, it is used in the synthesis of steroid hormones. Finally, dietary fats serve as carriers to absorb fat-soluble vitamins such as A,D,E and K.

Digestion of fat mainly occurs in the small intestine, via the production and release of digestive enzymes and bile salts. As the horse does not have a gall bladder, bile salts are continually released into the intestine.

From a biochemical point of view, fat belongs to a broad group of compounds called **lipids** which can divided into two categories:

- Glycerol-based
- Non-glycerol based

The first category consists of *phospholipids and triglycerides* - remember this for a game of hangman. The second category is made up by *cholesterol*.

Molecules that are long chains of lipid are termed **fatty acids.** All fatty acids serve structural functions. As such, fatty acids are the building blocks of fat in the body and nutrition. During digestion in the small intestine, fat is broken down into fatty acids which can then be absorbed by the blood. Fatty acids are the most prevalent components of triglycerides and phospholipids. Fatty acids have many important functions, including energy storage. When glucose isn't available for energy, the body uses fatty acids to fuel the cells instead.

Volatile fatty acids (VFA) are short chain fatty acids derived from triglycerides that the horse's body can use for energy. They are produced in the intestinal tract through bacterial fermentation in the hindgut.

Free fatty acids (FFA) are long chain fatty acids that are also produced from triglycerides through the fat metabolism in adipose tissues.

Essential fatty acids (EFA) are not synthesized by the horse's body and can thus only be provided through nutrition. These include *omega 3 and omega 6 fats.*

Omega-3 fatty acids carry anti-inflammatory properties which may assist with joint movement and arthritis. Additional benefits include:

- Good quality of skin, hoof and sperm
- Improving cardiovascular health
- Improving brain, eye and nerve function
- Reducing allergic reactions
- Aiding in the prevention/ treatment of ulcers
- Lowering heart rate in exercising horses
- Increased recovery rate in horses
- Positive effecting on tying up and heaves

On the opposite, **Omega-6** fatty acids aid pro-inflammatory processes. This doesn't mean omega-6 fatty acids are necessarily bad as inflammation is an essential biological reaction protecting the body. As such, omega-6 fatty acids are still essential.

Unfortunately, it must be noted that a specific required amount for essential fatty acids for horses has not been established. Furthermore, the horse needs a balance between Omega-3 and Omega-6 fatty acids to function at an optimal level, but the most desirable ratio of Omega 3:6 is not known.

So far, most research has focussed on establishing the effects of adding more Omega-3 to the horse's diet, which would increase the Omega 3:6 ratio. This is reasoned to be beneficial since Omega-6 increases inflammatory processes whereas Omega-3 fatty acids reduce these processes. As such, although Omega- 6 fatty acids are necessary, it is thought that it's consumption should be less compared to Omega-3 fatty acids.

Let's look at possible sources for Omega-3. Pasture grasses and hay usually contain only 2-3,5% of fat, however they have greater concentrations of Omega-3 than Omega-6 fatty acids. About 50% of the fat available in pasture grasses is omega-3 compared to about 25% of the fat available of the fat in hay. However, most horses do not get to consume enough pasture grasses or hay to meet their daily needs.

Opposite to pasture grasses and hay, cereal grains, such as corn, oats and sunflower seeds contain much higher concentrations of omega-6 than omega-3 fatty acids in reference to their total fat content and should thus be fed with caution.

The most concentrated vegetable source of omega-3 fatty acids is flaxseed (linseed) oil, though soy and canola oils also contain good amounts. Flax contains about three times as much omega-3 as omega-6 fatty acids. The most concentrated animal source of omega-3 fatty acids is fish oil, but it still contains less than flaxseed oil per measurement.

As mentioned earlier, a specific requirement for horse is not yet known, but several studies so far suggest that somewhere between 20-35 grams a day of total omega-3 is desired for an average size horse. As such, additional supplementation of Omega-3 might be beneficial for horses whose requirements are not met by pasture grasses or hay.

In regards to exercise, a high-fat diet could be considered to improve performance. More on this in part two in this manual that focusses on physiology.

MICRO NUTRIENTS

MINERALS

Minerals are critical inorganic compounds that must be present in adequate amounts for the body to function properly. Minerals are necessary for various physiological processes:

- pH balance
- Enzyme function
- Energy metabolism
- Tissue formation (including bone)

They are also part of vitamins, hormones and amino acids. Minerals can be divided depending on the quantitative needs by the horse:

- Macro minerals
- Trace minerals

Macro minerals are required in larger amounts and include *calcium, phosphorus, magnesium, potassium, sodium, chloride and sulphur.* These minerals are vital to:

- Activity of the nervous system
- Development of bone
- Hoof and hair growth
- Muscle contraction
- pH balance

Trace - or micro - minerals are required in smaller amounts and include *copper, zinc, manganese, selenium, cobalt, iodine and iron.* These minerals function to:

- Aid nutrient metabolism
- Maintain connective tissues
- Aid in oxygen transport to muscle
- Serve as powerful antioxidants

	Forage[a]						Cereal grains[b]				
	Grass	Legume	Oats	Barley	Maize	Wheat bran	Beet pulp	SBM[c]	Pea	CDDG[d]	Requirements[a,e]
Ca, g	4.7–7.2	12.2–15.6	1.2	0.8	0.5	1.6	14.8	3.9	1.3	2.4	2.0–4.7
P, g	2.6–3.4	2.8–3.1	3.6	3.9	3.0	11.4	1.0	7.1	4.6	9.5	1.4–3.0
Mg, g	1.8–2.3	2.7–3.3	1.1	1.3	1.1	4.8	2.0	3.3	1.6	3.3	0.7–1.2
K, g	20-26	24-28	5.2	5.5	3.7	14.1	4.8	24	11.3	14.1	2.5–4.2
Na, g	0.2–0.8	0.2–0.3	0.1	0.1	0.05	0.1	3.2	0.3	0.1	6.1	1.0–3.3
S, mg	1.7–2.4	2.3–3.1	2.0	1.5	1.3	2.2	2.7	4.5	2.3	3.6	1.5
Fe, mg	180–200	200–250	120	182	37	164	674	322	106	119	40–50
Mn, mg	70–90	45–50	45	18	9	128	78	43	10	21	40
Cu, mg	8–9	9–10	3	10	2	19	6	20	8	11	10
Zn, mg	25–27	24–26	26	35	22	85	21	53	37	74	40
Se, mg	0.06	0.2	0.2	0.1	0.1	0.5	0.1	0.2	0.2	0.4	0.1

An overview of average mineral content in commonly fed feeds.

Roughage contains some of the minerals required by the horse, but very often it is deficient or low in certain minerals to meet the horse’s total requirements. Many horse owners are under the impression that a trace mineralized salt block will do the job, but unfortunately most salt blocks contain 96% or more salt and only very little minerals and is thus by far not a solution to mineral deficiency.

Furthermore, careful attention should be paid not only to the absolute amount of minerals in the diet, but also the ratios of particular minerals such as calcium: phosphorus and zinc: copper and their sources [organic – inorganic].

So let’s take a closer look to each of the necessary minerals and their desirable ratios.

MACRO MINERALS

CALCIUM AND PHOSPHORUS

Both Calcium (Ca) and phosphorus (P) are needed for the proper growth and development of the skeletal system of the horse – including teeth. Calcium plays a role in enzyme regulation, aids to maintain normal brain and nerve function and assists in heart, skeletal muscle and intestinal contraction. Phosphorus assists in regulating muscle and heart contraction, cell integrity and glucose use. As such, it appears to play an important role in energy generating reactions within the body. Finally, phosphorus is a component of many lipid molecules.

		Digestible Energy (Mcal per day)	Protein (grams per day)	Calcium (grams per day)	Phosphorus (grams per day)
Body Weight (kg):					
200	Low	6.1	216	8	5.6
	Average	6.7	252	8	5.6
	High	7.3	288	8	5.6
400	Low	12.1	432	16	11.2
	Average	13.3	504	16	11.2
	High	14.5	576	16	11.2
500	Low	15.2	540	20	14
	Average	16.7	630	20	14
	High	18.2	720	20	14
600	Low	18.2	648	24	16.8
	Average	20.0	756	24	16.8
	High	21.8	864	24	16.8

From the NRC's *Nutrient Requirements of Horses* (2007)

Calcium and phosphorus must be provided in the correct levels and ratio. So first the absolute requirement of both minerals need to be satisfied before the ratio must be considered. A young growing horse with an expected average bodyweight of 500kg is estimated to need somewhere between 36-40 grams of calcium and 20-22 grams of phosphorus per day. Once the horse has matured to 500kg and is not working, pregnant or lactating it requires around 20 grams of calcium and 14 grams of phosphorus per day. The requirements for both minerals increase with exercise or pregnancy. Upon light work to heavy exercise, the calcium requirement increases to somewhere between 30-40 grams of calcium and 21-28 grams of phosphorus a day. As such, a balanced equine diet must have between 0.15-1.5% of calcium and 0.15-0.6% of phosphorus in dry matter feed.

A deficiency of either minerals often results in subtle clinical signs as most of the damage is internal. When blood levels are low, the horse's body will draw calcium and phosphorus from the bones to operate bodily functions, which can lead to serious consequences.

Calcium deficiency can show in signs such as weak bones or abnormal growth, neurologic signs, muscle trembling, intestinal problems and difficult pregnancy and birth in mares. A deficiency in phosphorus might show in muscle weakness and trembling. Furthermore, it can hinder the horse's energy metabolism leading to high blood levels of glucose and fats.

On the opposite, too much of both minerals could lead to toxicity which can show in somewhat the same symptoms as in case of a deficiency. However, it must be noted that a calcium toxicity is extremely rare as excess calcium is disposed of by the kidneys through urine. However, too much calcium can interfere with the proper uptake of magnesium - which I will explain in the next section.

Apart from considering the horse's absolute needs, it is important to balance the proper ratio. When the horse consumes more phosphorus than calcium, the absorption of calcium can be impaired and lead to poor growth and various skeletal and muscular disorders. Even if a diet contains the proper amount of calcium, excessive phosphorus intake might cause abnormalities. It is recommended that the total diet should meet a Ca:P ratio between the absolute minimum of 1:1 and a maximum of 2:1. In other words, a horse needs at least as much calcium as phosphorus in its diet and never the reverse.

Roughage and fibre sources contain different levels of calcium and phosphorus. Grasses and hay typically contain more calcium than phosphorus. Legume grasses and hay usually contain a higher amount of calcium than straight grasses and hay. On the opposite, plain grains such as oats, wheat and rice are typically much higher in phosphorus than in calcium. Commercial concentrates or supplements might or might not be balanced for calcium and phosphorus and thus it is advised to carefully read the labels of any bought product.

GRAIN	Ca %	Phos %	Ratio
Oats	0.10	0.35	1:3.5
Corn	0.02	0.31	1:15
Barley	0.08	0.42	1:5
Wheat Bran	0.14	1.17	1:8
Soybean Meal	0.32	0.67	1:2
Rice Bran	0.09	1.57	1:17
FORAGE/FIBER			
Alfalfa Pellet	1.43	0.29	4.7:1
Alfalfa Hay	1.21	0.22	5:1
Bermuda Hay	0.42	0.18	2:1
Ryegrass	0.32	0.24	1.5 :1
Timothy Hay	0.41	0.20	2.2:1
Orchard Grass	0.24	0.30	1:1.2
Beet Pulp	0.62	0.09	6:1

Above you can find an overview of the calcium and phosphorus ratios of some commonly fed grains and fiber sources.

MAGNESIUM

Magnesium (Mg) is crucial to the horse’s wellbeing. Magnesium is needed for muscle and nervous tissue function. It relaxes and is necessary to produce serotonin, to maintain a proper pH balance and stimulus transmission of muscle nerves. It also provides firmness to tissue and is necessary for energy production as it activates enzymes necessary for the metabolism of carbohydrates and amino acids. Furthermore, magnesium is known to play an important role in equine obesity and can lessen the risk of laminitis or aid the healing process.

Magnesium is also very important for the assimilation of calcium. When a muscle cell is triggered, the cell membrane opens to let calcium in. A raise in the calcium level sets off a reaction and as a result the muscle contracts. Then, the magnesium inside the cell helps to push the calcium back out again to release the contraction. As such, when there is not enough magnesium in the cell, calcium does not get pushed back out properly and the muscle cannot completely relax putting the body in a continually stressed state. Low levels of magnesium result in hypersensitive nerve endings and thus this explains why magnesium is so important for muscle and nervous tissue function.

Unfortunately, magnesium is one of the most neglected minerals in the horse diet. Especially spring grass is typically low in magnesium due to the fast growth rate. It is also typically in these times that horses are often considered a bit more ‘hot’. Although an increase in carbohydrates in the spring grass might be part of the story, it is often not considered that the change in behaviour might be due to a magnesium deficiency.

Furthermore, the metabolism of magnesium is also often impaired. Only about 1% of magnesium is stored in the blood, the rest is stored in tissue and bone. Now, as mentioned earlier, calcium needs magnesium. However, when too much calcium is being consumed, it prohibits the uptake and use of magnesium. To maintain the proper levels in the blood, the body will borrow magnesium from bones and soft tissue to make up for shortfall in order to assimilate the calcium. Over time, this leads to a series of negative reactions in the body. Eventually, the body releases adrenaline on top of this making the situation even worse.

As such, deficient horses often look stressed and/or ready to explode all of a sudden. They hold tension in the muscles and soft tissue – sometimes combined with tremors and twitches. Thus, they will have poor tolerance to work and the muscles will tie up quickly.

They can be ‘on edge’ and hypersensitive every now and then.

Especially when bodywork doesn’t seem to help these symptoms, you should really start to consider magnesium.

Picture adapted from the good-horse as illustration. A chronically stressed horse might suffer from magnesium deficiency. Naturally, there training and environment should also be considered to bring the horse to relaxation.

Now if you wonder about your horse your first idea might be to get a blood test sorted. However, as mentioned above, only 1% of magnesium is stored in the blood. This is why blood level tests are rarely a good measure of the horse’s true magnesium levels as the horse would be severely deficient and thus ill by the time a blood test would indicate a shortfall. As such, the best would be to simple supplement magnesium – without added calcium - and monitor the effects. A horse deficient in magnesium should improve quite quickly.

The magnesium requirement of a typical horse 500kg is set at 13 milligrams per kilogram of bodyweight per day which would be about 6,5 grams a day. However, horses that are growing, lactating or in work will need more as a lot of magnesium can be lost in sweat. As such, those horses might require 10-30mg more magnesium due to sweat loss. A normal forage diet can meet the magnesium requirements of the horse somewhere between 60-100% depending on the soils on which a horse is grazing / where the hay was cut from. Furthermore, there are many factors apart from calcium that can complicate the uptake of magnesium. For example, most grass is usually low in magnesium and sodium and high in nitrogen and potassium. High potassium levels can slow the absorption uptake of magnesium whereas sodium is known to aid this process. As such, it could be that a magnesium deficiency is not directly caused by too little absolute magnesium in the diet, but by too high potassium levels that inhibit a proper uptake.

Since it is usually impossible to start analysing each bale of hay or soil where your horse grazes for magnesium content it is thus most important for you to closely balance the horse's calcium, phosphorus, fat and potassium intake. Check the labels of your feed and familiarize yourself with the signs of a possible deficit. Feed according to season (in spring more horses have magnesium deficiency) and workload (horses that sweat a lot need more magnesium). If you think your horse needs extra magnesium it is pretty safe to supplement using common sense and monitor the result. Supplementation of magnesium in a deficient horse will have a huge effect on its overall wellbeing and performance.

Toxicity is extremely rare as excessive magnesium will be excreted in urine, but take extra caution in horses with kidney problems and always make sure your horse has access to sufficient clean water.

Furthermore, evidence is growing that feeding salt (sodium) at the same time as a magnesium supplement increases the horse's uptake of magnesium.

Coming at the end of this section you might be left wondering what type of magnesium supplement I would recommend. The most common forms of supplementation are magnesium oxide, magnesium carbonate or magnesium sulphate. Less common is magnesium aspartate and magnesium bisglycinate. The main difference between all these different from is the available amount of magnesium available and it's biological uptake. Without going too much into details, magnesium sulphate contains the least available magnesium followed by carbonate. As such, you need to give more of these supplements to get the desired effect. Magnesium oxide provides the greatest amount of magnesium for the most commonly fed sources. However, it is usually the less common sources of aspartate and bisglycinate that have a much higher biological uptake. As such, my personal preference is magnesium bisglycinate with taurine. However, this does not mean you should now run to the shop to get this. Use what is best available to you and always consult a nutrition expert to obtain the best result for your individual horse(s).

POTASSIUM

The next macro-mineral to be discussed is potassium (K). It is an electrolyte necessary for muscle function. Potassium maintains the cell's pH balance and internal cellular fluid pressure. Together with other electrolytes such as calcium, sodium and magnesium it plays an important role in muscle contraction and relaxation. About 75% of potassium is found within skeletal muscle.

Potassium channels are the most widely distributed type of mineral (ion) channel in the horse's body. These channels function to either let potassium in or out of the cells. In excitable cells, for example neurons, potassium is responsible for exciting the cell. So whenever a horse contracts a muscle, potassium is rushed across cell membranes. This includes the heart muscle! Potassium channels may also be involved in maintaining vascular tone.

Not only are potassium ion channels essential in excitable cells, they also regulate cellular processes such as the release of hormones. If there is a malfunction of the channels, some hormones, such as insulin, may be mis-regulated and thus lead to diseases such as insulin resistance.

The daily requirement for an average horse of 500kg is estimated to be 25grams a day. However, here also counts that performance horses in high level of activity – especially in warm temperatures - require more due to losses in sweat.

Most forages contain a large amount of about 1-4% potassium on a dry matter basis. Especially legume grasses are known to be high in potassium. For example, 10 kilos of Rye Grass would provide already about 33.4 grams of potassium. As such, the daily intake of potassium usually exceeds the horse's requirements. Interestingly, soaking hay can reduce potassium content up till 50%.

Other feeds that are inherently high in potassium include:

- Chicory
- Kelp
- Molasses
- Nettle
- Dandelion
- Rosehips
- Slippery elm
- Garlic
- Echinacea
- Chamomile
- Soya bean

In healthy horses, excess potassium is excreted through urine. However, in case of kidney failure, a large overdose or too much potassium moving from inside to outside the cells could result in *hyperkalaemia.* Horses that have history of massive cellular destruction such as after a trauma, injury or tying up are at greater risk of hyperkalaemia.

The most common signs of hyperkalaemia include:

- Muscle weakness & trembling
- Depression or lethargy
- Magnesium/calcium imbalances
- Possibly head flicking
- Laminitic episodes
- Overall stiffness

In summary, most horses will naturally consume more potassium than they need through forage. This doesn't necessarily have to be a problem in the healthy horse, but you need to make sure that other possible supplements do not add to the total potassium content of your horse's diet to avoid toxicity in the form of hyperkalaemia. Furthermore, make sure that the horse gets enough salt as a lack of sodium reduces urinations and thus limits excretion of excess potassium. Soaking hay or avoiding legume grasses might also be beneficial for horses that are prone to hyperkalaemia.

SODIUM AND CHLORIDE

Next up for discussion are the minerals Sodium (Na) and Chloride (Cl-) . Bound together, they form salt and are critical to the function of numerous cellular processes.

Sodium plays a vital role in the functioning of the central nervous system by facilitating the movement of signals throughout the system. A signal moves through an excitable less – for example a neuron - by what is called an action potential. An action potential refers to the creation of an extremely positive charge that moves from cell to cell.

Sodium is the major positively charged ion in the fluid surrounding cells and potassium is the main one within the cells. When an action potential starts – for example nerves being triggered – channels in the nerve cell membranes open and the sodium ions move into the cell while potassium is pushed out of cell. This results in a voltage change within the cell from negative to positive, which creates the impulse that allows the cells to send signals throughout the horse's body.

Apart from its function on the nervous system, sodium also transports glucose and amino acids across cell membranes. Furthermore it is also the major electrolyte involved determining the relative pH value of fluids and the levels of fluids inside and outside of cells, aided by chloride.

Chloride also plays an important role in fluid regulation as pH balance. Furthermore, chloride is a key component of bile as well as hydrochloric acid in the stomach necessary for digestion.

An average 500kg horse is estimated to have a daily requirement of 10 grams of sodium and 40 grams of chloride on a cool day doing no work. This would be about 30 grams of salt a day. The requirements for horses that are up to moderate work increases to 17.8 grams and 53.3 grams respectively when the horse is trained up to moderate level, not taking weather into account. As such, the horse needs even more under warm temperatures.

When sodium levels become too concentrated, a thirst response is triggered to motivate the consumption of water. Horses are very rarely overdosed on salt. In fact, most horses do not meet their daily requirements by a typical roughage diet alone.

Sodium and chloride levels in forages vary, but without specific analysis most of them only contain about 0.1% salt and thus do not meet the horse's maintenance requirement, let alone a day of work in warm temperatures. Commercial feeds usually include added salt, but the amounts are often still not enough to meet daily needs especially in working horses. Thus, most horses have a risk of potential sodium deficiency.

Horses are able to adapt quite well to reduced sodium intake due to various systems that monitor its concentration. Where sodium goes water tends to follow. As such, if sodium levels drop, blood volume decreases which impacts blood pressure. In response, receptors in the circulatory system send feedback to the nerves and hormone systems. As such, when circulating sodium levels are insufficient, the kidneys respond by holding on to sodium and instead will excrete more potassium. The urine will contain less water and be more concentrated. However, a dangerous downside is possible dehydration as, despite water is conserved by reducing excretion, lower levels of sodium means less thirst stimulus.

Thus, horses that do not consume enough sodium and chloride will usually have a low level of hydration and thus become more susceptible to heat stress, dehydration and even colic due to reduced fluid consumption and flow through the gastrointestinal tract.

Additional symptoms of sodium and chloride deficiency include:

- Less appetite
- Weight loss
- Licking objects
- Constipation
- Involuntarily muscle contractions

Most horses owners consider a salt block an easy supplementation. However, few horses will lock a block adequately enough to consume their daily requirement from it as their tongues gets sore after a while.

As such, the best solution would be freely offered salt in a loose form. For example, you can place a bucket somewhere providing loose salt in it so the horse can consume as much as necessary. You can provide a few different options to figure out what your horse likes best. Examples are table salt, sea salt or Himalayan salt. It doesn't really matter, as long as you use sodium chloride and not lie salts as the latter is potassium chloride and will thus not help to build proper sodium levels.

Finally, keep in mind that the purpose of providing salt is to meet the horse's daily maintenance requirements and not to replace sweat losses. As such, a good electrolyte supplement should be used in addition to salt for those horses that lose large quantities of sodium and chloride in sweat.

SULPHUR

The final macro-mineral is Sulphur. Each living cell contains sulphur. It regulates tissue structures, stabilizes vascular walls, is indispensable for protein production (collagen!), assists the liver, plays a part in detoxication, forms immunoglobin and repairs damage in pH balance. Insulin also contains sulphur as well as methionine – one of the essential amino acids. Furthermore, it regulates the structure and elasticity of tissue, muscle and joints. As such, it is indispensable for the integrity of skin, hair, hooves and nails.

Sulphur requirements for the horse have not been determined yet. The only form of sulphur that can be readily utilized by the horse is its organic form. Luckily, most of it found in plants is organic in the form of cystine and methionine, since plant proteins are also composed of those amino acids. High quality protein is the best way to ensure the horse's needs for the organic form of sulphur. About 90% of the sulphur in hay analysis is incorporated into plant protein amino acids.

Common feed items that contain inorganic sulphur include:

- Joint supplements: Glucosamine and Chondroitin sulphate, MSM

- Hoof supplements: Biotin and Methionine
- Mineral supplements: Copper and Zinc sulphate
- Calming supplements: Thiamine

Less known but possibly quite important is **taurine** which is another sulphur amino acid derived from methionine that plays an important role in the nervous system, detoxification, liver function and metabolism:

> *''Increased levels may be needed by horses with abnormal glucose metabolism to support the body in avoiding harmful interactions of glucose with body tissues, including nerve damage. Taurine also helps maintain neurotransmitters responsible for a stable, happy mood.''* – Kellon 2017

As mentioned earlier, taurine is often added to magnesium bisglycinate and thus might be a good magnesium supplement for horses suffering from insulin resistance.

A sulphur deficiency has never been described in horses. Excess dietary sulphur intake could potentially decrease intake of copper and selenium, but is quite uncommon. Toxicity also appears to be rare and was only reported in dramatic cases of large overdoses.

TRACE MINERALS

COPPER

Copper (Cu) is necessary for the proper functioning of many enzymes in the horse's body. It is an important player in the proper functioning of the immune system as well as the horse's energy metabolism. Without copper, the production of ATP could be reduced.

Furthermore, copper has an influence on iron metabolism. Iron deficiency is often considered a possible cause of anaemia in horses. However, it is usually more likely that this condition is due to a lack of copper as the latter is needed to mobilize iron.

Finally, the nervous system requires copper using enzymes and it is also essential to maintaining integrity of connective tissue as well as bone.

An average 500kg horses is estimated to need a maintenance dose of 100mg of copper a day. As workload increases the requirement could rise to 125mg a day.

The levels of copper in forages tends to be fairly low with most hays only providing less than 10mg/kg which would only just meet the minimum requirement if an average horse is fed at 2% of its bodyweight. Dietary sources with high copper include molasses, brewer's grains and soybean.

Furthermore, other minerals such as zinc can influence and reduce the uptake of copper. The ratio between zinc and copper must be adequate so that one mineral doesn't outcompete the other. The ideal ratio is still controversial because the amount of zinc required to cause a copper deficiency depends on how much of the latter is already stored in the liver which varies from horse to horse. On a broad scale, a ratio of 4:1 is usually accepted. If the horse consumes larger amounts of zinc along with small amount of copper, a secondary copper deficiency can be created.

Copper deficiency often shows in abnormal bone development in growing horses. Some common conditions that have been linked to copper deficiency include Developmental Orthopaedic Disease. In mature horses, connective tissue often weakens.

On the opposite, horses seem to tolerate excess dietary copper quite well. The estimated maximum tolerable concentration is set at 250mg/kg which is way above the recommended intake.

If you feel your horse could benefit from supplemented copper, it is always best to choose a balanced supplement rather than adding isolated copper to your horse's diet as it needs to be balanced to your horse's other minerals intake – especially zinc.

ZINC

Zinc is part of over 100 different enzymes in the horse's body. Zinc is necessary for building protein and plays an important part in the metabolism of carbohydrates and protein. It also transports oxygen through the body, assists in proper functioning of the immune system and wound healing mechanisms.

Most concentrations of zinc can be found in the eye, pancreas, hoof horn, liver and muscle. Dysbiosis in the intestine as well as phytic acid, oxalic acid and phosphor and high levels of calcium and copper inhibit the proper intake of zinc. Increased protein intake has also shown to possibly reduce zinc absorption and increase zinc incretion.

The maintenance dose for an average 500kg horse is set at 400-500mg of zinc a day. Most forages contain low- to average zinc concentration and thus supplementation might be required on a forage only diet. Also, a significant amount of zinc – about 20mg per litre – is lost in sweat. This could be substantial for highly performing sport horses – especially in warmer temperatures. Combined with its complex interactions with other minerals, many horses might struggle to meet their daily requirements. Commercial feeds usually add extra zinc and copper, which should be sufficient.

As such, zinc deficiency is not very common, but symptoms include:

- Hair loss
- Eczema / Sweet Itch
- Weak immune system
- Growth deficiency
- Poor wound healing
- Weight loss

On the opposite, horses seem to tolerate excess dietary zinc quite well. The maximum tolerable level has been sat at 500m/kg of the ration which is about 10 times the recommended maintenance dose!

However, in few extreme cases zinc toxicity has been reported in horses that consumed grass that contained very high levels of zinc. Symptoms included lameness, stiff gaits and epiphyses. It must be said though that even in these cases te absolute zinc content didn't seem to cause these problem, but that it was more likely to be caused by a secondary copper deficiency as the result of an imbalanced ratio.

MANGANESE

Manganese (Mn) plays a vital role in the energy metabolism of carbohydrates and fat. It also produces chondroitin sulphate, which is necessary for the development of cartilage. Finally, it is an important component of the antioxidant superoxide dismutase. As such, it assists in detoxication of free radicals.

The maintenance dose of an average 500kg horse is set at 400-500mg of manganese a day. Forages usually contain between 40-140mg manganese per kilo of dry end, which usually suffices for most the daily requirement of most horses. Grains typically contain less manganese than forages.

There are no reported cases of manages deficiency of toxicity, but too much manganese could interfere with the absorption of phosphorus. In certain areas, water can contain substantial amounts of manganese which could contribute to this effect, but it is quite rare.

As such, most forage based diets provide the horses daily needs of manganese sufficiently and supplementation is not needed.

SELENIUM

Selenium is an important part of the horse's cellular antioxidant defence system that mitigates damage from free radicals. It also plays a key factor in thyroid hormone production. Selenium works closely together with vitamin E. In fact, deficiency in one can be compensated for if there is adequate supply of the other. Optimal amounts of both however are necessary to minimize oxidation induced tissue damage.

The required maintenance dose for an average 500kg horse is set at 1-3mg a day. This is substantially less than other trace minerals. The upper safe total intake of selenium is set at 20mg a day.

Selenium levels in forages can vary strongly between areas. It all depends on the levels of the soil and as such, lab analysis is the only way to truly know the selenium levels in your horse's forage. Commercial feeds often include added selenium and/or vitamin E. As such, it is important to read your horse's feed labels and to familiarize yourself with possible signs of either deficiency or toxicity. When in doubt, the best way is to contact your vet for a blood test to determine your horse's selenium levels.

A selenium deficiency could lead to white muscle disease which affects both skeletal and cardiac muscles. Signs of white muscle disease include:

- Muscle weakness
- Recumbency
- Heart failure

On the opposite, too much selenium could lead to acute or chronic toxicity. Horses can be poisoned through eating forage growing in high selenium soil of by drinking water with high levels of selenium, especially during spring and summer. Certain weeds such as mild vetch, golden weed, purple locoweed and prince's plume are known to grow in high selenium soil.

Acute selenium toxicity is lethal within hours or days. Up to day, there is no widely available treatment known. Signs might include:

- Restlessness or depression
- Less appetite
- Diarrhoea
- Fever
- Respiratory disease
- Muscle weakness
- Gait abnormalities
- Bead breath

Chronic selenium toxicity – commonly refered to as *Alkali disease* - is the result of long-term exposure to high levels of selenium. Toxic levels of selenium damages the cells that form keratin. The keratin molecule gets replaced by sulphur and causes clinical signs such as:

- Hair loss / thinning
- Horizontal hoof wall cracks
- Separation of the coronary band

Signs of severe chronic toxicity could furthermore include:

- Blindness
- Lameness
- Respiratory failure
- Involuntary twitching
- Inability to stand
- Teeth grating
- Paralysis
- Abdominal pain
- Excessive salivation

If selenium toxicity is confirmed, the horse must be fed a high protein diet and kept away from any high selenium water, feed and forage. The horse may never recover completely and it could be fatal in some cases.

As such, selenium supplementation should be considered very thoughtfully. The best way to determine whether your horse's needs are met or not is to:

- Analyse the soil / hay
- Check your horse's feed labels
- Consult the vet for a blood test
- Consult a nutritionist / herbalist

COBALT

Cobalt (Co) has an important function for red blood cell formation and energy production due to its place as part of the vitamin B12. The bacteria in the horse's digestive system, especially those in the hindgut, use dietary cobalt and convert it to vitamin B12. Together with iron and copper, this vitamin is used in the formation and maintenance of blood cells.

The maintenance requirement for a typical 500kg horse is set at only 0.5-0.6 milligram a day. Horse usually consume a bit more since most forages include at least 0.05mg/kg dry matter if not more. Legume grasses such as Alfalfa usually contain more whereas grain contain a moderate amount. As such, most horses don't need cobalt supplementation.

A cobalt deficiency has never been reported in horses. If it were to occur, it would result in a vitamin B12 deficiency – I will list these symptoms later on.

Cobalt toxicity also has never been reported, this is probably due to the fact that cobalt has a very low absorption rate. However, research in other species have associated excess cobalt with issues such as thyroid failure, cardiomyopathy and cancer. As such, more research into its effect in horses is useful.

Since cobalt has the ability to promote red blood cell production, supplementation has been considered to enhance athletic performance. It seems that cobalt has been abused in various equine disciplines for this purpose (Ho. et al 2015). Although the longer term effect of excessive cobalt remain to be understood, experimental research suggested it might increase the risk of heart problems (Burns et al. 2016; Knych et al. 2015).

IODINE

Iodine is an important part of two thyroid hormones that regulate the horse's basal metabolism (see energetics chapters).

The maintenance requirements for an average 500kg horse is set at about 3.5-4.5 mg of iodine per day depending on exercise regime and breeding status. Iodine isn't usually measured in hay or forage analyses and thus it is difficult to estimate iodine concentrations. Some studies that specifically tested for iodine showed that most forage contains between 0-2mg/kg dry matter depending on the soil in which the feed was grown. As such, most horses on forage only diets might require supplementation. Iodine is usually supplemented by providing iodized salts, or salt with added trace minerals. Molasses, alfalfa and whey also contain iodine.

Kelp and other seaweeds contain large concentrations up to 1850mg/kg dry matter and could be used for supplementation in case of deficiency.

Both an iodine deficiency and excess cause the same symptom of an enlarged thyroid. In case of deficiency, not enough of the thyroid hormones can be produced and thus the production of thyroid stimulating hormones increase and the thyroid has to work harder. As a result, the horse ends up with an enlarged thyroid. Other signs of include:

- Lethargy
- Dull coat
- Hair loss
- Cold intolerance
- Thickened skin

Especially in foals deficiency can be dangerous. They can be stillborn or very weak, have hypothermia, poor suckle response and difficulty standing. On long term, it could possibly lead to DOD and problems in organ systems.

On the other hand, if there is an excess, the extra mineral present inhibits the production of the two hormones and thus also leads to increased TSH production resulting in an enlarged thyroid. Excess is also reported to cause:

- Larger susceptibility to infections
- Chronic respiratory disease
- Constant eye tearing
- Nasal discharge that doesn't respond to treatments

IRON

Iron (Fe) is vital for the transport of oxygen by red blood cells. It makes up the center of hemoglobin (see cardiovascular physiology) and is also present in myoglobin which gets the oxygen into the muscle. It is also part of some enzymes and muscle tissues.

The estimated requirement for an average horse of 500kg at rest or light work is 400mg iron per day which rises to 500mg for a horse in heavy work.

Forages are usually high in iron and provide somewhere between 100-300mg/kg dry matter. As such, most horses consume more than the daily requirement from forage alone. Grains usually contain less than 100mg/kg dry matter. Calcium and phosphorus supplements usually contain 2-3% iron.

An iron deficiency is not a concern for most horses on a forage based diet. Notable exceptions are horses that consume forage from unusual low iron content soils, but again this is quite rare. If deficiency were to occur, it would result in anaemia.

Excess iron is a more common issue. Iron is hard to digest. Only a very small amount of iron can be excreted in urine. Once in circulation, excess dietary iron is removed by the liver or spleen and stored linked to protein. Furthermore, supplemental iron interferes with the absorption of other minerals – especially zinc and copper.

Iron can also act as a pro-oxidant increasing oxidative stress – especially during exercise, stress and warm temperatures. This effect could be moderated by vitamins E and C, but then these vitamins would be required in larger amounts to counteract excess iron.

Furthermore, human studies have shown that iron plays a role in metabolic syndromes and obesity. A 2012 study also identified a link between iron and insulin resistance in horses, but more research is required to confirm this.

Iron toxicity can already occur at about 2-3 times the recommend daily intake, but signs might be unspecific and include:

- Gastric pain and ulcers
- Diarrhoea
- Dehydration
- Reduced immunity
- Increased rick of bacterial infections

Iron toxicity is especially dangerous in new born foals and could be lethal. In the 1980s, a product with high levels of iron caused lethal spikes in foals and has since been removed from the market.

In summary, horses rarely need supplemental iron. Excess levels of iron are more common and as such it is advisable to closely read the labels of commercial feeds to avoid unnecessary iron supplementation.

VITAMINS

Just as minerals, vitamins are another group of compounds that must be present in adequate amounts for the body to function properly. Together with minerals they perform hundreds of roles in the horse's body and influence many systems including:

- Immune system
- Structural tissues
- Wound healing
- Energy Metabolism
- Repair cellular damage
- Detoxification

Vitamins can be roughly divided into two categories:

- Fat-Soluble
- Water-Soluble

Fat soluble vitamins are stored in fat. Thus, if there is a deficiency in the diet, the body can survive for a period of time by using these stores. However, the down side is that excess levels of these vitamins are not easily excreted and as such there is a risk of toxicity. Furthermore, the horse needs to have a certain level of fat as otherwise these vitamins can't be stored. Underweight horses can quickly become deficient. Fat soluble vitamins are:

- Vitamin A
- Vitamin D
- Vitamin E
- Vitamin K

Water-soluble vitamins on the other hand are easily excreted. As such, dietary deficiencies of these vitamins will cause problems sooner than fat-soluble vitamins. On the opposite, the risk of toxicity is much less since excess vitamins can be easily excreted in urine.

Water soluble vitamins are:

- Vitamin B
- Vitamin C

So let's take a closer look to each of the necessary vitamins and their desirable ratios.

Vitamin	**Feed source**
Vitamin A	Green forages Yellow vegetables (carrots)
Vitamin D	Sunlight—causes chemical reaction causing 7-dehydrochoelsterol in the skin to convert to Vitamin D Sun-cured hay
Vitamin E	Green forage note: 30–80% of vitamin content is lost soon after cutting
Vitamin K†	Green, leafy plants (e.g., alfalfa)
Thiamine†	Green forage Brewer's yeast Cereal grains
Riboflavin†	Fresh forage; especially legumes such as alfalfa and clover Yeast supplements
Niacin†	Soybean meal Alfalfa and timothy hay Vegetable matter—some forms may have poor digestibility
Pantothenic acid	Vegetable matter—some forms may have poor digestibility
Pyridoxine	Green forage
Biotin	Alfalfa Barley Soybean meal
Folic acid§	Green forage
Cyanocobalamin§	–
Vitamin C (ascorbic acid)	Green forage

† Adapted from the National Research Council (2007).

FAT SOLUBLE VITAMINS

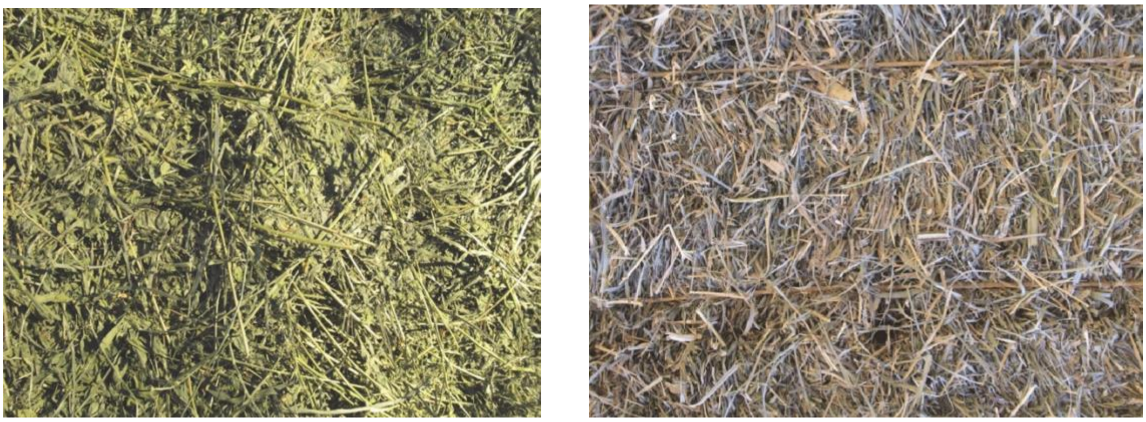
VITAMIN A

Vitamin A is a fat-soluble vitamin that supports normal vision, bone metabolism, red blood cell production, immune function, fertility, skin and hoof integrity and gene action. It also acts as an antioxidant.

An average horse of 500kg is would need about 15,000 IU (International Units) of vitamin A per day at rest and up till 22,500 IU per day when working. The suggested safe upper limit of intake is set around 160,000 IU per day.

Vitamin A is synthesized in the horse's intestine from carotenoids available in plants. The major carotenoid available in forage is beta-carotene. As such, fresh grass is usually rich in vitamin A and horses on pasture do not need supplemental vitamin A. Fresh legume grasses usually contain most vitamin A. For example, alfalfa usually contains almost 25.000 IU of vitamin A per kg, which already exceeds the total daily requirement. Grass hays are more variable. Canary grass was reported at 6,762 IU/kg on average, orchard grass at 13,366 IU/kg and timothy at 18,700 IU/kg. As such, even for the lowest containing source – canary grass – it would only take between 3-3.5 kg of fresh forage to meet the upper-level daily requirement for a 500 kg horse in work.

Freshly cut hay also contains some vitamin A, but the level declines quickly once the hay is baled. By the time hay is about one year old, the vitamin A content has decreased to ½ to 1/3 of the original level. Hay that is two years old usually contains about 1/10th of its original vitamin A content.



Left: freshly cut hay. Right: hay stored for a longer period of time

After digestion, vitamin A is stored in the horse's liver. Supplies are usually sufficient to see the horse through winter when fresh grass is not available. In some cases, for example pregnant mares or when the horse does not have access to fresh pasture at all, supplemental vitamin A could be considered. Carrots are high in beta-carotene and as such are a good choice for a winter treat.

While beta-carotene from forages is easily converted into vitamin A, supplemental forms are not as efficiently used. For this reason, supplements usually contain stabilized forms of vitamin A itself such as *retinyl palmitate or retinyl acetate.* Thus, make sure to scan your commercial feed and supplements for these ingredients to determine whether your feed meets or exceeds your horse's needs for vitamin A.

As mentioned earlier, a deficiency in vitamin A usually does not occur when the horse has access to fresh pasture. If your horse is on an old hay diet only for at least 12 months, a deficiency could occur and supplemental vitamin A might be useful. The most common symptom of vitamin A deficiency is night blindness, which has been reported in few horses. Impaired growth has also been reported in growing ponies deprived of vitamin A. However, these are rare exceptions.

As mentioned earlier, the horse has quite a high tolerance up till 160.000 IU per day for a 500kg horse. However, excess vitamin A above the safety limit can be toxic as it will accumulate in the liver. Signs of Vitamin A toxicity include:

- Developmental Orthopaedic Disease
- Bone fragility and grow issues
- Itching and peeling skin
- Birth defects

The only treatment would be to stop feeding excess vitamin A.

VITAMIN D

Vitamin D aids in calcium homeostasis. It's main job is to manage calcium levels, but it also influences the growth and differentiation of cells to some degree. It increases the absorption of calcium, phosphorus and magnesium in the intestines, it increases the release of calcium and phosphorus from the bone, and it increases the resorption of calcium in the kidney.
As such, while we think of vitamin D as a vitamin it's actually a hormone because it is transported in blood and has regulatory functions in various cells in the body.

Vitamin D in humans is closely related to sunlight exposure and deficiency is being more commonly recognized in geographic areas that do not have a lot of daylight – especially in the winter. Supplementation is often recommended and the commercial industry has developed various products such as sunlight lamps to combat the clinical signs of vitamin D deficiency. A 2015 study that summarized the current knowledge about vitamin D in horses concluded: *''We know next to nothing about vitamin D in horses.''* This statement makes it clear that it remains to be investigated whether the connection between vitamin D and daylight manifests the same in horses as in humans. So what do we know?

Vitamin D is available for the horse in two forms:

- Vitamin D2
- Vitamin D3

Vitamin D2 is found in plants and vitamin D3 is synthesized in the skin on exposure to sunlight or can be supplemented orally in synthetic form. Neither forms of vitamin D is active

and thus both must be metabolized in order to influence the physiologic functions of the horse's body.

The current guideline for vitamin D – although this is based at limited knowledge and thus horse's might require more – is currently set at 6.6 IU per kg of bodyweight. Growing horses could need up to 13.7 IU per kg of bodyweight. The presumed safe upper limit for vitamin D is set at 44 IU/kg body weight per day.

Forages are usually low in vitamin D2. Only sun-cured forages legume grass such as alfalfa usually contain dietary vitamin D, but the concentration is still quite low. Commercial feeds usually contain low fortified vitamin D3, which might be labelled as *cholecalciferol.* As such, horses seem to mostly rely on vitamin D3 through exposure to sunlight.

Sunlight deprivation and forage only diets might lead to vitamin D deficiency in horses which results in *rickets* – a soft bone disease.

Since most equine diets are low in vitamin D and the safe upper limit is quite high, toxicity is pretty rare. It could only happen when your horse gets multiple supplements or fortified feeds containing high levels of vitamin D. Most calcium or phosphorus supplements also include vitamin D3. The most common symptom of vitamin D toxicity is calcification of soft tissue (hypercalcemia). One study found that when young ponies were fed 14.000 IU vitamin D per kg of body weight daily, severe calcification of multiple organs occurred within 10 days. Chronic and severe toxicity occurred when 3500 IU vitamin D per kg of body weight per was fed.

As such, the take home message is that providing your horse with sufficient sunlight is the best way to ensure its daily needs. Future research is needed to fully understand vitamin D in horses. Be careful with supplementation as the tolerable dose varies with intake of calcium and possibly phosphorus, magnesium, protein and vitamin A. As such, a balancer might be the best option for horses on a hay only diet.

VITAMIN E

Vitamin E is a fat-soluble vitamin that mainly functions as a biological anti-oxidant (see chapter on oxidative stress for more information). The horse cannot provide this vitamin itself and therefore it must be provided in the diet.

The recommended requirements for vitamin E have not been well established. The daily needs are defined only because it is known that horses consuming it at a certain level haven't had any signs of deficiencies. As such, the recommended daily requirement is set at 1-2IU/kg body weight. For an average 500kg horse at rest this would be 500IU per day. This raises up to 800IU with light work and up till 1000IU with heavy work. These figures are the minimums however. It is argued by some that horses on high-fat diets also require higher intakes of vitamin E. High-fat diets can lead to great oxidation and thus a greater need for antioxidants. Higher levels might also be required for horses that are dealing with underweight, injury, inflammation or sickness.

The main source of vitamin E is forage, but concentrations can vary greatly. In general, fresh pasture provides sufficient content. Concentrations decline the longer forage is stored. Most commercial feeds are fortified with vitamin E. Synthetic vitamin E is usually listed as *dl-alpha-tocopherol* - or some variation starting with dl. Natural vitamin E is listed as *d-alpha-tocopherol*. Synthetic forms are excreted faster and thus a horse has to consume more of the synthetic form to achieve the same levels in the blood stream as the natural form. The latter is not cheap and thus only advised to supplement when necessary.

Furthermore, it is also argued that individual horses utilize vitamin E in the liver differently. This has been shown by horses who were fed the same vitamin E diet, but showed different levels upon blood tests.

For horses on a forage only diet that primarily consists of hay, with little or no grazing vitamin E deficiency is a possibility. A shortage of vitamin E might mean more oxidative damage occurs in cells throughout the body, including those in muscles, nerves and immune cells. In sport horses, signs of deficiency often include a slower-than-expected recovery from exercise and sore muscles. Muscular disorders linked to vitamin E deficiency include:

- Equine Motor Neuron Disease
- White muscle disease
- Tying up

When supplementing a vitamin E deficiency, make sure that you are not over-supplementing other nutrients to get to the level of vitamin E desired. Many vitamin E supplements also contain added selenium. Whether your horse can handle additional selenium relies on numerous factors already mentioned such as personal requirements, soil levels, additional feeds that contain selenium and the total feed volume. Always ask a nutritionist for advice. If over supplementing other nutrients is a viable risk, it is wiser to choose a sole concentrated form of vitamin E instead.

Excess vitamin E could complicate the uptake of vitamin A, because both vitamin E and beta-carotene have the same absorption pathway. Nevertheless, Vitamin E toxicity is not common in horses. Although an upper safe dietary limit has not been determined in horses, acute toxicity has never been reported.

In summary, vitamin E is usually not of a worry when the horse has access to fresh pasture or those that receive a balanced commercial feed. However, horses on a hay only diet might be prone to deficiency. Consult a nutritionist whether supplementation is needed. Preferably choose vitamin E in its natural form and be careful to not over-supplement other nutrients to get to the level of vitamin E desired.

VITAMIN K

Through a complex process, vitamin K is associated with blood coagulation – i.e. blood clotting. In this process, matrix Gla-proteins (MGP) are produced which play an important role in bone metabolism and heart health.

Dietary requirements for vitamin K have not yet been determined for the horse. It is generally assumed that upon ingestion of adequate forage vitamin K is synthesized by bacteria in the cecum and colon in sufficient quantities to meet the horse's requirements. As such, when the horse has access to sufficient and a decent quality of forage, vitamin K should not be something to worry about.

In fact, deficiencies and toxicities in the horse have never been reported. It is estimated that the upper safe intake level of vitamin K is at least 1000 times the daily recommended intake.

WATER SOLUBLE VITAMINS

VITAMIN B

The B vitamins are a group of water-soluble vitamins, each with its own distinct use and chemical properties.

Some of these vitamins can be produced by the horse itself, whereas others need to be provided in the diet.

The most important B vitamins for the horse include:

- Vitamin B1 – Thiamin
- Vitamin B2 – Riboflavin
- Vitamin B3 – Niacin
- Vitamin B5 – Pantothenic acid
- Vitamin B 6 – Pyridoxine
- Vitamin B9 – Folic acid
- Vitamin B12 – Cobalamin

Vitamin B1 (Thiamin) is very important for carbohydrate digestion and thus the horse's energy metabolism and the production of ATP – which will be explained in the chapters on equine energetics.

The requirement of Vitamin B1 for an average 500kg horse is set between 3-6mg/kg of dry matter depending on workload.

Although some vitamin B1 can be synthesized through microorganisms in the hindgut, the horse also needs a dietary source. Vitamin B1 is sourced from pasture and cereal grains. The most significant source of vitamin B1 is brewer's yeast.

Since vitamin B1 is water soluble, it is not stored in the body and therefore must be consumed on a daily basis in proper amounts. Signs of a vitamin B1 deficiency include:

- Dysbiosis in the intestine
- Neurological afflictions
- Slow heartbeat

- Muscle twitching
- Loss of appetite

On the opposite, a toxicity of vitamin B1 is never reported since excess can be easily excreted.

Vitamin B2 (Riboflavin) is involved in oxidation-reduction reactions used in energy metabolism (ATP production), lipid metabolism and antioxidant mechanisms.

The requirement of Vitamin B2 is set at about 0.04-0.05 mg/kg body weight depending on workload.

Vitamin B2 is found in relatively high concentration in legumes and slightly less in grass hays. These concentrations will be reduced to about 70% upon storage. Cereal grains contain the lowest concentrations in the equine diet.

Legumes	13-17 mg/kg DM
Grass hays	7-10 mg/kg DM
Cereal grains	1.4-1.7 mg/kg DM

Both a deficiency or toxicity has never been reported in horses.

Vitamin B3 (Niacin) is essential to pretty much everything that goes on in the horse's body. It is involved in various oxidation-reduction reactions. Furthermore, it creates one of the co-enzymes essential to DNA processing, cell differentiation and calcium mobilization from cells.

As of yet, requirement of daily vitamin B3 intake of the horse has not been established. It is estimated somewhere between 35-100mg per day depending on workload. No deficiencies or toxicities has been reported so it is assumed most horses generally consume an adequate amount of vitamin B3.

Vitamin B3 is widely available in forage and grains, but horses are not likely to be able to consume it all. Vitamin B3 can be in bound or unbound form. The latter is unavailable to the horse. Up to 90% of the vitamin B3 content in grains might in bound form and thus not available to the horse. Legume hays have high levels of B3, but there is no idea how much might be bound form.

To some extent, vitamin B3 can also be synthesized from tryptophan by the microbes in the hindgut.

Vitamin B5 (Pantothenic acid) is critical to metabolize and synthesize proteins, carbohydrate and fats. It is also needed to synthesize co-enzyme A which is involved with neurotransmitters, steroid hormones and the production of hemoglobin. It is also required for adequate use and absorption of folic acid.

Dietary requirements have yet to be established, but since no deficiencies or toxicities have been reported it is assumed most horses consume enough Vitamin B5 through their diet. Just as with other B vitamins it can be synthesized by microorganisms in the hindgut.

Vitamin B6 (Pyridoxine) is part of most enzymes that are involved in amino acid metabolism. It is an essential factor for energy production and also plays a role in the production of hemoglobin.

Dietary requirements have yet to be established, but since no deficiencies or toxicities have been reported it is assumed most horses consume enough Vitamin B5 through their diet. Just as with other B vitamins it can be synthesized by microorganisms in the hindgut.

Vitamin B9 (Folic acid) is necessary for the normal production of red blood cells and cell duplication.

Dietary requirements have yet to be established, but since no deficiencies or toxicities have been reported it is assumed most horses consume enough Vitamin B5 through their diet. Just as with other B vitamins it can be synthesized by microorganisms in the hindgut.

However, it must be noted a study in 2002 found negative effects on vitamin B9 levels in horses that were treated for Equine Protozoal Myeloencephalitis (EPM – caused by a parasite that affects the central nervous system) with sulfadiazine and pyrimethamine. A deficiency of vitamin B9 would lead to anaemia.

Vitamin B12 (Cobalamin) is involved in the metabolism of carbohydrates, proteins and fats. It also promotes red blood cell production and is involved in the functioning of the central nervous system. Unlike other water-soluble B vitamins, vitamin B12 can actually be stored in the body in small amounts.

B12 is somewhat unique in that is does not exist in plants. It's synthesized by the bacteria in the hindgut. This process needs cobalt and research has shown that supplementing 15mg of cobalt chloride has an impact on vitamin B12.

Dietary requirements for Vitamin B12 remains to be established and as such neither deficiencies or toxicities have been reported. However, supplementation could be useful when the microbial population in the hindgut is disrupted. Possible risk factors include:

- Long term anti-inflammatory drug use
- Antibiotic administration
- General poor health
- Dietary changes
- Poor quality forage
- Reduced appetite
- Diarrhoea
- Ulcers
- Stress
- Parasites

While isolated B-12 supplementation is available, it is more effective to use a complex B vitamins supplement. This is because the other B vitamins are also synthesized by the horse's hindgut bacteria, so if there are problems with B-12 production due disruption of micro bacterial population in the hindgut, it is likely that the production of other B vitamins is also affected.

In summary, it can thus be said that many factors influence availability of B vitamins. Apart from Vitamin B1-B2, dietary requirements have not yet been established and is thus assumed that most horses receive an adequate amount of B vitamins through their diet. However, B vitamins are produced by the microflora of the hindgut and therefore if the micro bacterial population is disrupted, vitamin B availability can be reduced and supplementation may be beneficial. It is advised to use a B complex product rather than supplementing isolated sources of B vitamins.

VITAMIN C

Vitamin C acts as a powerful anti-oxidant. Is also needed for collagen and hormone synthesis. Furthermore, Vitamin C also plays a role in the immune system – including histamine control - by stimulating the formation of antibodies.

The horse is able to produce vitamin C from glucose. However, since many factors can cause depletion the horse still needs dietary sources as well. A dietary requirement for vitamin C has yet to be established. Furthermore, knowledge about vitamin C levels in feedstuff is generally lacking. It thus simply assumed that horses who have access to fresh forage should get sufficient vitamin C through their diet.

The horse's needs for vitamin C might be affected by factors such as age, disease and stress, but so far research is limited and contradictory. Investigating the response to supplementation of vitamin C is tricky, because different forms of vitamin C have different absorption rates and it is believed that horses have large individual utilization differences. So far research has mostly looked at supplementation between 4.5-20 grams a day.

Supplementation at the higher end might lead to a decrease in the horse's vitamin C production. This could potentially be problematic when supplementation is suddenly withdrawn.

The take home message is that most horses do not seem to need supplementation of vitamin C, but further research is needed. Always consult a nutritionist and if you do choose supplementation then select a form with good availability such as *Ester-C* and monitor results. If withdrawing after a while, it is advised to do so gradually.

THE ROLE OF PLANTS, TREES & VEGETABLES

In the past chapters I sometimes referred to herbal feeds that contain certain amounts of vitamins and minerals. Herbs are an important source in providing the horse's nutrient requirements. In nature, the horse naturally selects a range of tree barks, herbs etc. depending on its needs. Planting certain bushes, trees or herbs into your field could allow your horse to self-medicate when necessary. Furthermore, most herbs are seasonal and thus you could also pluck what is available during each season and provide this in the meal. Of course buying them commercially from a good organic manufacturer is also an option.

Feeding herbs requires common sense (there is a lot of pseudo-science), patience and a degree of monitoring and observing. In general, herbs could be selected for nutrient or healing properties in their seeds, flowers, stems, roots or leaves.

The most commonly available herbs, vegetables and tree barks include:

- Stinging nettle (Iron, Vitamin A & C – also serotonin)
- Comfrey (allantoin – healing properties for bone, cartilage and tissue)
- Dandelion (Vitamin A, B,C sodium, calcium, potassium, choline)
- Chamomile (healing properties – parasympathetic nervous system; Ph and Ca)
- Rosehips (healing properties – immune system; Vitamin C)

- Garlic (healing properties – protection against infections; anti-oxidant)
- Tumeric (healing properties – anti-inflammatory; most minerals)
- Carrots (Vitamin A; calcium, magnesium, folic acid, potassium, phosphorus)
- Kelp (Vitamins A, B-2, C,D and E; Zinc, Iron, Iodine, copper, calcium, potassium)
- Slipper Elm (healing properties – anti-inflammatory; detoxification)
- Wheat Germ (Iron, Potassium, Magnesium, Calcium, Zinc, Manganese; Vitamin E)
- Meadowsweet (healing properties – anti-inflammatory & pain killer)
- Willow bark (healing properties – anti-inflammatory & pain killer)
- Boston Ivy (healing properties – anti-inflammatory & pain killer)
- Birch leaves (healing properties – detoxification)
- Green veggies (Vitamin A, C, K; Folate, Calcium, Iron)

Since the full scope of gemmo therapy or herbal medicine falls beyond the scope of this manual, the list above is very basic. Many more herbs are available, but these are generally the most commonly used. So how to integrate some of these herbs?

- Plant some trees so the horse can choose and self-medicate
- Leave the 'good' weeds so the horse can choose and self-medicate
- Pluck during season (for example rosehips usually grown in spring and autumn)

For more specified uses of herbs please consult a qualified herbalist or gemmo therapy specialist.

CONCLUSION

Whoohoo!! You made it all the way to the end of Part 1 of this manual. Studying nutrition for is complex. In fact, recommended requirements for a lot of feeds has not yet been truly established. Most daily needs are defined only because it is known that horses consuming it at a certain level haven't had any signs of deficiencies or toxicities. As such, further research is needed.

Although complex, I do hope you have gained some new insights. In summary, keep the following things in mind when it comes to optimizing your horse's diet:

- *Provide sufficient clean water to ensure optimal digestion*
- *Feed between 1.5-2% of the horse's bodyweight in good quality fiber*
- *Avoid high levels of sugars, starches and fructan to keep a healthy pH*
- *Balance vitamins and minerals properly: Pasture or a hay only diet can easily exceed energy requirements of most horses at rest or in light work, but it doesn't supply everything that they need in terms of trace minerals.*
- *Feed according to workload: a horse in heavy work (or pregnant) burns more calories than a horse at rest or in light work*

I will now continue to elaborate on exercise physiology and the relationship between nutrition and energy.

PART 2: BASIC EXERCISE PHYSIOLOGY

The horse as an athlete

Athletic ability, regardless of sport of species is determined by three main factors:

- Genetics
- Environment
- Training

Environment includes factors such as surface, nutrition and equipment.

The horse shows some unique physiologic adaptations to exercise which makes it difficult to apply findings from human physiology directly to the horse.

The superior athletic capacity of the horse is made possible to various physiologic adaptations. Some of these adaptations are not affected by training – for example lung size, whereas others change in response to exercise – for example blood volume. The most important adaptations include:

- Aerobic capacity
- Thermoregulation
- Energy metabolism

In the coming chapters I will dive deep on each of these physiologic adaptations.

CARDIOVASCULAR PHYSIOLOGY

In order to support a high metabolic rate of strenuous exercise, horses have structural adaptations that allow for the transportation of large volumes of oxygen. The maximal aerobic capacity of horses is +/- 2.6 times that of similar sized animals and +/- 2-2.5 times that of highly trained humans (Jones et. al 1989). This large aerobic capacity is associated with a number of key factors, the most important including:

- Cardiac output [stroke volume x heart rate]
- Hemoglobin concentration [splenic contraction]

The heart and longs of an 1.47 Arabian horse.

Cardiac output is the volume of blood pumped by the heart each minute and increases during exercises. Cardiac output is *''the product of heart rate and stroke volume. It is the cardiac output that determines the delivery of blood, and hence oxygen, to tissue.''*
– Hinchcliff & Geor 2008

CO	=	SV	x	HR
cardiac output	=	stroke volume	X	heart rate
(ml/minute)		(ml/beat)		(beats/min)

Stroke volume [SV] is the volume of blood pumped from the left ventricle per beat. It depends on various factors such as heart size, contractility, exercise, preload and afterload.

In general, horses with a **heart weight** of 0.9-1.1% of bodyweight have proportionally large hearts and thus stroke volume. The heart weight of the famous racehorse Secretariat [1970-1989] was estimated at 10 (!) kilograms, which is about 2.5 times that of the average horse.

Secretariat [Thoroughbred] became the first Triple Crown winner in 25 years in 1973 - aged just three years old. His record-breaking victory in the Belmont Stakes is widely regarded as one of the greatest races of all time.

The heart size as a proportion of total bodyweight varies greatly among breeds, with draft horses generally having proportionately smaller hearts than those of sports breeds.

Apart from heart size, prolonged aerobic **exercise** [something which will be explained in depth in coming chapters] may also increase stroke volume, which often results in a lower resting heart rate.

Finally, **pre- and afterload** also play a factor. Preload is the degree to which the ventricles are stretched prior to contracting. Stroke volume is intrinsically controlled by preload. An increase in the volume or speed of venous will increase preload, and thus increase stroke volume. The opposite is true for decreased venous return.

Afterload is measured as the aortic pressure during systole – the period of contraction of the ventricles of the heart that occurs between the first and second heart sounds of the cardiac cycle [the sequence of events in a single heart beat]. Within healthy horses it usually doesn't affect stroke volume, but in case of cardiovascular diseases, increase afterload will hinder the ventricles ejecting blood, causing reduced stroke volume.

The second factor that contributes to cardiac output is **heartrate**. Resting heart rate [HR] values are between 28-40 in adult horses[1], whereas values of 40-60 are more usual in athletic humans under the same conditions. However, it must be said that conditioned horses generally have a slower resting heart rate than normal horses.

During exercise, heart rate values between 240-260 beats per minutes have been recorded in racehorses, whereas maximum values between 180-200 beats per minute are more common in the athletic human. From this it stems that a well-trained racehorse has the ability to increase its heart rate almost 10-fold from rest to maximal exercise whereas humans are only capable to increase heart rate 3-4 fold.

All of the above explains why horses have a greater cardiac output than humans and this greatly contributes to their superior athleticism. The cardiac output of Thoroughbred horses during intensive physical exercise is measured as high as 400 litres per minute.

The second most important factor contributing to the horse's large aerobic capacity is the large concentration of **Hemoglobin**. Hemoglobin is a protein in red blood cells that carries oxygen to the organs and tissues and transports carbon dioxide from the organs and tissues back into the lungs.

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[1] *It is higher in the first five years of the horse. See manual Basic Anatomy for more information on factors that affects general heart rate.*

Oxygen transport depends on the ability to transfer oxygen from the air to pulmonary capillary blood[2]. Horses have a large surface of the lungs and a high flow rates generated by pressure differences between the pleural space and ambient air.

In addition to cardiac output, oxygen delivery is limited by the oxygen carrying capacity of blood. The oxygen carrying capacity of blood is determined by the presence of red blood cells relative to the total blood volume – otherwise known as *haematocrit*. Within athletic humans, this haematocrit value is maintained between 40-50% and this is only slightly influenced by exercise:

> *''The total number of red blood cells contained in that volume may increase only slightly during exercise in humans''*

The horse on the other hand has the unique ability, specifically during exercise, to release a large number of red blood cells through **splenic contraction[3]:**

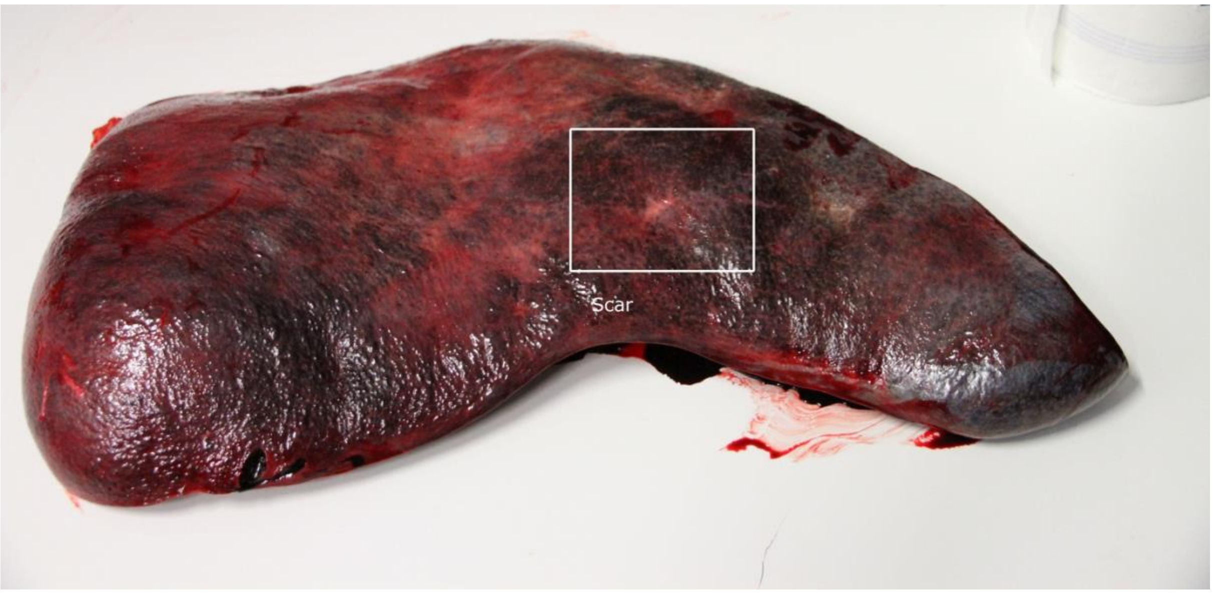
> *''Horses achieve rapid increases in the oxygen-carrying capacity of blood by increasing Hemoglobin concentration in blood through splenic contraction. Splenic contraction in anticipation of exercise and during exercise increases the circulating red cell mass without concomitant increases in plasma volume. The resulting increase in hemoglobin concentration increases the oxygen carrying capacity of arterial blood by up to 50% during intense exercise ''*

As such, the equine spleen is thus a major contributor to the horse's athletic performance by the ability to drastically increase the oxygen-carrying capacity of the horse's blood during exercise. The beneficial effect of this release of red cells at the start of exercise is evident in horses from which the spleen has been removed. Splenectomised horses have a lower

[2] For the exact process, please read manual Basic Anatomy

[3] *Remember, the human spleen is a defensive type whereas the horse's spleen – just like cats and dogs – is a storage type. For more information see manual Basic Anatomy.*

haematocrit value during exercise and show reduced capacity to perform strenuous exercise.



The equine spleen. On this picture there is scar tissue visible on the surface of the spleen which affects its function and thus the horse's athletic capability

The final step in the oxygen transport is the utilization of oxygen in the muscle. A great aerobic capacity in muscle is supported by the high capillary density and high activity of enzymes [mitochondria] involved in energy utilization of oxygen in the horse's muscles. **Mitochondria** provide the energy for muscle contraction. The greater the amount of mitochondria per unit of muscle weight, the greater is the oxidative capacity of the muscle. Equine muscles contains +/- twice the concentration of mitochondria as does muscle of cattle.

THERMOREGULATION

Thermoregulation is the ability of the horse's body to maintain or return to its normal internal temperature. Depending at the situation at hand, a horse has several mechanisms in place to either lose produced heat when it needs to cool down, or to increase heat production when it needs to warm up.

Heat dissipation – Cooling down

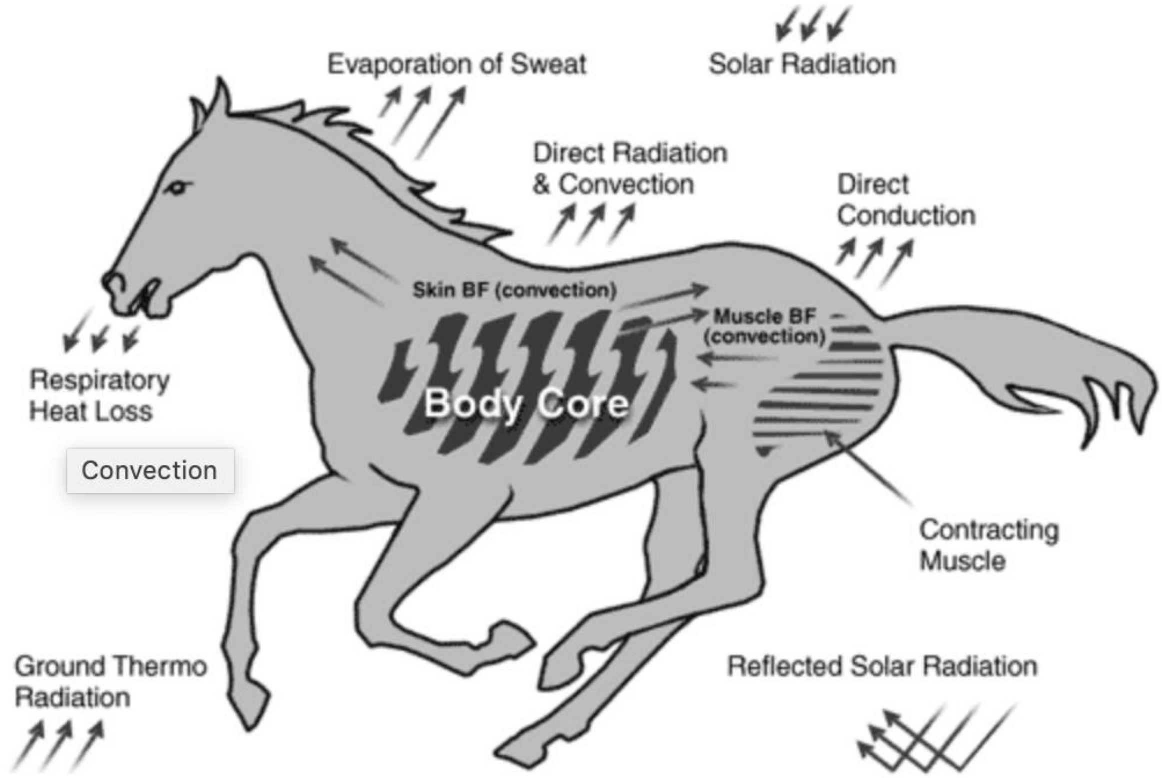
Heat production occurs with the metabolism of energy sources for exercise. Muscle contraction produces heat which, if not effectively dissipated, results in hyperthermia. The heat generated by an exercising horse is sufficient to raise its body temperature by 3-5 degrees Celsius. If the exercise is prolonged and not accompanied by effective heat dissipation, the temperature may exceed 42 °C posing risk of head shock and illness:

> *''Conversion of stored energy into mechanical energy during exercise is relatively inefficient with approximately 80% of the energy being given off as heat. Relative to many species the horse suffers an apparent disadvantage by possessing a high*
>
> *metabolic capacity yet a small surface area for dissipation of heat, particularly as evaporation of sweat is the major method of heat dissipation*. '' – Hodgson & McConaghy 1994

Heat generated in muscle is transported by the blood to the skin and respiratory tract, from where it is lost into the ambient air. Heat dissipation from horses is achieved by evaporation of sweat and respiratory tract secretions as well as convective loss of heat in air moving over the horse's skin and respiratory membranes.

So, put together, the hose 5 major mechanisms for losing heat:

- Convection
- Direct Conduction
- Direct Radiation
- Sweat evaporation
- Respiratory heat loss



Convection is the dissipation of heat from deep within into the ambient air. As heat moves to the surface, it is carried away by air movement – such as wind. As such, on hot, humid days not much wind, putting a fan in the stable or paddock will help to cool your horse off more quickly.

Direct conduction is the loss of heat by contact and concerns the transfer of heat built up in the horse's blood into the air. Hot temperatures affect the efficiency of this mechanism.

Direct radiation is the radiant heat coming directly off the horse. The process is slowed down if the sun is burning down. Therefore, moving your horse to the shade will help this cooling process to be more efficient.

Sweat evaporation is the main cooling process a horse relies on. However, keep in mind that sweat is unable to evaporate during humid weather and as such you need to assist the cooling down process by providing shade and/or placing a fan or mist shower in your horse's direct environment.

Furthermore, you also need to take into account that horses also lose sodium and chloride in sweat. As such, you might need to replenish these losses with an electrolyte supplement when the horse sweats a lot.

Finally, horses can lose heat while **exhaling.**

Heat production – Warming up

When a horse is exposed to decreasing temperatures, the horse can rely on a few mechanisms for cold adaptation, including:

- Coat production
- Shivers
- Vasoconstriction
- Piloerection
- Respiratory rate
- Neuro-endocrine system

We all know that during winter the horse **produces a thicker and longer coat** which serves as protection for lower temperatures.

Furthermore, when needed the horse can generate heat via **shivering.** The contraction of muscles produces from the aerobic metabolism of carbohydrates and fats. This reflex mechanism can be maintained for quite a long time.

Vasoconstriction is the constriction of blood vessels of limb extremities which limit heat loss. This what causes cold and white fingers and toes in humans as well. The blood flows back to the central organs and as such can avoid tissue damage when horses have their hooves in snow.

This mechanism can also be activated when cooling your horse's feet with water in hot weather circumstances. This why you need to walk a bit in between so that the blood vessels will open again.

Piloerection is the mechanism that bristles hairs and increases hair thickness up to 30%. However, when the horse's coat gets very wet it will lose the ability to employ this mechanism.

The horse can also reduce the caloric loss through evaporation by **decreasing its respiratory rate.**

Finally, the horse can **mobilize its neuro-endocrine system.** The adrenal glands will release adrenaline and norepinephrine which allows for the mobilization of glycogen in muscle.

Thermal Comfort Zone

The Thermal Comfort Zone refers to the temperature range within the body that does not consume extra energy to maintain the internal body temperature.

For a mature, unclipped horse the thermal comfort zone is roughly between 5-25 degrees Celsius. However, this might vary between breeds as well as individuals. Factors that play a role include:

- Age
- Breeds
- General health
- Management
- Nutrition
- Habitat

Foals usually have a thermal comfort zone between 16-25 degrees Celsius. In older horses, thermoregulation might be impaired.

Certain breeds or types are more suited for either colder or warmer climates. In general, more compact, robust and type of horses with sufficient fat can adapt more easily to cold. They can mobilize fat reserves for a long period of time without the production of lactic acid.

On the opposite, leaner and sportier type of horses adapt more easily to a bit warmer temperature. They usually are a bit more difficult to fat and adapt to rapid temperature changes by using muscle glycogen.

General health naturally also plays a role. Infections generally increase internal heat as the body is busy fighting off the intruders.

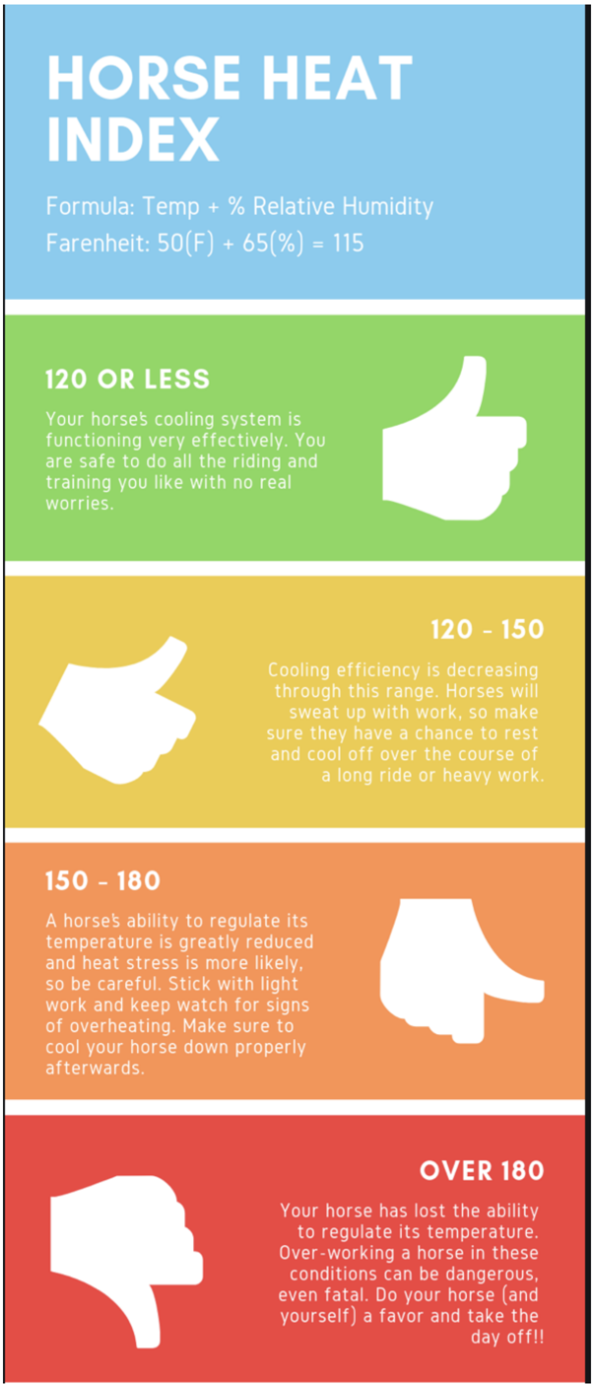
Management is also an important factor. Today, many owners choose to clip and/or rug their horses. This affects the horse's natural ability to regulate body temperature. As such, the horse relies more on humans to aid in thermoregulation. It might be necessary to change the thickness of rugs even several times a day depending on the outside temperature. This can be quite a hassle. The discussion whether clipping and/or rugging is appropriate goes beyond the purpose of this manual, but I would advise anyone to never take such a decision lightly simply because 'everyone does it' and to consider your horses needs in depth.

Since horses use energy sources to generate heat, **nutrition** determines the horse's ability to either lose or generate extra heat. For example, replacing some of your horse's carbohydrate intake with fat (see high-fat diet) might be useful for horses that need to perform in hot weather conditions. Low levels of sodium results in a low level of dehydration and as such the horse will be more susceptible to heat stress.

Finally, horses also adapt to their natural **habitat.** Horses that live outside usually gradually adapt to the climate it lives in. A horse that lives in a country with a strong change of seasons the horse will adapt to lower temperatures by a change in coat, different metabolism of fat tissue, modifying behaviour and food digestion. These adaptations allow for example Bosnian Mountain Horses to easily cope in freezing temperatures and heavy snowfall.

In general, horses will need about 10-20 days to adapt to a temperature change of about 15 degrees Celsius.

Heat Index



A useful tool to determine whether it is too hot to train is the so-called heat index:

HI = Temperature (F) + Relative humidity (%)

Thus, you need to measure the temperature in Fahrenheit and add the percentage of Relative Humidity. The total outcome number roughly determines your horse's ability to regulate its temperature at that time.

Of course, this equation is not definite, and you need to closely monitor your horse's vitals as well.

Furthermore, also consider that when you want to travel your horse that temperatures inside a trailer or horse lorry can be about 50 degrees Fahrenheit (10 °C) higher than outside temperature. This naturally increases the total outcome of the heat index.

Source: Horse Handbook

EQUINE ENERGETICS

The subject of equine energetics can be divided into two closely related topics:

- Energy generation (metabolism) during exercise
- Dietary considerations to provide or replace the energy used during exercise

Just like humans, horses need energy to perform various athletic activities. The requirements for performance are met through metabolizing various nutrients:

> *''Fundamentally, the body's ability to extract energy from food nutrients and to transfer the energy to the muscles that power the body determines the horse's capacity to run and jump.''* – Geor 2000

AND

> *''The basic driving force behind all different types of equine performance is the conversion of chemically bound energy from feed in mechanical energy for muscular movement.''* – Pagan 1998

Put simply, the horse's body is an engine that requires fuel to run. The fuel tank consists of the body energy stores and is filled by the digestion and absorption of nutrients [primarily carbohydrates and fats] in the diet. The faster the engine runs, the more fuel is required. Conversely, when the fuel runs out, the engine will stop running.

In the coming chapters I will elaborate on the horse's energy metabolism and its relation to nutrition to help you better understand this complex, but fascinating relationship.

ENERGY DEFINITION

As mentioned in the previous section, the macronutrients are the main source for providing energy. But what really is energy?

Energy exists in a number of different forms, namely nuclear, light, chemical, electrical, mechanical, and heat energy. Beyond this, energy becomes a bit more difficult to define:

> *''Unlike the physical properties of matter [size, shape and weight], energy cannot be defined in concrete terms.''* - Geor 2000

The word energy refers more to a concept that can be paraphrased as *''the potential for causing change''.* As such, the most commonly accepted definition of energy is *the work that a certain force can do.*

The many forms of energy can be grouped into two major categories:

- Kinetic energy
- Potential energy

Kinetic energy is the energy of movement. Think of a ballerina leaping through the air, or a horse performing advanced dressage movements. **Potential energy** on the other hand is stored energy. When someone tells you that you have potential, they are telling you that you have the ability to do something in future. Hence, potential energy has the ability to become kinetic energy.

That ability may come from gravity[4]. For example, if you sit on your horse you have potential energy because if you begin to slide, you will gain kinetic energy as gravity pulls you to the earth.

[4] It could also be elastic, chemical or nuclear

Lots of energy here;)

Nutrition is also a source of potential energy: stored fuel from nutrients can be transferred into a mechanical energy enabling muscle contraction and movement:

> *''Among the nutrients that are important to the performance horse, energy is the dietary factor most affected by exercise. Energy is not a nutrient per se but is, rather, a measure of a feed's potential to fuel body functions and exercise.''* – J. Pagan 1998

The latter makes clear that there are some physical principles that constitute the concept. One of the most important principles states that energy is a **conserved quantity**, meaning that it cannot be created not destroyed, but only converted from one form into another. For example, in case of physical activity, stored fuel sources provided by macronutrients are broken down by a series of reactions and result in the release of chemical energy. In turn, this chemical energy will be converted into mechanical energy enabling muscle contraction and movement. The remainder of the chemical energy will be released as heat energy.

Although we mostly think of energy in terms of physical activity, energy is also required for the maintenance of virtually all of the body's functions. For example, energy is required for digestion, absorption, respiration, building new tissues and brain function. The term **basal metabolic rate** is commonly used to described the energy used for these maintenance functions. In reality, more than 60% of the body's daily energy needs relate to this basal metabolism. If these needs are satisfied, the body can use additional available energy for processes such as physical activity.

ENERGY METABOLISMS

So now let's dive a bit deeper in the connection between nutrition and energy. The energy present in food cannot be used directly to drive the body's functions. It relies on a chain of chemical reactions that take place inside the horse's body to unleash the energy, i.e. the process of metabolism!

The process of metabolism can be divided into two different categories:

- Anabolic reactions
- Catabolic reactions

During **anabolic reactions**, energy is used to build structural components of the body such as muscle. These usually occur just after feeding. During **catabolic reactions** large particles are broken into smaller particles and produce energy. These usually occur a couple of hours after feeding or during exercise when energy is needed.

One of the most important molecules produced in catabolic reactions that unleash the energy within food is **Adenosine Triphosphate [ATP].** Each ATP molecule contains 3 high energy phosphate bonds. A large amount of energy is released when a phosphate splits from the original ATP molecule. This released energy can be used to drive energy-requiring processes in cells of the body. For example, the energy release from ATP allows muscle fibres to contract during physical exercise. As such, ATP can be considered as the '*energy currency'* of the body.

There is not much ATP stored in muscle cells. This is a critical point because the energy needs of a muscle cell increase enormously during exercise, whereas the amount of ATP stored is barely enough to support two of three contractions. Hence, during exercise ATP must be [re]produced as quickly as possible to maintain the supply at the same rate at which it is used.

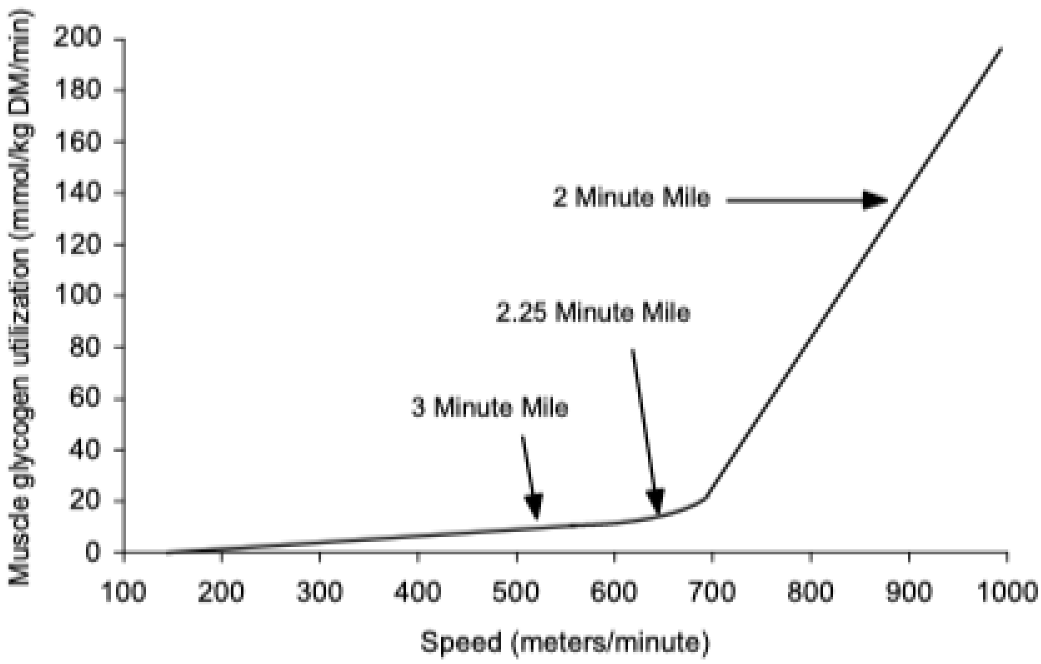


Figure 1. Muscle glycogen utilization as a function of speed

This is the point where we can start to see the link between nutrition and exercise: the stores of energy that are used to produce ATP quickly comes from the food that the horse consumes.

As mentioned earlier, the three macronutrients in the horse's diet are carbohydrate, fat and protein. It has also been explained that carbohydrate and fat provide the main energy sources for physical activity. Since horses do not eat continuously while exercising, feed energy must be stored in the horse's body for later release.

The storage form of carbohydrate is glycogen, a substance made of glucose molecules. Glycogen is stored both in the liver and in the muscle. Glycogen storage in the liver is mainly used to supply glucose for all tissues in the body, especially the brain and nervous tissues as well as red blood cells.

The vast majority of the horse's glycogen storages are present within skeletal muscles. These storages serve exclusively as source of energy for working muscles. Up to 1-2% of the muscles weight is in the form of glycogen. Impressive as this might seem, it is nothing compared to the storage of fat.

The storage form of fats is adipose – or fatty – tissue. It surrounds the body's major organs and can be found scattered throughout the muscles. The amount of fat present differs greatly between individual horses, but on average about 7-8% of the horse's body weight is fat. Interestingly, this is much lower than the percentage of the average human – which is about 10-20%.

That being said, fat is an extremely energy dense fuel. In terms of energy, the storage of fat is virtually inexhaustible and could sustain light to moderate exercise for a number of days. However, the horse cannot solely rely on fat providing energy for exercise, meaning that the storage of glycogen is critical to the maintenance of energy supply during exercise. Let me explain this further. The relative contributions by carbohydrate [glycogen] and fat to ATP regeneration during exercise are primarily dependent on two elements:

- Speed of exercise
- Duration of exercise

In turn, these elements are managed by two fundamental metabolic processes that drive ATP regeneration:

- Aerobic metabolism
- Anaerobic metabolism

AEROBIC METABOLISM

The process of aerobic metabolism involves the breakdown of carbohydrates ánd fats into water, carbon dioxide and heat. These reactions requires oxygen, hence the term aerobic. It is highly efficient as it produces much more ATP than the process anaerobic metabolism. It does not lead to fatigue and so exercise based on aerobic metabolism can be sustained for much longer.

The downside is that the process is a bit slow as an adequate delivery of oxygen must be maintained. This involves expending energy to ventilate the lungs and to pump the blood through the lungs and to the muscles. Especially the aerobic metabolism of fat requires large amounts of oxygen. It can take 20-30 minutes to get production up to speed and the rate of ATP production is slow.

The advantage of fat on the other hand is that it contains more potential energy than glucose or glycogen. As such, fat is an important source for light to modern exercise, but it won’t win a race. For that, the horse mostly relies on carbohydrates.

Oxidative stress

Aerobic metabolism uses oxygen to produce energy. However, about 1-2% of this oxygen is not used and result in the formation of free radicals, otherwise known as Reactive Oxygen Species (ROS). It's easy to label free radicals as "bad," but they are, in fact, a perfectly natural consequence of aerobic metabolism. Oxidants can be beneficial, but they need to be balanced and stabilized by anti-oxidants. Anti-oxidants include vitamins, minerals, enzymes and proteins that must be synthesized from the body or obtained from the diet.

Oxidative stress occurs when there is an imbalance between oxidants and anti-oxidants. When there are more free radicals present than can be kept in balance by anti-oxidants, the free radicals can start doing damage to DNA, fatty tissue and proteins and thereby contributing to degenerative changes throughout the horse's body.

During periods of stress, such as exercise, the rate of oxidation is higher because the horse's body needs to produce ATP by drawing upon nutrient energy sources. Anti-oxidant defences help prevent free-radical induced damage. However, after strenuous exercise, oxidant production might overwhelm the system and oxidative stress can occur.

All horses are subject to oxidative stress. Major factors include increased workload and diet:

> *''Increases in oxidative stress and changes in antioxidant status have been shown during endurance and intense exercise and eventing competition in horses (…) Exercise level and diet are both factors that play a role in influencing oxidative stress and antioxidant status of the equine athlete. Along with exercise intensity and duration, diet, age, and training program can also affect oxidative stress in the horse''* – Williams 2016

I want to add that also mental stress increases oxidative stress due to the production of adrenaline.

When oxidative stress occurs, the requirement for antioxidants such as vitamin B12, C, E and lipoic acid increases. These antioxidants convert free radicals into hydrogen peroxide and water. As such, horses prone to oxidative stress might benefit from supplementation:

''Several studies using exogenous supplementation of vitamin E, vitamin C, and alpha lipoic acid have shown positive results in decreasing the effects of exercise (endurance and intense-exercise) induced oxidative stress and increasing the antioxidant status based on the markers and antioxidants measured, whereas other studies using superoxide dismutase showed little effects on the exercise horse.''
– Williams 2016

In conclusion of this chapter, it is thus important to avoid stress levels and provide sufficient anti-oxidants to allow your horse to maintain a proper oxidant – antioxidant level.

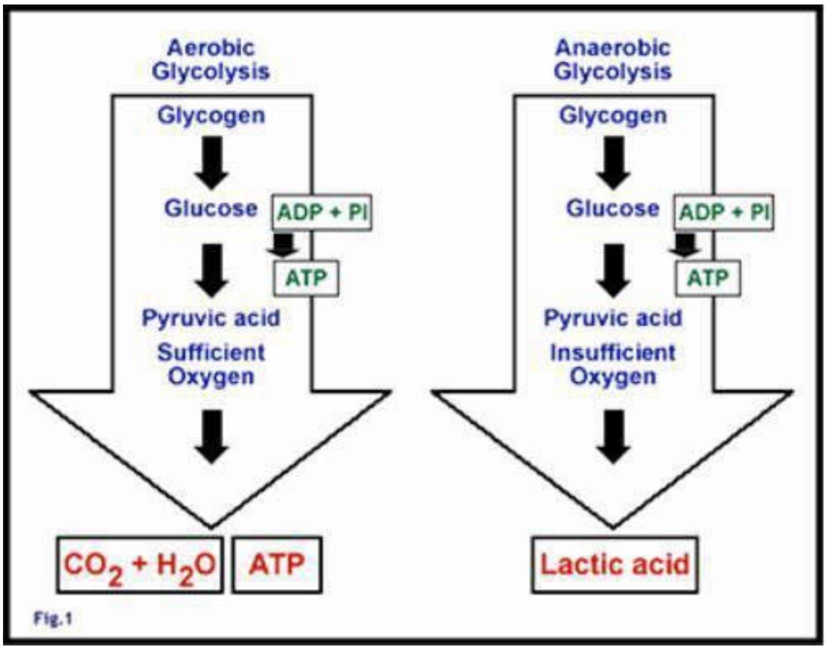
ANAEROBIC METABOLISM

The process of anaerobic metabolism involves the breakdown of glucose from glycogen into lactic acid. These reactions do not need oxygen. Since fat does not contain glucose, anaerobic metabolism exclusively deals with carbohydrates only.

The speed and duration of the exercise determine the balance between the activation of aerobic and anaerobic metabolism. Exercise at a continuous speed such as endurance can be maintained almost entirely by the aerobic metabolism. However, when the speed of exercise increases, so does the energy demand placed on the muscle. More oxygen is consumed by the horse until it reaches a speed where the delivery of oxygen or the ability to utilize oxidative processes become limiting. This is where the anaerobic metabolism starts to kick in. To meet the demands of performance at an increased speed, the anaerobic metabolism can provide a rapid supply of ATP without the need of oxygen. As such, exercise that requires speed such as racing, cutting, jumping etc. involve a substantial amount of anaerobic metabolism.

However, it must be said, that although endurance exercise is typically referred to as aerobic and speed exercise as anaerobic, in reality, all forms of exercise usually combine a bit of both elements. Research data suggest that the horse enters the **anaerobic threshold** when the heart rate rises above 150-170 beats a minute. At this level, lactic acid begins to accumulate faster than it can be removed. Heart rates above 200 lead to rapid fatigue.

The breakdown of glycogen to glucose units is trigged by a number of factors including increases in adrenaline as well as insulin – which will be explained in the next chapter. The glucose is then metabolised through a series of specialized chemical reactions catalysed by a number of enzymes to regenerate ATP. This is the process of glycolysis and leads to lactic acid.



The breakdown of glycogen to lactic acid is really the equivalent of rocket fuel. It can be accelerated immediately and doesn't have to wait for an increase in breathing and heart rate to deliver oxygen to the muscles. It is this phenomom that enables a racehorse to accelerate straight into a gallop out of the starting stalls.

However, there are two down sides to this process: it is inefficient and self-limiting. It is inefficient – compared to aerobic metabolism – as it only produces a small amount of ATP from the potential energy locked in the glucose resulting from the breakdown of glycogen to lactic acid.

It is self-limiting as it can lead to fatigue. Fatigue is often considered as an annoyance, but it actually is an excellent safety mechanism allowing the horse's body to say: I've had enough. Pushing beyond the point of fatigue can lead to injury. Fatigue is dependent on the type of exercise being undertaken and other circumstances such as weather conditions, hydration and general fitness. During intense exercise fuelled by glycolysis, fatigue occurs as a the result of numerous factors, but is partly due to the accumulation of lactic acid within the muscle. The lactic acid splits into lactate and a hydrogen ion. Hydrogen ion lowers the muscle pH value and makes the conditions inside the muscle cell acidic, which in turn slows down the process of glycolysis. As such, anaerobic metabolism is self-limiting when it is running flat out.

Left: endurance training is typically labelled as aerobic work. Right: speed activities are usually labelled as anaerobic work.

THE ROLE OF INSULIN

As mentioned in the previous chapters, ATP can be resynthesized through drawing upon nutrient energy sources. Insulin is a key player into converting the potential energy from food and thus we need to dive in a little bit deeper.

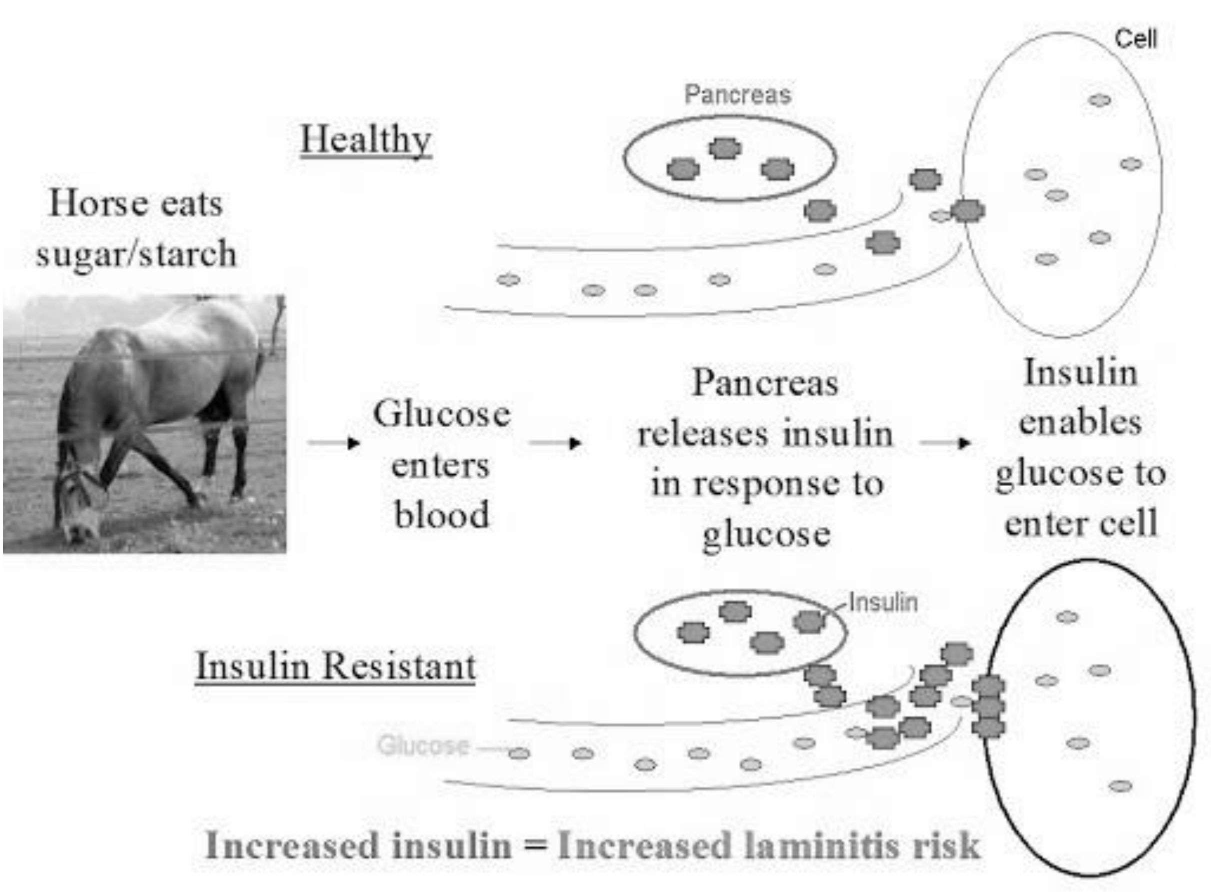
Insulin is a hormone produced by the horse's pancreas. Insulin plays a number of roles in regards to the horse's energy metabolism as it activates glycogen synthase. Insulin allows liver, muscle, fat and kidney cells to iniate the following actions:

- Storage of glucose in the form of glycogen
- Regulating blood glucose concentrations
- Conversion of fatty acids and glycerol into fat
- Conversion of amino acids into protein
- Prevention of gluconeogenesis

The most important function of insulin is transport glucose from blood through the cellular wall into the cell so it can be used. As mentioned earlier, the horse needs sugar for energy. However, sugar cannot be used to fuel energy requiring activities - such as brain function and exercise - directly. Upon ingestion, blood sugar level in the horse rises. In reaction, beta cells in the pancreas are signalled to release insulin into the horse's bloodstream. Insulin then attaches to and signals cells to absorb sugar from the bloodstream. As such, insulin is often described as a 'key' that unlocks the cell and thereby allowing sugar to enter the cell and be used for direct energy or to be stored for later use.

Excess glucose that isn't directly needed will be stored in the form of glycogen (both in muscle and liver) or fat as a reserve for the future so it can be released when blood sugar level is low or when more glucose is needed. Therefore, insulin helps balance out blood sugar levels and keeps them within a normal range. As blood sugar levels rise, the pancreas secretes more insulin.

Since insulin is the main fat and glycogen storage hormone of the body, it is evident to understand that it is a major player in the horse's energy metabolism. When activity is increased, the horse activates either aerobic or anaerobic metabolism to draw upon the fat and/or glycogen reserves (that are created through insulin) to produce ATP and thus generate the energy required for performance. Disruptions in insulin production and sensitivity could have a major impact on the horse's overall health and performance.



Picture adapted from thelaminitissite.org

If the horse's body does not produce enough insulin or when cells are resistant to the effects of insulin, long-term implications can occur such as **insulin resistance.** In this condition, the insulin receptors become less sensitive to the effects of insulin. Therefore, the horse is unable to properly deal with glucose entering the body. Since blood glucose levels remain high, the pancreas continues to produce insulin. This leads to elevated concentration of insulin in the bloodstream. Since the glucose remains in the horse's bloodstream, the body cannot properly use glucose for energy. As such, horses suffering from IR often lack proper energy for performance and can be labelled as 'unwilling to work', 'phlegmatic', or 'flaggy'. Other common symptoms of insulin resistance include:

- Laminitis
- Obesity or underweight
- Fat pads at manes, tail and belly
- Skin problems – sweet ich
- Cushing Disease
- Decreased fertility
- Fatigue and muscle aches
- Back pain and tightness

Common causes of insulin resistance include:

- Nutrition
- Obesity
- Infection
- Stress
- Genetics??
- Insufficient movement
- Hormonal disbalances in mares

You might have noticed that weight issues could both be a symptom as well as a cause of IR. Now let me explain a bit more in depth. A horse can become underweight because the body cannot make use of glucose for fuel. As a result, the horse has no energy and is forced to raid its existing fat and muscle stores to produce energy. This can result in exhaustion and loss of muscle and weight.

On the opposite, insulin resistance also leads to obesity as insulin inhibits the breakdown of fat in adipose tissue:

> *''From a whole body perspective, insulin has a fat-sparing effect. Not only does it drive most cells to preferentially oxidize carbohydrates instead of fatty acids for energy, insulin indirectly stimulates accumulation of fat in adipose tissue.''*

In summary, complications of IR are multifaceted. Because it disrupts energy metabolism, it is important to prevent as much as possible, or to manage optimally when already present to enhance your horse's overall well-being as well as performance.

THE ROLE OF MUSCLE FIBER TYPES

In the manual Basic Equine Anatomy I have already explained that the horse has three basic types of muscle fiber:

- Type I
- Type II [A]
- Type II [B]

These fiber types have **different contractile and metabolic characteristics.** Type I fibers contract slowly whereas types IIA and IIB are fast contracting ones. Type I and type IIA fibers have a high oxidative capacity and can thus utilise fuels through aerobic metabolism whereas type IIB fibers tend to depend on anaerobic metabolism for energy generation.

Classification	*Type I ST*	*Type II FTH (II A)*	*FT (II B)*
Speed of contraction	slow	fast	fast
Max. tension developed	low	high	high
Oxidative capacity	high	intermediate to high	low
Capillary density	high	intermediate	low
Lipid content	high	intermediate	low
Glycogen content	intermediate	high	high
Fatiguability	low	intermediate	high

Metabolic characteristics of different muscle fiber types. Table adapted from Pagan 1998

There are various differences in the ratio of Type I to Type II muscle fiber constitution among breeds. For example, generally speaking Quarter horses and Thoroughbreds have a lower proportion of Type I muscle fibers compared to Arabians or Andalusians. This is what makes quarters and thoroughbreds more suitable for racing and western disciplines such as reigning. These disciplines require short-term, high-intensity activity outbursts that use anaerobic metabolism by fast twitch muscle fibers. On the opposite, the disciplines commonly associated with Arabians or Andalusians are long-term, submaximal intensity[5] aerobic events and therefore more slow twitch fibers are required.

Slow twitch (type I)	Intermediate fibers (type IIa)	Fast twitch (type IIx)
Slow oxidative fibers Aerobic metabolism Long distance/low intensity sports Fat accumulation Low glycogen content Small diameter and red color	Fast oxidative fibers Intermediate aerobic/anaerobic metabolism High myoglobin content High glycogen content Highly adaptive to training	Fast glycolytic fibers Anaerobic metabolism Power sports/ short distance Lactic acid producing metabolism High glycogen content Large diameter and white color

EFFICIENCY OF GAIT

The economy of locomotion refers to the optimal gait at a given speed of exercise at which the energy cost is least. It is well documented that this gait is naturally chosen by freely moving horses. So there is a speed of each gait where the energy cost of locomotion is minimal. In fact, at the optimal speed of each gait, the amount of energy consumed to move a give distance is much the same.

Stride frequency is a logarithmic function of walking speed in all species, a linear function of trotting or running speed, and nearly independent of speed in galloping. A 2004 study by Griffin et al. found that the absolute walk-trot transition speed increased with size, but it occurred at nearly the same speed-to-length ratio. In addition, horses spontaneously switched between gaits in a narrow range of speeds that corresponded to the metabolically

[5] *Although working equitation is usually a combination of aerobic and anaerobic work*

optimal transition speed. These results support the hypotheses that the walk-trot transition is triggered by inverted-pendulum dynamics and occurs at the speed that maximizes metabolic economy. The effects of training and athletic activities on horses are subject to the needs to be considered with regard to the economy of locomotion. Endurance horses forced to use extended gaits for prolonged period may become more fatigued rapidly than if they were to move at their natural speed for each gait.

For most large animals, energetically efficient gait is challenging due to the slow rate of contraction and low power output of the muscles. However, the gait of horses is energetically efficient, *''with the muscular work of galloping being halved by elastic storage of energy in muscle and tendon units.''*

For the front limb, the use of stored energy and the subsequent catapult action (recoil systems in the fetlocks) means that the *biceps and brachiocephalic* muscles are less than 1-100 the size they would need to be were there no use of stored energy. Horses are therefore biomechanically suited to energetically efficient locomotion.

However, a complication of understanding the biomechanics of horses during intense exercise is the fact that most equine events are not run in a straight line. While this has not been extensively studied in horses, greyhounds running around a bend have a 65% increase in peak force and a 70% increase in effective weight. Whether this phenomenon occurs in horses, and the impact of such forces on energetic efficiency, are uncertain.

PRACTICAL APPLICATIONS

The practical applications of the theoretical knowledge provided in this manual can be divided upon two closely related categories:

- Dietary considerations – in relation to performance
- Training considerations – in relation to goals and efficiency

Dietary considerations - in relation to performance

The dietary considerations in relation to performance are generally concerned with **what and when** to feed to enhance performance. For example, is it beneficial to feed the horse just before training or should this be avoided? What to feed after training to replenish depleted glycogen store?

In Part 1 of this manual I already explained the basic nutrient requirements for a horse as well as the benefits of a low sugar/low starch diet. I also explained that a horse mainly relies on carbohydrates for calories and that you need to measure your ratios properly to control your horses calorie intake. However, a specific dietary consideration in relation to performance that I didn't discuss yet is that of a high-fat diet.

High fat diet

In general, a **high-fat diet** for horses is a much discussed topic. The term 'high-fat' is a little bit of misnomer though. Normal fat content in the horse diet might be between 3-8% and high fat could be anything above that up till 20%. Above this, horses might suffer from digestive disturbance. By comparison, a typical human diet provides about 40% of calories from fat. If you choose to eat foods like ice cream or fast-food you may be getting up to 70% of your calories from fat. As such the horse, can only tolerate a relatively low fat diet – especially compared to humans, but there is evidence that feeding a horse an increased amount of fat (up to around 15%) has potential benefits for certain type of horses depending on the athletic demand at hand.

The potential benefits of fat supplementation include:

- Rich calorie source
- Increase in the digestibility of fat
- Improved energetic efficiency
- Metabolic adaptation that increases fat oxidation during exercise
- Enhanced heat tolerance
- Calming effect

The benefits of feeding high-fat diets to horses to increase performance remains controversial, although benefits for horses with problems such as recurrent tying up and gastric ulcers are unequivocal. Differences in the conditions of the horse, type of exercise, the length of the adaptation period to the diets, the type of fat used as supplement and the level of fat supplemented, especially in relation to carbohydrates make comparing the publishes results difficult. Feeding an increased level of fat is suggested to cause metabolic adaptation that permit horses to preferentially utilize fat and spare glycogen during exercise, but the evidence to support such a proposal is inconclusive (Lawrence 1990, Snow 1994).

First, fat is a **potent source of calories**, making it extremely useful in the diets for horses with high energy demands. Fat is best used to provide calories when needed, or as a replacement for some of the grain in an otherwise high-grain diet. So if you want to supply more energy to your horse without increasing the overall feed intake, supplementing fat is a great way to accomplish that. By doing so, the risk of digestive issues associated with feeding large amounts of starch-rich meals (such as grain) can also be possibly reduced.

Furthermore, in situations that require limited carbohydrates, such as horses that suffer from tying up, laminitis, colic or insulin resistance, fat can be used to help meet the caloric requirements when forage alone cannot do the job.

If you choose to supplement fat for benefits other than calories, realize that you might have to make other adjustments in the diet such as reductions in grain and hay to accommodate the extra calories and prevent obesity.

It must be noted though that when a horse already received too many calories exceeding its requirement, the primary goal should be to cut back on food ratios. In specific cases, a relative high fat diet might still be beneficial to the horse, but then one should be really careful with the calories and adjust the diet properly.

Second, several studies suggest there is an **increase in the digestibility of fat** when fats or oils are added to feed (Potter et al. 1992). This leads to an **improved energetic ability** as it can push back the anaerobic threshold. Remember, fat can only fuel aerobic metabolism, but not anaerobic. Adding fat to the diet provides a greater source that the body can continue to work with aerobically, delaying the switch-over to anaerobic metabolism and thus postponing build-up of lactic acid and fatigue.

However, once heart rate increases above around 180 beats per minute, even a horse that is on a high-fat diet for many months cannot continue to use fat and will rely on anaerobic metabolism as fat is high in energy, but the release of energy is slow and thus will only support low-moderate intensity exercise to any appreciable extent.

Certain studies have indicated that if the horse's system has supplemental levels of fat available as an energy source, the body can learn to use it in preference to glycogen. However, other studies on the effect of dietary fat supplementation on muscle glycogen storage provided conflicting observations. Thus, in some studies, muscle glycogen content was increased after oil or fat supplementation, while other studies reported no change or a moderate decrease in muscle glycogen content. As such, there is no consensus on the effects of dietary fat supplementation on muscle glycogen storage in horses. The variability in results between different studies could be due to differences in diet composition, duration of fat supplementation, muscle sampling and analysis techniques, breed, age and training state of the horses studied.

Third, in humans and rodent species high-fat diets result in **enhanced capacity for fatty acid oxidation** in skeletal muscle. There some evidence that dietary fat supplementation results in similar adaptation in fat metabolism of horses. Several studies found an increase in the utilization of fat, with a concomitant decrease in carbohydrate utilizations, during low- and moderate intensity exercise following oil supplementation (Dunett et al. 2002; Pagan et. al 2002; Kronfeld 1996). However, again, some studies failed to observe such an enhanced capacity to burn fat as the result of increased fat supplementation. Furthermore, few studies quantitatively assessed fat oxidation. These non-conclusive findings might be due to the apparent tremendous variation between horses in their ability to use fat during exercise. As such, for some horses it is a real winner, but in other horses these beneficial effects might not be observed.

Fourth, fat is a **'cool' energy source** in the sense that less heat is generated when utilising fat/oils as an energy source versus starch and non-structural carbohydrates. This decrease in the horse's heat load increases the amount of energy available for physical activity. Furthermore, it could help the horse to deal more efficiently with warmer outside temperatures.

Finally, fat is also considered a cool energy source in the sense that **it is reported to have a calming** effect on horses. The energy released is much slower than that in carbohydrates and as such fat supplementation appears to cool 'hot minded' horses. Horses fed fat added diets compared to typical sweet feeds have been found to be less reactive to novel stimuli. Obviously, fat supplementation shouldn't be considered as a substitute for proper training that focusses on relaxation, but could possibly aid.

In summary, it can thus be said that dietary fats have many potential benefits. I want to stress out the word potential, as so far scientific results have been inconclusive. There is still so much to learn and it shows how incredibly difficult this area of equine research is. There are so many individual differences within horses, that my best advice is to simply try if there is reason to assume that adding fat might be beneficial. Horses can easily digest up to 20% fat without any side effects or harm – apart from possible obesity. As such, it is relative 'safe' to try to upgrade to a more high fat diet if desired when you take into account the following important factors to ensure a smooth transition:

- Introduction time
- Adaptation time
- Nutritional balance

Supplemental fat needs to be introduced gradually to avoid averse affects such as greasy faeces or temporary decreased fiber digestibility. These effects can be avoid when the horse can gradually adjust, with an accommodation period of 4-14 days depending on the level of fat supplementation (Zeyner 2002; Kronfeld 2004).

Second, the length of time required for expression to metabolic adaptation to dietary fats has been debated. Some suggest a minimum of 10-12 weeks is required for full adaptation (Kronfeld and Harris, 2003), whereas others observed the effects as early as 3-5 weeks after oil supplementations (Pagan et al. 1987, 1995, 2002; Orme et al. 1997). Thus, whereas a 2-3 month period may be required for complete adaptation to an oil-supplemented diet, some of the metabolic responses will already be evident earlier. Importantly, the metabolic response to oil supplementation is apparently transient and dependent on its continued use.

As such, it is advised to adhere to a 3-5 weeks adaptation time to monitor for benefits and decide whether a high fat diet is likely suitable for your horse or not.

Finally, when you decide to add fat to your horse's diet, you must consider how it will affect the nutrient balance of its daily ration. As mentioned earlier, you must adjust the feed intake for the increased energy intake to avoid the horse from getting fat. But in the process of cutting back on other nutrients, your horse might miss out on essential minerals of vitamins. For example, It is argued by some that horses on high-fat diets require higher intakes of vitamin E. High-fat diets can lead to great oxidation and thus a greater need for antioxidants.

If you go with feeding a fat added feed, the feed company has likely already done the balancing for you to avoid vitamin and-or mineral deficits. If you choose to top dress your existing feed with oils, and thereby decreasing the total amount of feed, be sure the total diet still meets the horse's other requirements.

Feeding before exercise

So now that I've considered what to feed, I still need to consider when to feed to enhance performance.

Although a specific 'perfect' timing of feeding before exercise has not been established in horses, one thing to avoid is to start exercise with a high blood glucose. Physiologic research in humans has shown that eating a high-sugar feed 10-15 minutes before exercise has a negative effect on performance. The same is true horses. When exercises is started with a high blood glucose, insulin is secreted by the pancreas and blood glucose level drops. Furthermore, adrenaline will be released as well, causing a shift towards glycogen utilisation (instead of fat), even during aerobic low intensity exercise.

There are two ways to avoid staring exercise with an elevated blood glucose levels:

- Fasting
- Hay only

Fasting a horse is not a favourable option because of the possible risk of stress, ulcers or colic. Hence, that leaves us with the second option. In contrast to grains, hay has little effect on blood glucose concentration. Feeding grains only can lead to a marked increase in blood glucose concentration levels for 2-4 hours after feeding. Feeding grains in combination with hay (at the same time) is already much better, but then it still needs to fed at least 4-6 hours before the onset of exercise to avoid high glucose levels. As such, the best option is to provide a restricted volume – as you don't want to overfeed - of hay about 4-6 hours before the start of exercise. Naturally, the horse should have free access to clean water to properly digest this hay.

Feeding after exercise

There are two main factors that need to be taken into account when it comes to feeding the horse after exercise:

- Sweat losses
- Glycogen replenishment

In the section about sodium as well as thermoregulation I explained that the horse uses the process of sweating too cool down. Since the horse loses sodium and chloride in the process, heavy sweat losses need to be replenished after exercise. A good quality electrolyte supplement is recommended.

Second, (heavy) exercise leads to a depletion of glycogen stores. As such, these needs to be replenishment sufficiently before exercise is asked again. Especially during multiple day events this becomes essential. The level of glycogen in muscle is one of the factors that determine how fast the glycogen can be broken down to resynthesize ATP. As such, when muscle glycogen stores are low, the speed of ATP generation will be low. Hence, this could explain why a horse performs great on the first day of an event, but not in a second day as the horse could literally lack sufficient energy with glycogen depletion has not been replenished before the onset of a next training session or performance.

Glycogen replenishment after exercise is much slower in horses than it is in humans. In fact, horses produce glycogen two or three times slower than humans or other animals. Thus, it is important to give the horse sufficient resting time between performances, but also feeding after exercise could help into building up muscle glycogen levels.

As explained earlier, glycogen is formed via the actions of the enzyme glycogen synthase (GS). Glycogen synthase in turn is highly regulated by insulin.

During exercise, insulin concentrations decrease, facilitating the mobilisation – rather than the storage – of energy sources. However, it is likely that a significant amount of insulin actually reaches the muscles as blood flow is increased. In human and other species, insulin sensitivity is high following exercise, promoting glycogen production. Furthermore, contraction-mediated increases in glucose uptake [insulin independent] remain high after exercise, providing substrate for glycogen synthesis.

GS activity also appears to be affected by the amount of glycogen present such that following exercise, when muscle glycogen concentrations are low, GS activity is increased:

> *''the degree of GS activation is largely dependent on the intensity of the exercise and the extent of glycogen depletion.''*

Both studies in humans (Nielsen and Richter 2003) and horses (Pratt et al. 2007) have found inverse correlations between GS activity and glycogen concentrations. In humans, the replenishment of glycogen following exercise is rapid and depends largely on glucose supply to muscle. It is recommended that athletes consume carbohydrate immediately after glycogen depleting exercise and then every 2 hours for a total of 6 hours to maximize glycogen resynthesis (Ivy 1998). With this program, glycogen concentrations are replenished within 4-6 hours. However, in horses, glycogen replenishment following exercise is much slower.

A 2006 study performed by Geor et al. found that oral administration of carbohydrate over 6 hours [3g/kgBW) following glycogen depleting exercise resulted only in 56% of pre-exercise glycogen concentrations. On the other hand, venous infusion of glucose (at 0.5g/kgBW) for 6 hours {for a total of 3g/kgBW) resulted glycogen concentrations returning to almost 75%. However, despite even the latter did not result in to a glycogen increase greater than the levels normally present in the body.

Starch consumption (2.8 kg of corn) resulted in muscle glycogen of only 52% of resting concentrations at 24 hours following exercise (Jose-Cunilleras et al. 2006). Interestingly, it has been showed that electrolyte supplementation along with hay and grain feeding results in greater glycogen replenishment that does feeding alone (Waller et al. 2009).

As such, it is likely that factors beyond substrate availability influence glycogen resynthesis in the horse. In fact, the provision of acetate following glycogen depleting exercise, which can be oxidized directly, may preserve any glucose derive from the diet for use in glycogen resynthesis (Waller et al. 2009).

The differences in glycogen metabolism between horses and other mammals (may be attributed to differences in glycogen content and insulin sensitivity. For example, muscle glycogen stores in the horse can range from 500-650 mmol glucosyl units per kilogram, whereas in humans stores ranges between 320-400. Furthermore, glycogen itself may be different between species (Brujer et al. 2006).

Finally, as indicated earlier an increase in insulin sensitivity is observes in most species following glycogen depleting exercise, which is believed to hasten glycogen resynthesis when carbohydrate is consumed (Holloszy 2005). In horses however, no such increase in insulin sensitivity exists following glycogen depleting exercise to approximately 60% of original stores (Pratt et al. 2007). In fact, insulin sensitivity was lower when assessed 30 minutes following exercise compared with the baseline insulin activity. Furthermore, although GS activity was increased following exercise, it was not to the same extent as observed in other species (Pratt et al.. 2007). It is possible that that these differences contribute to the relatively slow glycogen resynthesis following exercise that is observed in horses.

In summary, it can thus be said that it seems that glycogen replenishment is influenced by other factors than nutrition alone. As such, the way to ensure optimal glycogen stores when starting exercise is to give the horse enough resting time in between performances. The combination of electrolyte supplementation together with good quality hay and a balanced commercial feed might prove to be the best combination so far.

Training considerations – optimizing performance

So now let's talk practical regarding training. The optimization of performance relies on maximizing the efficient use of energy stores available within the body. However, keep in mind that training is task specific: a dressage horse will be poorly trained for barrel racing.

It has already been explained that a high initial muscle glycogen concentration leads to a high rate of breakdown or longer time to fatigue. As such, performance of intensive exercise can be optimized when the glycogen concentrations in the horse's muscles are as high as possible when starting the activity.

Hence, we need to focus on how to **optimize the use of fat or aerobic utilisation of glycogen** as it is glycogen depletion that often leads to fatigue. As such, if we can use as much fat as possible, it spares glycogen. When we are training the horse at a faster pace, and we cannot avoid using glycogen, then it is best to ensure that the glycogen breakdown is mainly aerobic, which is slower, but more efficient. Of course we cannot avoid anaerobic metabolism altogether as it naturally happens when we go very fast of accelerate.

However, we can minimise unnecessary use of the anaerobic system and production of lactate by preparing the horse properly.

As such, when you give an eventing, jumping or racing horse a short fast gallop one day before an event, it is most likely the horse's glycogen concentration will not have recovered by the day of the competition or performance. The same applies to prolonged exercise. It would be unwise to do any fast activity with an endurance horse 3-5 days prior to the event. So if you have a big trail ride planned, it is not wise to jump shortly beforehand as this has the risk of glycogen depletion.

Thus, heavy training towards an event is quite inefficient. This does not mean the horse shouldn't be prepared, but that it would be wise to keep training to a moderate level in the days leading up to the event.

Furthermore, as already been explained, the major fuel for low to moderate intensity training is fat through aerobic metabolism. As such, if you want your horse to **lose weight**, you will have to stay within the aerobic metabolism to burn off the fat. This is often quite contradictory to human training principles of fat burning that promote heavy exercises (such as HITT). This shows that a horse cannot be trained upon human principles. Heavy exercise will not 'burn off the fat'' in the horse. Furthermore, fat burning in the horse is like a car running on diesel: it takes a while [20-30 minutes] to start running smoothly – but when it does it is highly efficient.

As such, to burn off fat the horse relies a lot on cardiovascular conditioning. Heartrates between 70-140 beats per minute will result in a significant utilisation of fat. At higher heart rates between 140-190 beats per minute, the horse will be using a mixture of fat and carbohydrates aerobically at the lower heart rates and aerobic glycogen breakdown at the upper end. Any event that lasts less than a minute at high intensities almost exclusively uses anaerobic metabolism to produce ATP. At heart rates about 200 beats per minute, the horse will get the majority of energy from aerobic glycogen breakdown [not fat] and with increasing speed, the proportion of energy coming from anaerobic metabolism will increase.

Taking physiology into practise: changing an unfit, obese and IR horse to a fit horse!

Another factor to take into account is the **swiftness in the horse's ability to switch between systems.** The anaerobic metabolism can be switched on and off quickly. For example, an acceleration from a medium canter to a gallop causes a spike in anaerobic breakdown of glycogen. If the speed is slowed back to a regular intensity, the anaerobic metabolism can be turned off within seconds.

On the other hand, the switch between aerobic metabolism of fat and carbohydrates is quite slow. For example, when exercising at a steady pace in trot for 25-40 minutes, the rate of ATP regeneration from fat will probably be at its maximum. An acceleration in speed will lead to an increase in the contribution from carbohydrates through glycogen. When again returning to a slower pace, the return to utilisation of fat at the previous rate can take 10-20 minutes or longer. Therefore, when aiming to preserve glycogen – for example to train endurance – it is best to try to achieve and maintain as regular and steady rhythm as possible.

It must be said that all of the above are generalisations as other factors such as breed, age, general health and muscle fibre composition also play a role into the effectiveness of using energy sources.

Knowledge of physiology applied for an underweight horse

Finally, before you think that endurance training is the answer to all your problems, I need to point that a limited amount of anaerobic work is necessary as well. The two main reasons are:

- Building lean muscle mass
- The adaptive response

Aerobic fat burning is sufficient for a horse that needs to lose weight, but it doesn't build **lean muscle mass.** Calories are burned more efficiently in bodies that have more muscle. As such, aerobic work is needed to ''burn fat'' whereas anaerobic work is beneficial to build lean muscle mass:

> *''With physical conditioning, there are metabolic adaptations that encourage fat burning. As well, there will be conservation or even an increase in muscle mass. Over a period of weeks, the horse will become more "athletic" in appearance. As lean tissues such as muscle have a higher rate of metabolism than fat tissue, this change in body composition will raise the horse's resting metabolism.''*

Second, the horse has an **adaptive response** that kicks in after a while. An important concept within equine physiology is that certain physiologic processes or anatomic structures are able to adapt in response to the stresses and strains imposed by repetitive exercise. Induction to these adaptive responses to exercise is called training or conditioning. Although both terms are often used interchangeably, they are different in essence:

> *''Strictly speaking, training refers to changes in behaviour induced by certain practises whereas conditioning refers to the physical changes that occur in response to repetitive exercise.''*

Conditioning by repeated exercise increases the maximal rate of both aerobic and anaerobic metabolism (Hinchcliff et. all 2002)

The adaptive response is common to most, but not all, body systems that results in a change in body composition and capacity for performing physical work. The adaptive response acts to reduce the effect of the strain induced by exercise. Put simply, repetition will enable the horse to be able to perform the same exercise with more ease. The body acts by increasing the capacity of the system to deal with the work imposed by exercise.

For example, the stress of increased force production by muscle during exercise stimulates changes in muscle structure and function that act to reduce the stress on the individual muscle fibers, while increasing the overall capacity of the muscle.

For training to be effective in inducing the desired conditioning, there must be some 'over reaching': the performance of an activity must be at a sufficient intensity and duration to induce some strain into the organism. Without this strain, there will be no conditioning effect. As such, the horse needs some interval to keep triggering it's muscles and maintain ideal body weight and fitness. If you simply repeat the same type of exercise over and over again, you will not get the desired effect. Thus, anaerobic work is beneficial in addition to aerobic work – even if your goal is to lose weight.

The art of training involves the judicious use of exercise of various intensities and durations in order to induce the optimal adaptations that will permit successful performance while preventing injury or occurrence of overtraining.''

CONCLUSION

Whoohoo, you are at the end of this manual! I know that the material might have been a bit abstract and theoretical, but it will enhance your training to an even deeper level. Isn't it amazing how everything is all structured and connected? So let me quickly summarize:

Cells cannot directly use the energy in food as it is eaten. It must be converted into ATP. Energy locked up in ATP is released through the process of metabolism. While the body stores of ATP are not insignificant, if a horse were to take an explosive undertaking such as running fast for 2-3 seconds, this would use up all the ATP stored within the muscles. This is where other forms of energy stored in the body come into play as these can be used to regenerate ATP. The stored from of fat is adipose tissue whereas the stored form of carbohydrates is glycogen.

It is commonly summarized that during heavy exercising the most important source out of which energy can be produced is glycogen through anaerobic metabolism. During low intensity training, the major fuel is fat through aerobic metabolism.

The process from getting energy from fat is like a car running on diesel: it takes a while to get going, but it is highly efficient. The process of getting energy from glycogen to regenerate ATP is relatively rapid and can be accelerated from standing within a matter of seconds.

Both aerobic and anaerobic exercise is needed to optimize your horse's fitness. Within the Online Support Program, several schedules will be released that allow you to apply the principles of basic physiology in order to reach your training goals and get the most of your training. Knowledge of physiology allows us to evolve from inefficient training principles. Let's give something back to our horse, let's evolve!

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