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Equine Laminitis

Managing pasture to reduce the risk

RIRDC new ideas for rural Australia

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Foreword

Laminitis is a leading cause of death in horses and makes a significant financial and emotional impact on the horse industry.

Around the world the success of pasture improvement programs is measured against increased meat, fibre and dairy production. Increasing the readily available carbohydrates in pasture and hay is the primary focus. As the technology available to forage breeders and producers has improved, the resultant increased amounts of sugar, starch and fructan (collectively called non-structural carbohydrates or NSC) has made some pastures inappropriate for horses and ponies prone to obesity, insulin resistance and laminitis.

Environmental conditions can trigger three-fold increases in NSC in pasture plants and hay, so it is imperative that the owners of horses prone to laminitis and feed producers catering to such animals, understand how to manage pasture and hay crops to decrease NSC concentration. Such horse owners also need to understand under which conditions pasture or hay NSC content become so dangerous that access for high risk animals should be limited or eliminated.

Some practical methods for minimising pasture NSC are provided in this report, such as timely slashing, proper fertilisation and avoidance of pastures species that have high genetic potential for excess NSC accumulation under stress.

This report provides strategies to prevent laminitis based on principles of plant science: growing grass that is under less stress to reduce NSC concentration; limiting access to pasture for high risk animals by use of a sacrificial area; and preservation and re-introduction of native grass pastures that are inherently lower in NSC.

Some pasture management practices that minimise pasture NSC also happen to be important features of environmentally friendly, sustainable land stewardship. So laminitic horses will benefit first from employment of these strategies and later generations of Australians may benefit as well.

This report is an addition to RIRDC's diverse range of over 2000 research publications and forms part of our Horse Research and Development Program, which aims to assist in developing the horse industry and enhancong its export potential.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Tony Byrne
Acting Managing Director

Acknowledgments

Dr Don Walsh and his dedicated Animal Health Foundation in Pacific, Missouri, USA, have funded many of the projects described in the text and the authors are sincerely grateful. Dr Sandra Pollitt is thanked for tirelessly proof reading the document and for putting commas in the right places.

Dedication

To my horse Kelcie, because she took good care of me when I was a stupid new horse owner. And for her daughter Guinness Kaliber; God won't have her, and the devil doesn't want the competition, so I have to keep her on this earth as long as possible. KAW

To 'Twinkle' Duckett, the foundered pony that made me ask a question that has guided my research career for the last 25 years. CCP

Figures

All figures are the work of the authors Kathryn Watts and Christopher Pollitt except Fig 10-1 and Fig 20-1 (Don Walsh), Fig 15-1 (Alan Renner) and Fig 17-1 (Darrin Hatchman).

Abbreviations and glossary

C3 grass: cool season, temperate grass that can contain fructan

C4 grass: warm season, tropical grass than contains sugar and starch, but no fructan

Crown: the base of the plant that joins the stems to the roots

Diurnal: having a daily cycle

DM: (dry matter): the amount left after all the water has been removed. The only accurate way to compare amounts of nutrients in animal foodstuffs

FOS: Fructo oligo saccharide): inulin that has been hydrolysed so the range of chain lengths are from 2-5

Forage and fodder: fresh or preserved plant material for animal feed. Usually considered the roughage part of an animal's diet

Fructan: a broad term for a polysaccharide formed from a chain of fructose molecules (>3), starting with a single glucose molecule. Found in most C3 grasses and some broadleaf plants

Graminen: a specific type of fructan with 2-6 backbones, and side chains with 2-1 bonds, found in wheat and rye families of grasses

Inulin: a type of fructan found in broadleaf plants characterized by 2-1 fructosyl bonds, with a range of fructosyl chain lengths from 2-60

Leaf blade: the part of the leaf that collects the sunlight

Leaf sheath: the part of the leaf that wraps around the stem

Native grass: a species found in the area in which it evolved

Naturalised grass: non-native species that is so well adapted to a region that it grows without being planted. Some may be considered weeds

NSC: (non-structural carbohydrates): sugar, starch or fructan, found in plant sap and inside plant cells

NFC: (non-fibre carbohydrates): an old fashioned, inaccurate way to determine the fraction that contains NSC, among other things

Node: the knob on a grass stem where sections (internodes) connect and the base of the leaf sheath joins the stem. Sometimes called the joint

Phlein: the type of fructan found in most temperate, C3 grasses. It has primarily 2-6 fructosyl bonds on the main structure, and may be up to 200 units long

Rhizomes: a horizontal underground stem from which new tillers and roots can arise

Senescence: the natural process by which grass gradually dies of old age

Starch: a polysaccharide formed from chains of glucose molecules

Stem: the stalk to which grass leaves are attached

Stubble: base of the stems left after mowing or harvesting a crop

Structural carbohydrates: also known as fibre; hemicellulose and cellulose, found in the cell walls

Sugar: in this booklet sugar means sucrose, fructose and/or glucose

Tiller: a grass shoot comprised of a stem and leaves. Tillers can arise from the base of plant, or from runners called stolons or rhizomes

Stolons: a horizontal above-ground stem from which new tillers and roots can arise

Vegetative reproduction: reproducing without forming seeds, usually by making new tillers

Vegetative stage: compromised of only leafy tissue, not seed heads

Weed: a plant out of place, frequently an invasive species that spreads easily

WSC: water soluble carbohydrates. Sugars and fructan mixed together

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The owners of horses and ponies prone to laminitis should understand how to manage pasture and hay crops to minimise the risk of laminitis

Executive Summary

What the report is about

This report explains how environmental conditions can trigger three-fold increases in the sugar, starch and fructan (collectively called non-structural carbohydrates or NSC) content in pasture plants and hay. Horses and ponies consuming pasture excessively rich in NSC can develop laminitis. The owners of horses and ponies prone to laminitis, and feed producers catering to such animals, need to understand how to manage pasture and hay crops to decrease NSC concentration and thus minimise the risk of laminitis. They also need to understand under which conditions pasture or hay NSC content become so dangerous that access for high risk animals should be limited or eliminated. It is important to realise that the success of most pasture improvement programmes is measured against increased meat, fibre and dairy production in farm animals other than horses. Increasing the readily available carbohydrates in pasture and hay is thus a primary focus of modern production based agriculture. However the resultant increased amounts of NSC has made some pastures inappropriate and dangerous for horses and ponies prone to obesity, insulin resistance and laminitis.

Who is the report targeted at?

This report is targeted at the owners of horses and ponies so that they can make informed decisions about pasture management and to more safely feed animals prone to laminitis or obesity. It is written for those horse owners who are prepared to make a serious effort to learn how to grow the 'best' pasture, and seek the 'best' feed to prevent and manage laminitis.

Background

Laminitis is a leading cause of death in horses and makes a significant financial and emotional impact on the horse industry. Recent studies show that insulin alone can induce laminitis in horses and ponies thus implicating as causal factors those dietary carbohydrates that have an insulin stimulating, metabolic impact. Fermentation of fructan in the equine gut releases laminitis trigger factors and may induce laminitis. High insulin concentration in the blood (hyperinsuliaemia) and fermentation of excess fructan in the hindgut act separately or in concert to trigger laminitis. For detailed knowledge on equine laminitis consult the RIRDC companion volume "Equine Laminitis - Current Concepts" Publication No.08/062.

Most grasses in tropical and sub-tropical regions of Australia are of a type that does not contain fructan. However, they contain high levels of sugar and starch, especially in conditions of intense sunshine, drought or cold stress. Temperate region grasses can contain high levels of all the NSCs (sugar, starch and fructan) especially under intense sunlight accompanied by cold stress or nutrient deficiency.

Aims/objectives

This booklet aims to provide strategies based on principles of plant science. Grass grown under less stress will have reduced NSC concentrations. The use of a sacrificial area and preservation and re-introduction of native grass pastures that are inherently lower in NSC will decrease the risk of laminitis by reducing NSC intake. Some pasture management practices that minimise pasture NSC also happen to be important features of environmentally friendly, sustainable land stewardship. Grazing horses in wooded areas that limit exposure to sunlight is an easy way to provide low NSC pasture. The planting of trees to provide shade can lower NSC in pasture, whilst controlling erosion and improving hydrology. Some practical methods for minimising pasture NSC are provided, such as timely slashing, proper fertilisation and avoidance of pastures species that have high genetic potential for excess NSC accumulation under stress. Weed control, rotational grazing, appropriate fertilisation and de-stocking of pastures during drought are also discussed as methods to minimise pasture NSC. Laminitic horses will benefit first. Later generations of Australian land owners may benefit as well.

Methods used

The existing forage science literature is reviewed to provide the reader a better understanding of carbohydrate metabolism in grass. The authors consulted widely with the managers of horse and pony establishments to understand the association between laminitis and the pastures growing in Australia.

Results/key findings

When grass is considered 'the enemy' by the owner of a horse with laminitis, the strategy of deliberate overgrazing to limit grass intake, is sometimes adopted. This is misguided and may lead to 'horse sick' pastures that are prone to erosion, soil compaction, degradation of soil fertility, weed infestation and accumulation of parasites. All too often, these tactics fail. The possible reasons for these failures are explained here.

Implications for relevant stakeholders

Traditional graziers are selling off tracts of land near cities as 'lifestyle acreage' for people seeking a more peaceful, rural way of living. These new land owners often acquire horses, donkeys and ponies for recreation or pasture ornamentation. Many receive pasture management advice directed towards maximising NSC production and thus weight gain in cattle and sheep. Future projects directed towards developing sustainable pasture management programmes for lower, rather than higher NSC content in pasture, for the owners of non-athletic, grazing horses would be beneficial. It would lower the incidence of pasture associated laminitis and provide an opportunity to develop environmentally responsible land stewardship. A better understanding of the links between pasture consumption and laminitis will lead to a more unified approach and rational preventive and treatment strategies, by owner, veterinarian and farrier alike.

Recommendations

The lack of affordable, accurate testing for NSC in feed and forage in Australia is a hindrance to horse owners trying to limit sugar, starch and fructan levels in their animal's diet. Implementing appropriate analytical laboratory procedures in Australia for quantification of NSC, would benefit all animal managers. It would help those maximising pasture NSC for improved production animal weight gain, as well as those seeking low pasture NSC to more appropriately feed horses and ponies prone to or already suffering from laminitis. Feed producers catering to horse owners could manage pasture and hay crops to decrease NSC concentration and make them safer for horses and ponies with a risk of laminitis. With appropriate validation and labelling, such laminitis accredited horse feeds may be a profitable business opportunity. Likewise the production of seeds that result in low NSC pasture suitable for laminitis prone horses and ponies may have a niche market. Contained in this report are recommendations enabling horse and pony owners to make informed management decisions on a daily to annual basis. Perhaps in the future, these recommendations can be tested and refined, based on properly conducted scientific studies.

Examining for laminitis – the most serious disease of the equine foot causing pathological changes in anatomy that may lead to long-lasting, crippling changes in function. Photo source: **What Causes Equine Laminitis?** *by M Sillence, K Asplin, C Pollitt and C McGowan; RIRDC Pub. No. 07/158*

1. Introduction

The suspensory apparatus of the distal phalanx

In the normal horse or pony the distal phalanx (coffin or pedal bone) is attached to the inside of the hoof by a tough, but flexible, suspensory apparatus. The surface of the inner hoof wall is folded into leaf-like lamellae (laminae) to increase the surface area by which this suspensory apparatus is attached (*Figure 1-1*). A horse has laminitis when the lamellar suspensory apparatus fails. The failure of the suspensory apparatus can be sudden or gradual. Without the distal phalanx properly attached to the inside of the hoof, the weight of the horse and the forces of locomotion drive the bone down into the hoof capsule. Important arteries and veins are sheared and crushed and the corium of the coronet and sole is damaged. There is unrelenting pain in the feet and a characteristic lameness. For detailed knowledge on equine laminitis consult the RIRDC companion volume “Equine Laminitis - Current concepts” Publication No.08/062.

The Problem of Laminitis

Laminitis is the most serious disease of the equine foot and causes pathological changes in anatomy that may lead to long-lasting, crippling changes in function (chronic laminitis or founder). Laminitis has a developmental phase during which lamellar pathology is triggered. This precedes the appearance of the foot pain of laminitis. The developmental period lasts 40 - 48 h in the case of laminitis caused by excessive ingestion of soluble, non-structural carbohydrates (NSC), such as sugar, starch or fructan. Sometimes no developmental phase can be recognised; the horse or pony is discovered with painful laminitis with no apparent ill-health or inciting problem occurring beforehand. This appears to be the case when the blood concentration of insulin is abnormally high. Many people own and care for horses all their lives and never encounter a horse with laminitis. Others have come to realise that certain horse and pony breeds tend to be affected more than others and susceptible animals succumb to laminitis again and again. It is likely that there are phenotypic or genetic factors that confer susceptibility or resistance to laminitis (Geor, 2009) and there is now evidence implicating

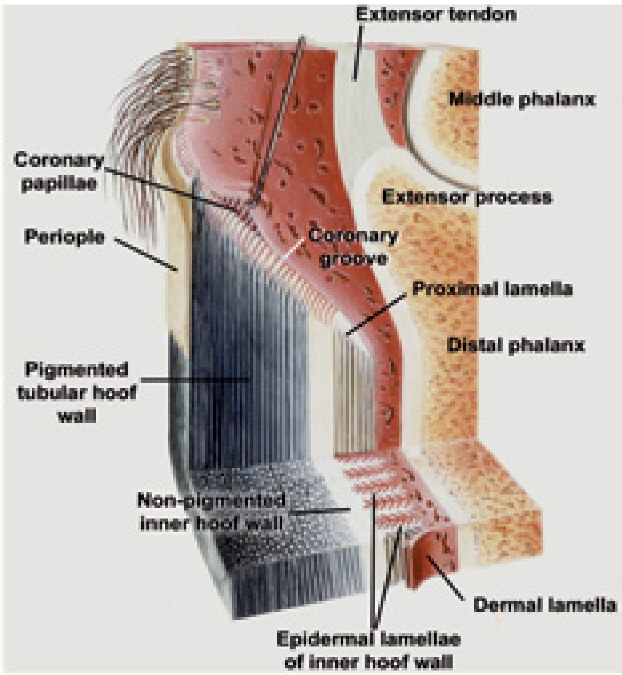


Figure 1.1 Diagram of the anatomy of the hoof wall.
From RIRDC Publication 08/062: Equine Laminitis - Current concepts
Design: Chris Pollitt. Art: John McDougall.

metabolic factors, particularly obesity, insulin resistance and hyperinsulinaemia, as significant predisposing factors for pasture laminitis (Carter et al, 2009). When laminitis does strike it can be heartbreaking. The pain and suffering are relentless and sometimes euthanasia is the only responsible option for an owner, despite the stoic ability of many horses to live on as cripples. Other milder cases may resolve with proper dietary restriction and expert hoof care. Formulating an effective management plan for a horse with laminitis is one of the most difficult tasks a horse owner can be confronted with. The owner, in consultation with a veterinary clinician and farrier, will have to decide if the investment of money, time and energy is worthwhile, keeping in mind the pain that the horse must endure during the process. After months of treatment and the expenditure of perhaps thousands of dollars, the horse in question may still be suffering severely. The clinical signs, the extent and severity of lamellar pathology and the response to therapy vary unpredictably between individual horses and this makes a rational treatment strategy, with an accurate prognosis, difficult to formulate. Severe damage to the internal anatomy of the hoof can occur, out of sight, within the space of a few hours and the severity and extent of this initial damage is the single most important factor influencing the final outcome.

Laminitis and Pasture Research

Scientific understanding of laminitis is incomplete and the horse owner often becomes committed to the symptomatic treatment of a chronic condition that inexorably deteriorates. This lack of understanding of the processes involved is frustrating to the horse owner and veterinarian alike, and of little use to the horse. Horse owners seek knowledge that will help prevent laminitis occurring again in an individual animal or amongst others that may be at risk. Serious diseases such as colitis, post-foaling infections (metritis) or pneumonia/pleuritis may precipitate laminitis, but most commonly it is what the horse has eaten over the last few days, weeks or months that triggers laminitis. In fact most cases of laminitis occur in horses and ponies kept at pasture. A 1996 survey in the United Kingdom showed that 61% of laminitis cases occurred in animals kept at pasture. In the USA a similar survey showed 46% of cases were associated with grazing on pasture. Over the last ten years, the RIRDC Horse R&D Program has made understanding laminitis and seeking improved preventive and treatment strategies a priority. This report is the result of years of continuous RIRDC funding to the Australian Equine Laminitis Research Unit (AELRU) based in the School of Veterinary Science at The University of Queensland. We have recruited the skills and knowledge of an experienced agronomist and horse owner (Kathryn Watts, Research Director of Rocky Mountain Research & Consulting, Colorado USA) to help Australian horse-owners appreciate the potential of pasture to trigger laminitis. The hope is that a better understanding of the links between pasture consumption and laminitis will lead to a more unified approach and rational preventive and treatment strategies, by owner, veterinarian and farrier alike.

The pasture grasses most often recommended for horse pasture in Australia are perennial ryegrass (pictured), phalaris, cocksfoot, tall fescue and kikuyu with the legumes white or strawberry clover. However these high-yielding pastures are designed for Thoroughbred studs and for intensive cattle and sheep production, with the result that some susceptible pony and horse breeds will founder if allowed unrestricted grazing

2. Grass: terminology, form and function

In order to better understand grass, it is necessary to learn proper terminology, the parts of the plant, and their function (*Figure 2-1*).

The leaf blade is the more or less horizontal part of the leaf held away from the plant. Its primary function is to gather light and carbon dioxide, and along with water, make carbohydrates via photosynthesis from these raw materials. It also expires waste products, in particular carbon dioxide. The leaf sheath is the part that wraps around the stem. It is also photosynthetically active, and is the conduit for carbohydrates made by the leaf blade. The stem (also called the 'culm') supports the seed heads and transfers carbohydrates from the leaves to the developing seeds. The embryonic seed head is fully formed at the base of the stem, with all the future leaf buds and stem sections in place, awaiting development (*Figure 2-2*). The seed head is sometimes referred to as the 'inflorescence' or flower of the grass plant.

The crown is the portion that connects the stem to the roots, and may also serve as a storage organ for excess non-structural carbohydrate (NSC) not currently needed for growth or reproduction. In some species, new shoots called tillers may arise from the crown. This is another reproductive strategy, called vegetative reproduction, where new plants are created without the formation of seed.

New tillers can also be formed on stolons, which are horizontal stems (*Figure 2-3*), or runners that form above ground. Rhizomes are underground, horizontal stems from which new tillers arise (*Figure 2-4)*. As reproductive organs, both stolons and rhizomes will gather excess NCS to be held for this purpose.

The root system of grass is fine, highly branched, and may extend meters into the soil vertically as well as horizontally. The mass of the roots remains equal to the mass of the above ground portions by a variety of only partially understood mechanisms. If the biomass of the tops changes from growth or removal, the biomass of the roots reflects this change. The function of the root system is to seek, gather, and deliver nutrients and water to the rest of the plant; hence roots are vital to the overall health and vigour of the above-ground parts. Most neophyte graziers do not appreciate the importance of maintaining a vigorous, healthy root system; but the out of sight, out of mind philosophy should not apply.

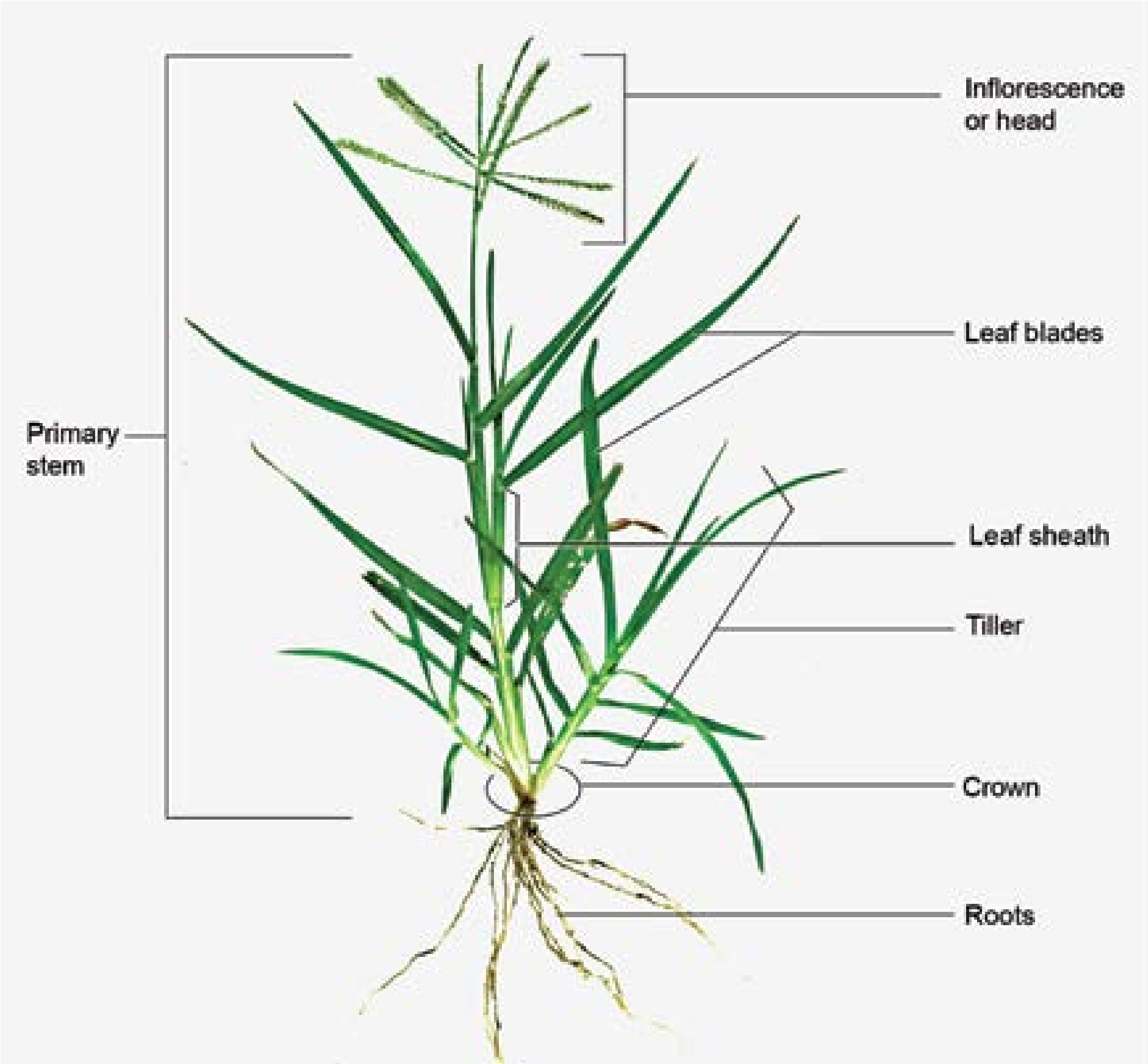


Figure 2-1 The parts of a grass plant.

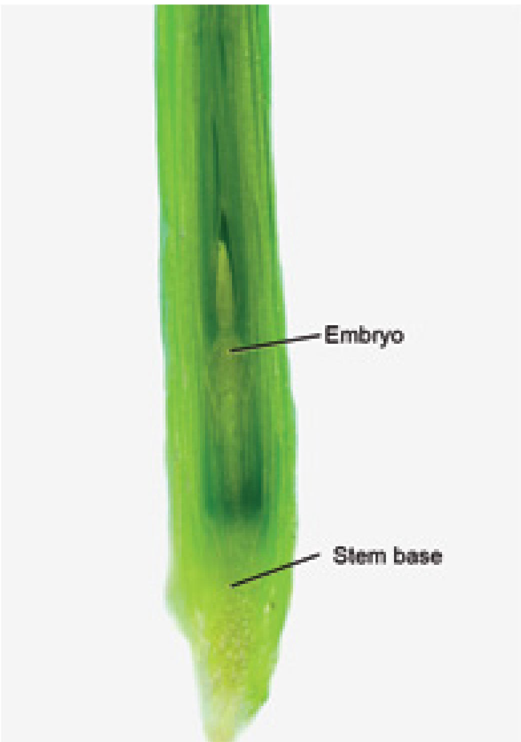


Figure 2.2 The embryonic seed head is formed at the base of the stem ready to elongate and form the inflorescence.

Figure 2-3 ***A grass plant showing a horizontal stolon.*** *New shoots called tillers are branching from the stolon and forming new plants without the formation of seed; this is vegetative reproduction.*

Figure 2.4 Rhizomes are the underground, horizontal stems of grasses and can store large amounts of NSC.

3. Stages of growth

To understand how a grass plant forms and accumulates NSC we need to recognise the following stages of its growth.

Germination: this only happens when grass arises from seed. Grass will generally grow 2-3 leaves on the main stem, and then start forming tillers, or new shoots with their own stems and leaves.

Tillering: many new tillers may arise from the same crown, essentially making the grass 'thicker' rather than taller (*Figure 3-1*). This stage ends when demands for seed production take priority (Jones and Lazenby, 1988). Certain management practices may lengthen this growth stage.

Stem elongation: this process initiates seed production. During this period, the developing seed produces hormones that confer priority for nutrient allocation. The embryonic seed head sits on top of the apical meristem, a region of compressed embryonic stem and leaf tissues that are arranged like the sections of a telescope. As the stem internodes grow, the bottom most stem sections lengthen first, raising the developing head above the level of the crown (*Figure 3-2*). When the nodes, or 'joints' as they are sometimes called, rise from the crown, this stage is referred to as 'the joint stage'. As each successive new stem section (internode) grows, leaf bud growth is also triggered. Growth continues until all the leaves have extended and all the stem sections have elongated, at which time the seed head is held up above the rest of the plant. When the head is nearly fully formed and swollen inside the topmost portion of the stem just before emergence, it is called 'boot stage'.

Heading/flowering: each embryonic seed will flower once the head is free from the stem. This may also be referred to as 'anthesis'. You can see pollen sacks, or

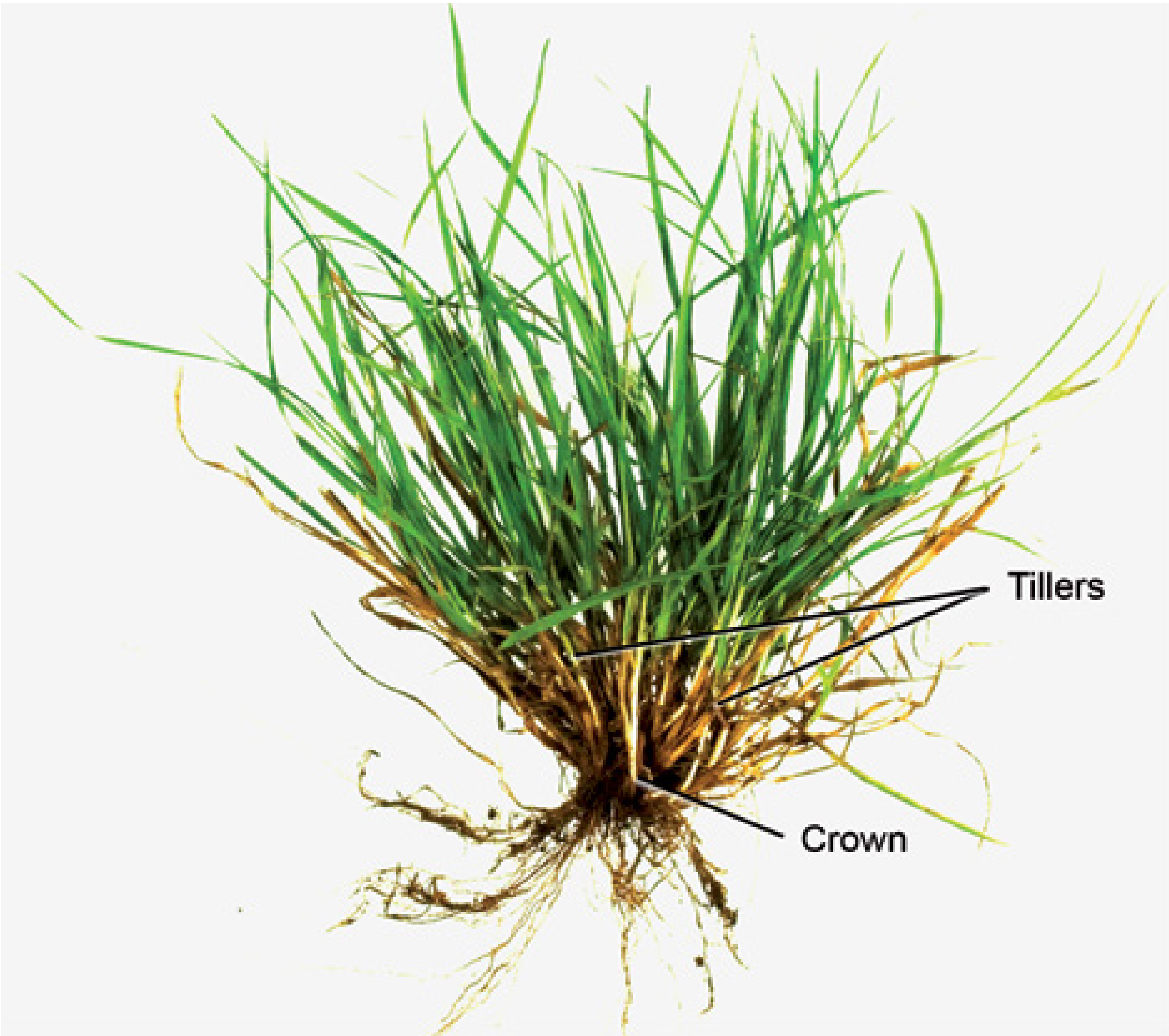


Figure 3.1 Grass with many tillers arising from a single crown.

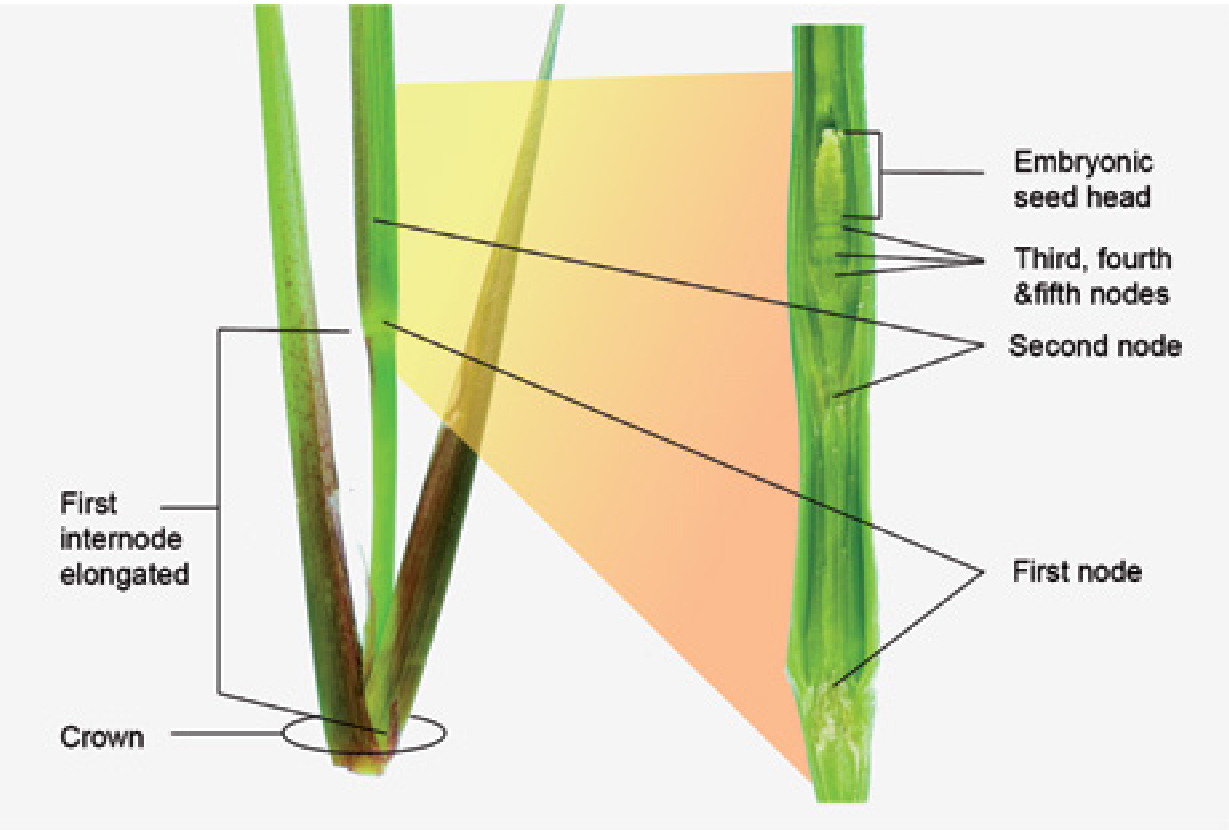


Figure 3.2 A grass plant with the first stem internode elongated, raising the developing seed head above the level of the crown.
Lengthening of the remaining nodes will raise the seed head above the rest of the plant. Unelongated nodes and the undeveloped seed head are meristematic tissues, comparable to embryonic tissue in the animal world. They await hormonal signals to trigger growth and development.

anthers, hanging out at this stage (*Figure 3-3*). Each kernel must be pollinated, after which it will begin to gather carbohydrates and swell. If frost, hail, broken stems, nutrient deficiency or insects damage the flowers at this stage, the seeds cannot develop and the NSC poised in the stem for seed development will remain in the stem. This may yield hay or straw with unusually high levels of sugar and fructan.

Seed formation/ripening: when the new seeds are full of milky sap, they are at the 'milk stage'. Starch starts to form and the seeds firm to the consistency of soft dough, (called the "soft dough stage") then "hard dough", and finally, fully ripe or mature.

Figure 3-3 A grass fully in flower; at the anthesis stage of development.
Pollen sacs (anthers) are releasing pollen that will pollinate adjoining plants.

Sunlight, carbon dioxide and moisture drive photosynthesis; the carbohydrate factory of grass. Simple sugars are used for respiration and growth but when pasture is stressed they may be converted and stored as starch or fructan

4. Grass carbohydrate metabolism

Temperate vs. tropical or fructans vs. starch

There are various forms of plant metabolism. There are two types that concern us, commonly known as C3 and C4 metabolism. In C3 type plants, the first product of photosynthesis is a three-carbon organic acid, and in C4 type plants, the first product is a four-carbon acid. C3 grasses are often referred to as 'cool season' grasses because they grow better under cool, temperate conditions. C4 grasses are referred to as 'warm season' or 'tropical' grasses, as they like it warmer, and usually die off at the first touch of frost (*Table 4-1*). The different types of grass have internal structures to support the different types of metabolism. C3 grasses generally form fructan as their preferred storage carbohydrate, although certain genera took an evolutionary side-track due to the early separation of Gondwanaland and rely on starch as their storage form of carbohydrate. These are well represented by native Australian grasses that are C3, cool season grasses, but produce no fructan. (Smouter and Simpson, 1989).

They include:
- *Microlena stipoides;* Weeping grass
- *Poa* sp.*;* Tussock grass
- *Danthonia* sp.*;* (also *Australodanthonia* sp.); Wallaby grass
- *Stipa* sp.*; (* also *Astralostipa); Speargrass*
- *Aristda* sp.*;* Wire grass

C4 grasses, such as Kangaroo grass (*Themeda triandra*), form starch as their storage carbohydrate." They are incapable of making fructan. Some earlier work suggested they may have had small amounts of fructan (Chatteron et al, 1988), but new work using more purified enzymes for extraction shows there is no fructan at all (Chatterton, personal communication). Most of the tropical grasses are C4, as are many of the shorter-lived native grasses that spring up quickly after rain. Notably, the grasses that die from frost have C4 metabolism. The exotic grasses imported from Africa to Australia for intensive grazing of cattle and sheep are all C4. Having evolved under heavy grazing from large, hoofed animals that congregate in large herds they have evolved the ability to make and store large amounts of sugar and starch to replenish their reserves after animals have eaten and trampled them. Trampling is stressful; the plant uses up reserves to heal and regrow.

Table 4-1 The differences between C4 tropical and C3 temperate grasses

C4 tropical grass	C3 temperate grass
Optimum temperature for growth 15-40°C	Optimum temperature for growth 10-25°C
First photosynthetic products are 4 carbon acids-malate and aspartate	First photosynthetic product is a 3 carbon acid - phosphoglyceric acid.
Forms starch as storage form of carbohydrate in bundle-sheath chloroplasts found near leaf veins	Forms fructan for storage carbohydrate (with some exceptions)
Starch formed and stored in chloroplasts in leaf tissues	Fructan formed and stored throughout the plant in vacuoles
Photosynthetic efficiency increases with increasing light intensity up to full sunlight	Photosynthetic efficiency peaks at lower light levels
More efficient use of water	Less efficient use of water
Photorespiration absent	Photorespiration does occur

Photosynthesis - the sugar factory

Photosynthesis is the process by which plants convert light energy into simple sugars. Carbon dioxide from the air and water from within the plant provide the materials for the formation of organic acids, which are then converted to sugar via an enzyme called "rubisco" (ribulose-1,5 bisphosphate carboxylase). Rubisco makes up a significant portion of the protein content of plants. It utilises light energy and is active whenever there is light and the plant is not frozen or desiccated. Rubisco for photosynthesis is less sensitive to changes in temperature than the enzymes that regulate respiration. This is an adaptive advantage, as it allows plants to continue to make sugars when various forms of stress may shut down growth. They save carbohydrates for a rainy day, when they will come in very handy. Simple sugars are the basic building blocks used to construct numerous other compounds inside the plant, as well as providing energy.

Tropical C4 grasses have more efficient photosynthesis when it gets hot. In addition, the photosynthetic process in C4 plants is not saturated until the plant is in full sunlight; in other words, photosynthetic rate continues to increase with increasing light intensity. This is important in the humid tropics, where afternoon rain showers are frequent and the plants have to make best use of sunlight when they get the chance (Whiteman, 1980). The photosynthetic efficiency in C3 plants peaks at half the amount of luminescence, so it is more efficient in cloudy or foggy climates. When it's hot and dry, with full sun and the days are long, C4 plants have double the photosynthetic capacity of C3 plants, giving them a competitive advantage. When cool, wet and cloudy conditions prevail C3 plants have the advantage.

Respiration - the plant factory

Respiration is the process by which grass uses the sugar produced by photosynthesis to create the energy and the raw materials to make other compounds. Carbon dioxide is released by this process. Respiration is a chemical process, relying on enzymes that function best within a specific temperature range. When the temperature is out of the optimum range, respiration slows, or ceases altogether. The critical low temperature for C3 plants is below 5°C and for C4 plants below 10-15 °C, depending on how well the variety of grass is adapted.

While most respiration takes place at night, C3 plants utilise a rather wasteful form of respiration in the daylight called photorespiration. In this process, oxygen competes with carbon dioxide as a substrate for rubisco, forming fewer 3-carbon acids, waste products, and no energy. It wastes water, making C3 plants less water efficient. This is one of the reasons why C3 plants have a higher photosynthetic rate in higher carbon dioxide concentrations. Photorespiration is considered an evolutionary relic from a time when oxygen levels were much lower in the atmosphere. Plant scientists would like to eliminate photorespiration by genetic engineering, but so far have not succeeded. C4 plants are considered more highly evolved as they have an efficiently organized photosynthetic apparatus suitable for the current high oxygen atmosphere. They do not possess mechanisms for photorespiration.

When grasses are cut the material does not die immediately but continues to function until moisture levels in the cut stem and leaf tissues fall below about 40%. Respiration continues to metabolize sugars. This is why hay is generally lower in NSC than the fresh material it was cut from. Wilted clover and lucerne averaged about 30% lower in NSC than fresh forage (Owens et al, 1999).

When photosynthesis exceeds respiration

When more sugars are formed than can be utilised for growth, they accumulate. The accumulation of sugars triggers the formation of storage carbohydrates; either starch or fructan, depending on the type of plant. Fructan and starch are too large to be transported inside a plant, but can be readily converted back to simple sugars for transport in the plant sap when the limiting factors are no longer in effect. This may change quickly back and forth throughout the day, as temperature, sunlight, drying winds, grazing, trampling, invasion by insects or disease organisms affect grass metabolism. When environmental conditions change, plants are in a high state of metabolic flux. They lack the homeostatic systems inherent in the animal kingdom that keep metabolism in equilibrium. Plant composition is far more a product of the environment compared to animals. The enzymes utilised for formation and conversion of starch and fructan back to sugars will be more concentrated in plants under stress, as well as in plants undergoing rapid growth whilst utilising storage carbohydrates. Amylase, the enzyme that digests starch, will be higher in C4 plants subjected to stress. Fructanase enzymes will be higher in C3 grasses subjected to stress. It is not known if these grass enzymes affect the digestive processes of horses.

Optimum temperature

C3 and C4 grasses utilise different enzymes with different optimum temperature ranges. This makes them perfectly suited for the climate they evolved in. The optimum temperature for photosynthesis in C4 grasses is above 35°C. Photosynthesis reduces drastically between 5-10°C, depending on species. In an experiment, Green Panic and Setaria (both C4 grasses) and two varieties of Perennial Ryegrass were grown under controlled conditions. As the temperature regimen was changed from 16°C days/10°C nights to 32°C days/27° C nights they responded very differently. Two varieties of Perennial Ryegrass were highest in NSC at the lower temperatures, (24 and 20% of DM) while the tropical grasses where highest at the higher temperatures, 23 and 27% of DM respectively. Of the NSC in the tropical grasses, 16 and 19% was starch (Wilson and Ford 1971).

Distribution in Australia and New Zealand

Of the native grasses that cover 50% of the Australian continent, 90% are C4, tropical grasses. Queensland, the Northern Territory, and the northern portions of WA average over 90% C4 grass types (Chatterley, 1983). Introduced grasses from Africa that have naturalised to Australian conditions also follow this distribution pattern. Exceptions include prairie grass (*Bromus catharticus* and *Bromus willdenowii* Kunth) that grows best in cool weather, and annual ryegrass that may be over-seeded for winter pasture. Most of the C3 native grasses that evolved in Gondwanaland do not make fructan. C3 grasses that have been introduced from Europe and England have naturalised in cooler areas with adequate moisture. In general the C4 species are most prevalent where the Australian summer is hot and wet. C3 species predominate where spring is cool and wet. The southern states of Victoria, NSW, Tasmania and the southern parts of WA and New Zealand are nearly all C3. South Australia is intermediate with coastal areas mostly C3. Where there is adequate moisture in the well developed coastal regions, ryegrass and clover predominate, as these are traditionally considered the best pasture forages for cattle and sheep.

In a book on Pasture and Crop Science for NZ, the chapter on species selection dismisses the value of native species by listing reasons for changing species to more productive grasses of higher quality (White and Hodgson, 1999). The dairy industry is very important to the NZ economy. Ryegrass is "king" in NZ and clover is "queen". Because most of NZ has enough rain to maintain ryegrass year round, the value of native species for conservation purposes is dismissed.

The effect of shade on grass NSC

The more light a plant receives on its green leaves, the more sugars it will produce by photosynthesis. Phalaris shaded the previous day was 31% lower in WSC than unshaded the following morning, although the difference was made up within 2-4 hours after the shade was removed (Ciavarella et al, 2000). Cloudy climates will generally produce lower sugar pasture and hay.

Grass grown under trees was lower in NSC and the accumulation rate was lower under thicker foliage that intercepted more sunlight (Burner and Belesky, 2004). A practical application of this concept is to graze horses in the forest, or by planting a line of fast growing trees around the perimeter of a paddock designated for susceptible horses. Also consider creating a paddock next to a building that shades the grass for part of the day. Broad leaf weeds can capture a large amount of sunlight, making them especially efficient in converting sunlight into sugars. Unfortunately, certain weeds are much higher in sugar or fructan than grass, so the effect of shading on the grass may be offset if horses eat the higher NSC palatable weeds.

The effect of day length on grass NSC

The longer the day length, the longer the sugar factory will operate. The long summer days that occur in high latitudes provide the opportunity for more sugar creation in grass when compared to regions closer to the equator where the day length tends to be shorter and less affected by season. The longer days of spring increase the opportunity for grass to produce sugars. Cool nights and the development of seed heads may coincide, creating a situation where both the concentration per mouthful of grass and the availability of NSC per acre peaks in late spring. Increased NSC concentration frequently coincides with increased biomass production, which is why spring is traditionally considered the worst season for laminitis. Indeed the number of horses with pasture associated laminitis in England is highest in spring (Katz, et al, 2001).

The effect of time of day on grass NSC

Since sugar consuming respiration occurs mostly during the night, the NSC levels will be lower in the morning, if conditions are optimum for respiration and growth. Pangola Grass (*Digetaria decumbens*) sugar levels were 75% lower after a 14 hour night in warm conditions (Shatters et al 1993). In Canberra, the water soluble carbohydrate concentration of Phalaris went from 103 mg/g dry matter at sunrise to 160 mg/g by midafternoon; a 55% increase (Ciavarella et al, 2000). The WSC increased in a linear fashion from sunrise to late afternoon, nearly doubling in grass grown in full sun. Notably the effect of time of day was less in grass growing under trees (Burner and Belesky, 2004). If some grazing is to be allowed for horses at "high risk" of developing laminitis, it should occur between dawn and late morning. If paddock space is limited and must be shared, put 'high risk' horses out for a short time in early morning, and put the rest out for a longer time in afternoon or evening.

The effect of grass density on NSC

The position of grass within the canopy will determine how much light falls on its leaves. Bottom leaves may be shaded, and therefore less able to make sugar. Sparse, isolated plants that have all the leaves exposed to sunlight will function at full sugar manufacturing capacity. A dense grass sward will create a microclimate such that a higher percentage of the leaves are shaded by neighbouring plants. This may well be the reason why properly fertilised grass tends to be lower overall in sugar concentration. There may be more sugar per acre in a thick, vigorous stand of grass, but each mouthful is lower in sugar. Depending on how horses are managed, either total grass intake or grass NSC concentration may be more important. If horses have unlimited pasture access they will, of course, over-eat when grass is plentiful. Thus the amount of NSC per acre may be more important even if the concentration per mouthful is lower. If intake is limited by a grazing muzzle, strip grazing or limited turn out time, having lower NSC per mouthful is more valuable.

Plant density will also be a factor in the NSC content when hay is cut. A sparse stand of grass will create a thin windrow that exposes most of the leaves to sunlight. Appreciable amounts of sugar can be made even after the grass is cut, if it is exposed to sunlight (Cairns and Ashton, 1993). If the stand of grass is very dense, the shape of the windrows will tend to be mounded, with a large percentage of the grass shaded by the top layers. The cells of cut grass continue to function until they dry out. Therefore, even after cutting, the same rules apply; in the shade sugar is lower and in the sun sugar concentration is higher

Grass grown under trees is lower in non-structural carbohydrates (NSC). A practical application of this concept is to graze horses in the forest

Some types of grass will be stressed more when conditions are hot, others in cool conditions

5. The effect of stress on NSC

The concentration of nutrients in forage, especially sugars, starch and fructan, is more dependant on environmental conditions than genetic potential. Stressed grass is higher in NSC. When production in the factory slows down, the raw materials in the inventory pile up. When plants cannot grow, sugars accumulate. There are many forms of stress, all of which cause simple sugars to accumulate. The high sugar level triggers the formation of storage forms of polysaccharides; either fructan or starch depending on the type of grass. Some types of grass will be stressed more when conditions are hot, others in cool conditions. It depends on what the grass is adapted too. The affect of stress may change as the plant becomes adapted physiologically to its environment. Sudden cold creates a different reaction than gradual cold. Sudden drought creates a different reaction than gradual drought. Keep the following discussion in context; there are no absolutes but the aim is to explain some of the factors affecting the NSC concentration of grass. Some factors will overrule others and cancel them out while some factors will exacerbate each other and be additive. There are not many 'rules of thumb'. No research has been done to be able to say 'if this and this happen, on that kind of grass, the NSC content will increase by X % hourly until 4 PM upon which it will decrease by Y%'. Even if we had research on your type of grass under your environmental conditions, the equation would be so complicated it probably wouldn't do you or your horses much good anyway. You, the owner, will have to make daily observations and decisions about the body condition and current soundness of your horse to judge if the current amount of grazing time is suitable. We can only point out times and seasons when you should be more observant and consider decreasing turnout time for horses and ponies considered at high risk for laminitis.

Cool temperatures increase NSC

Under good conditions for growth, the concentration of sugars is lower in the morning. However, sugars may accumulate when the nights are too cold for optimum growth and sugars may still be quite high in the morning. The process of respiration and growth in grass is dependant on enzymes which do not function well when the temperature drops below 5° C for temperate, C3 grasses, or 15° C for tropical, C4 grasses. Thus horses are at higher risk for laminitis during times when temperatures fluctuate in and out of the low range. In pangola grass, a tropical grass from Africa, the decline in sugar content through the night went from 78% under warm conditions to only 2% when plants were chilled to 10° C for one night. Subsequent nights averaged nightly reduction of only 47 and 44% (Shatters et al 1993). When sugar is not reduced by respiration, it accumulates. Cool nights cause the NSC content of plants to increase.

A study of 128 temperate and 57 tropical grass selections, grown in controlled conditions, either at 10° C days and 5° C nights, or 25° C days and 15° C nights, under full illumination for 12 hours per day illustrates the effect of temperature on NSC production (Chatterton et al, 1988). The temperate grasses averaged 312 mg NSC per gram of structural dry weight (equivalent to about 24% percent of total dry matter) grown under cool conditions, but only 166 mg NSC per gram of structural dry weight (gSDW) under warm conditions (equivalent to about 14% percent of total dry matter). The tropical grasses averaged 166 and 92 mg NSC per gSDW under cool and warm conditions, respectively (14 and 8 % total dry matter). NSC production was highest in species from the Brome, Fescue, wheatgrass, Phalaris, timothy, bluegrass and cocksfoot families when grown in cool conditions. Being C3, cool season grasses, these were high in fructan under cool conditions, but low in fructan when grown under warm conditions. Of the C4, tropical grasses, the highest in sugars and starch were members of the Panic, Paspalum, Pennisetum and Sorghum families (Chatterton et al, 1988). Forage Pennisetum (*Pennisetum glaucum*) is being marketed as high quality forage for breeding and growing horses in Australia, with a claim that it is 'safe' because it contains no prussic acid (Stuart, 1993). Whilst the development of low prussic acid forage is commendable, the definition of 'safe' does not apply to laminitis high risk horses or horses already with laminitis associated with the consumption of excess carbohydrate (NSC).

Traditionally, the spring season is considered the most dangerous for pasture associated laminitis. In many parts of the world this is the time when low temperatures cause NSC to accumulate. The temperatures that cause fructan accumulation in C3 grasses occur in mid-winter in England, where grass growth is slow, but remains green throughout the winter. Fructan levels peaked in December, then dropped when growth resumed in spring (Pollack and Jones, 1979). Fructan formation is triggered in C3 grasses when sugar levels reach a certain concentration. This may vary between species, and grasses that are more tolerant of long term freezing conditions have higher genetic potential to form fructans. The time when fructan concentrations are highest is when the night time temperatures are between 0 and 5° C and the days are very sunny, such that sugar production (driven by photosynthesis) continues during the day. Cold, but not freezing conditions, cause increases in both sugars and fructans (NSC), and this process is called 'hardening'. If wheat is hardened with a period of cold, but not freezing temperatures, it is better able to survive a subsequent hard freeze, or subfreezing temperatures (Vagujfalvi et al, 1999). Grass that has hardened slowly at above freezing temperatures had very different levels of fructan and sugar compared to grass that froze quickly without a period of acclimation in near freezing temperatures (Dionne et al, 2001).

When grass freezes hard, below 0° C, the fructan is broken down to simple sugars which act as a cryoprotectant, or antifreeze, by adjusting the osmotic gradient and preventing the cells from bursting when ice crystals form. Any time you see green living tissue on grass that has been recently subjected to below freezing temperatures; it will be very high in simple sugars or disaccharides. The amount of fructan that a plant can accumulate prior to subfreezing temperatures is related to its freezing tolerance, because the fructan is the substrate for production of the sugars that prevent it from freeze damage. High sugar is associated with freeze tolerance.

In a study using timothy, orchard grass, and perennial ryegrass the amounts of sugars or fructans throughout a winter with snow cover, but unfrozen soil, varied by species (Moriyama, and Abe, 2003). This study pointed out the inadequacies of studies that measure WSC, which include both sugar and fructan fractions. Differences in ratios of sugar/fructan will vary by grass species, or possibly even by varieties selected for vigour under specific climates, as it has an impact on freezing tolerance.

Heat stress

The optimum temperature range for C3 cool season grasses is from 5-32°C. The optimum temperature range for C4 warm season grasses is 15-40°C. This will vary by species and variety depending on their individual adaptation. When the temperature gets around 30°C, the C3 species will start to be heat stressed. On the other hand, the C4 species will be just starting to work at peak NSC manufacturing capacity. For all grasses, the start of hot weather often coincides with peak concentrations of fructan or starch. Under heat stress, some C3 grasses will slow their photosynthetic rate, while photorespiration increases. They can lose NSC as they cook to death. Under the same conditions, a better adapted C4 grass can be working at maximum efficiency.

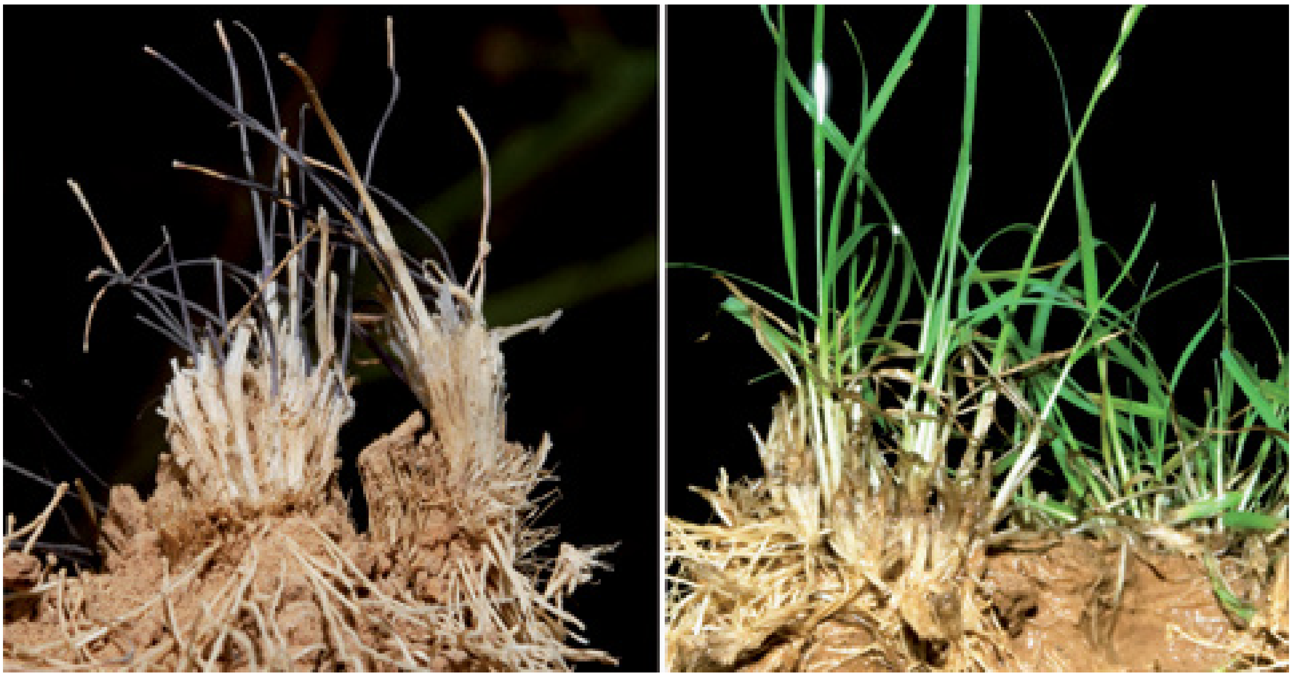


Figure 5-1 Seemingly dead grass, dormant from drought, with stores of fructan or starch in the crown and stem bases (left). *After rain, the stores are used up to produce new growth (right) until such time as the grass has enough leaf area to start producing more carbohydrates.*

Drought stress

When drought causes water supplies to fail the enzymes involved in respiration are compromised before those involved in photosynthesis. This has evolved so that the plant gathers a reserve of stored energy before going dormant. Tropical C4 grasses accumulate starch and sugars, temperate C3 grasses generally accumulate fructan and sugars. A plant with a generous store of fructan or starch will have the fuel for rapid growth when rain resumes (*Figure 5-1*), thus giving it a better position within the plant community to gather both sunlight and nutrients (Volaire et al., 1998). WSC, mostly large fructans comprised 35-40% of the dry matter of grass stem bases of cocksfoot after 3 months of drought (Volaire and Levievre, 1997). Numerous studies by plant scientists show that drought stressed forage is high in NSC.

The ratio of sugars to starch in a drought stressed plant can be different depending on whether the drought came on suddenly or developed slowly. In setaria (*Setaria sphacelata),* a C4 tropical grass that does not make fructan, the relationship between sucrose, hexoses (glucose + fructose) and starch were studied after dramatic short term drought of exposed leaf discs and long term drought of 45 days duration. While short term water loss caused a reduction of sucrose and starch, presumably due to increased respiration, a long term, gradual drought caused sucrose to increase 2-fold to almost 50% of the dry matter. Glucose and fructose also increased significantly, and starch decreased (Da Silva and Arrabaca, 2004). In cocksfoot and ryegrass, subjected to 45 days of drought, the WSC content rose steadily in leaf tissue to over 40 % of dry matter, most of this being large fructans and sucrose. Upon rewatering at 90 days, fructan and sucrose fell to levels similar to irrigated controls. Simple sugars increased, however (Volaire et al 1998). The increase of fructan during drought, and the increase in simple sugars after rewatering was also found in perennial ryegrass, tall fescue and white clover (Karsten and MacAdam, 2001). Other studies agree that fructan increases under long term drought, and decreases upon rewatering, after which an increase in simple sugars accompanies resumption of growth (Thomas and James 1999). In another study, increases or decreases of WSC and fructan concentrations occurred depending on the interaction of drought stress severity, season of drought, species and defoliation frequency (Boschma et al., 2003). Again, without research on your species of grass, under your climatic conditions, and your management practices, you will never know for certain what is happening to the NSC concentrations of your pasture. Rules of thumb are all we have and even they have exceptions. Watching your horse carefully and limiting access is going to be your best laminitis management plan until more field research is conducted.

Salinity

Disturbed underground hydrology by irrigation and the removal of trees has increased the salinity of soil and is a serious problem in Australia. High salt in the soil is another stress that can increase NSC in grass. It essentially has the same effects as drought as the plant must work harder to pull water into the roots across the now high osmotic gradient. Wheat subjected to salt in the growth medium initially increases in sugar concentrations and later in fructan concentration. Salt tolerance is highly correlated with high WSC and fructan in particular, in different varieties of wheat (Kerepesi and Galiba, 2000). Some native grasses are better adapted to saline soils and are worth considering for horse pastures.

Nutrient deficiency: Starving grass may be higher in sugar

When the factory slows down due to lack of an essential component, the other parts of the inventory pile up. When nutrients are low, growth slows, sugars build up and this triggers the production of fructan or starch. This effect will be more pronounced in grass species that evolved a high need for nutrients, such as the exotic, highly productive grasses from Africa or Europe growing in fertile soil. Native grasses, especially those that evolved in Australia's relatively poor soil, don't need as much fertiliser; they have developed highly efficient use of the limited nutrients available to them.

Improved grasses and cereal grains have high nitrogen requirements and will experience growth limiting stress when nitrogen is deficient. The sign of nitrogen deficiency is yellowing of the green leaves, which is more evident on the newest growth. If a pasture has clover or another nitrogen fixing legume growing in it, it may be evident that only the grass growing adjacent to the legume is dark green, while away from the legume the grass is paler green. This is a sign that nitrogen application is indicated.

Fructan and nitrogen showed a strong inverse relationship in wheat, oats and barley, with over 20 % DM fructan in the most severely deficient tissue (McGrath et al., 1997). The presence of nitrate in leaf tissue inhibits fructan formation in barley (Morcuende et al., 2004). Nitrogen deficient leaf tissue of perennial ryegrass had over twice the concentration of WSC, and up to 10 times the fructan as that where nitrogen was not limiting (Morvan-Bertrand et al., 1999).

Barley leaves deficient in phosphorus were higher in fructan, whilst starch levels were not affected (Wang and Tillberg, 1997).

Overgrazing

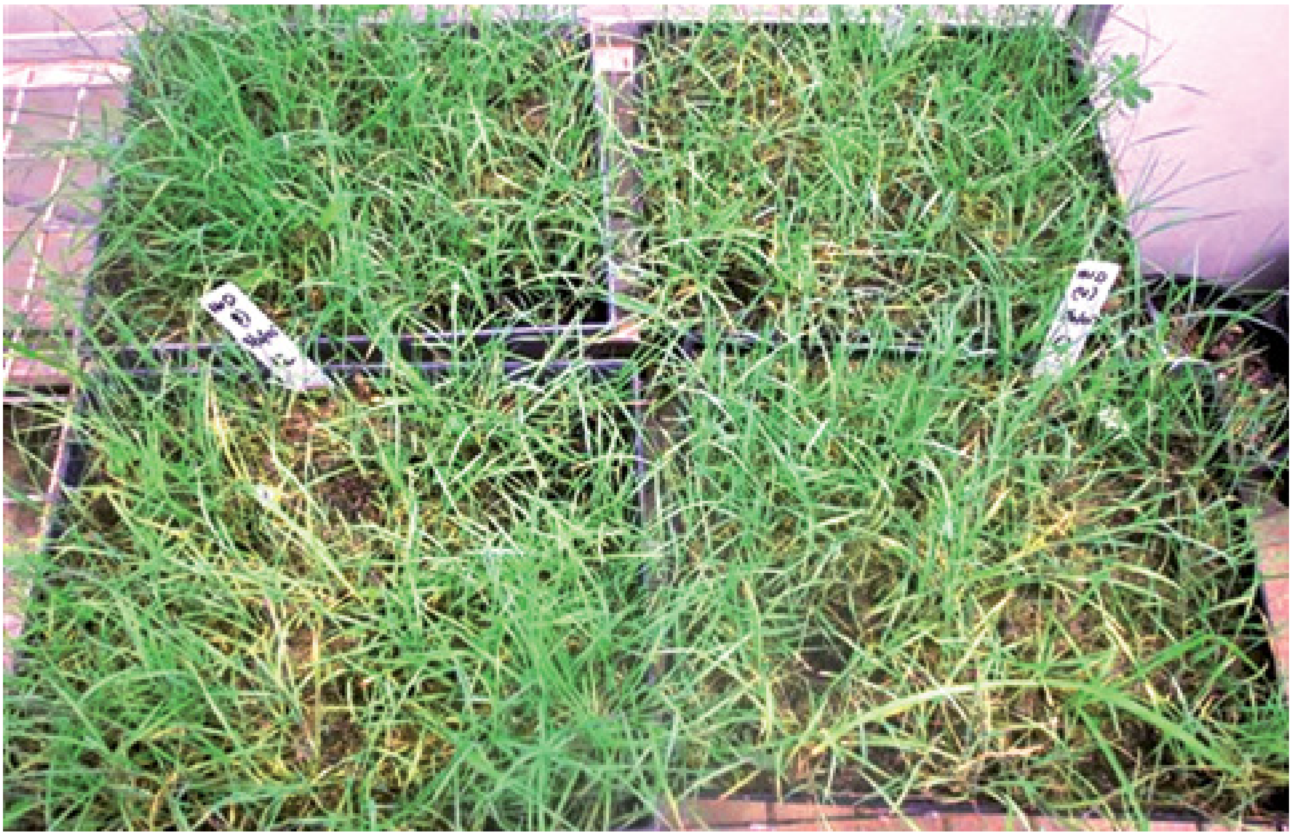
Overgrazing may change the plant community forever. The extent and length of the overgrazing will determine which plants survive to reproduce. With moderate grazing pressure, horses will tend to select the more palatable, exotic species, leaving the lower sugar grasses. This may allow the native species to maintain a foothold in the pasture, and grow enough to set seed. If horses are forced to eat everything in the paddock, the native species will have less chance of competing with any introduced species in the community because they have not developed grazing resistance mechanisms. Intensive grazing by large hoofed animals can irreversibly alter the community of plants within a paddock in as little as two years. Low carbohydrate native species die out quickly, never to return, leaving the soil bare for opportunistic broadleaf weeds which are often very high in sugar and fructan. If horse owners are interested in encouraging and nurturing native species in their paddocks, it is imperative to practise rotational, or cell grazing and not allow horses to eat grass down to the base of the plants.

There is a large body of research and practical knowledge about sustainable grazing of native grass in Australia. For more information on native grass refer to the section at the end of this booklet.

Most of the surviving native grasses in Australia have been subjected to intense grazing pressure for nearly 200 years, and consequently they have already started to adapt (Oram and Lodge, 2003). There is evidence that native species have also adapted to fertilised soils and the introduction of nitrogen fixing legumes. They have also started to develop grazing resistance mechanisms. This may complicate finding suitable lower NSC native species for laminitis high risk horses and ponies. Recreational horse owners fortunate enough to own native grass pastures should consider them a national treasure, and should be encouraged to graze them sustainably.

Acclimatisation: stress is relative

Species or varieties of plants that have evolved in a specific set of environmental conditions will become stressed when those conditions change. Grass that evolved in a cool climate will be stressed when it's too hot. Grass that evolved to thrive in wet soil will be stressed when it's dry. Grass that evolved in Europe and England may be stressed when grown in parts of Australia, where soil and climate are different. Australian droughts are more frequent and longer lasting than those in Mediterranean regions. Australia is sunnier, hotter and drier. Australian soil has poor water holding capacity, may be salty, and less fertile than European soils where higher rainfall encourages recycling of organic matter and nutrients. If the response to stress in grass is to accumulate NSC, it is easy to see why the first importers of temperate grasses were initially thrilled with the increased weight gain and wool production amongst their cattle and sheep.



Many plants depend on grazing animals like horses to help germinate and disperse their seeds. The seedlings pictured are Queensland blue couch (Digitaria didactyla) 36 days after they grew from dry horse manure planted in potting mix

6. Co-evolution of grass and grazing animals

Sustainable, natural eco-systems have evolved over eons with specific plants and animals fitting together under a particular set of environmental conditions. Plants and animals frequently have a symbiotic relationship. Many plants depend on grazing animals to disperse and fertilise their seeds. Many seeds pass through the digestive system no worse for wear and sometimes require the action of grinding teeth or stomach acids to abrade a tough seed coat and thus facilitate germination. The moist, fertile manure that the seed ends up in is the perfect nursery for germinating plants. This is one of the reasons that high palatability and large seeds, filled with tasty starch, is a successful reproductive strategy for grass that evolved in conjunction with large herbivores. Grass can also reproduce vegetatively which is reproduction without producing seed. The formation of new shoots from the base of the plant or from runners is called vegetative reproduction (*Figure 2.3*). Grazing resistance mechanisms evolved to counter the effect of excess intensive grazing that can kill grass by taking away too many resources.

Grazing resistance

Grazing resistance is a combination of avoidance and tolerance mechanisms. Some kinds of grass may deter grazing by producing alkaloids that make the grass taste bad or by developing rough or tough leaves or seeds with long serrated awns that are uncomfortable in the mouth. Grazing tolerance mechanisms are those which confer on a plant the ability to compensate with increased growth to quickly replace resources lost to the grazing animal (Briske, 1996). These are the tolerance mechanisms that most concern us as they tend to encourage grasses that hoard carbohydrates under intensive grazing scenarios.

While sacrificing valuable carbohydrate reserves for the sake of making and spreading seeds grass has to hold back some materials for regeneration of leafy tissue in order to survive the next season of drought or cold. This is accomplished by storing NSC close to or under the ground away from the easy reach of animal teeth. NSCs are arranged spatially within a grass plant and generally the concentration in vegetative tissues is higher in lower portions of the plant. Grasses often store NSCs in the base of the stem, the crown and rhizomes (*Figure 2-4*) or stolons; those runners from which new shoots arise (*Figure 2-3*). To recover quickly after defoliation from intensive grazing grass must have sufficient reserve carbohydrate to grow rapidly enough to displace rival plants competing for the same resources of light, water and nutrients. The more NSC they can store, the better their chance of establishing themselves in a niche better suited for displacing their rivals. Grass that is able to get tall quickly to shade out competing plants will predominate after defoliation. When comparing perennial ryegrass and colonial bentgrass (a turf species) under weekly clipping regimen, the ryegrass yielded 5 times more dry matter after 6 weeks (Alexander and Thompson 1982). Perennial ryegrass is consistently the highest in NSC when compared to other species of grass under a variety of growing conditions.

Grass will sacrifice nutrients from its root systems for the opportunity to gain a more competitive position in the plant community. The biomass of the root system stays in balance with the biomass of the tops. A broad, deep root system under each grass plant will supply maximum water and nutrients to above ground foliage and will prevent the seeds of other plants from gaining access to bare ground where they can germinate. Dense sod and a strong well branched root system is the best defense against invasion from broadleaved plants, such as weeds or brush.

Mycorrhiza recycle dead root nutrients

While the mechanism is not completely understood, grass plants will slough off excess roots after the tops have been removed. The nutrients from the dead root tissue are taken up by symbiotic fungi called mycorrhiza, that live around the roots and recycle nutrients back to the plant. When the leaves (the factory for building materials) have regrown the roots can then flourish from the newly available resources. The migratory nature of grazing herds allows this to function as a renewable system. If confined animals remain too long on grass that has already depleted its root resources, roots can no longer maintain the most efficient gathering of nutrients and water to feed new growth. The smaller root system, along with damage caused by trampling, allows bare soil between grass plants. Other more competitive plants with deep tap roots (weeds) invade. This is why weeds thrive in overgrazed, degraded or 'horse sick' pastures. Overgrazing leads to a collapse of the sustainable system of a healthy grass sward. It also forces horses to eat only the lower portions of grass plants, where the concentration of NSC is highest.

Figure 6-1 This kikuyu grass plant has been grazed down until all that is left are the stem bases where starch is stored.
Kikuyu stems divide into branches when eaten. Pasture experts recommend heavy grazing of kikuyu to stimulate increased productivity.

Vegetative reproduction is a successful grazing survival mechanism

Another successful grazing survival mechanism is stimulation of vegetative reproduction when seed heads are removed. When a grazing animal eats all the developing seeds at the top of the plant, grass resorts to an alternative mode of reproduction; the formation of new shoots from the base of the plant or from runners. Hormones secreted by the developing seed heads claim priority for nutrients, much like a developing foetus in a mammal. When removed by a grazing animal, or by timely slashing/mowing, the source of these hormones is removed, promoting stimulation of new growth points in the stolons or crowns. This new growth will use up accumulated NSCs, and prevent selective grazing of developing seed heads that are higher in NSC than leaves. Later, we will learn how to can take advantage of this mechanism to manage pastures for lower NSC concentration per mouthful, and, at the same time, help the grass to grow thick and strong.

Grasses that evolved under intensive grazing may reproduce more by this 'vegetative' type of reproduction than by seed formation. Examples of these are kikuyu (*Figure 6-1*), and some varieties of couch which do not make seed at all. These must be planted from runners or sprigs, which are dormant stolons or rhizomes. These grasses respond to grazing by branching out and making more stolons. The formation of a dense network of branching rhizomes either above or below the soil creates dense sod that helps pasture withstand trampling by hoofed animals.

Most of the grasses used for intensive grazing by cattle come from regions where grass co-evolved with large herds of hard-hoofed herbivores. Imported, exotic grasses have become the basis for intensive grazing in topical and sub-tropical regions of Australia. Grasses of African origin include kikuyu, paspalum, Rhodes (pictured), green panic, and setaria

7. Why 'improved' grasses tend to be high in NSC

Agriculture started around 10,000 years ago in the area around the Euphrates and Tigris Rivers on the eastern side of the Mediterranean. Sometimes called the 'Fertile Crescent', it is now called the Middle East. Agriculture spread first to southern Europe, and then around the world. Farming required herders to abandon their nomadic lifestyle and stay in one place to tend their crops. They kept their animals confined for easier access. Animals were fed by-products of crop production such as straw and surplus grain. The development of fodder crops began. Perhaps more importantly, the natural selection for grasses that could withstand intensive grazing of confined animals also began (Yudkin, 1969).

Natural selection of grass may produce higher NSC offspring

Plants evolve more quickly than animals. Agriculturists selected and bred from individual grass plants that thrived in their new cultivated environment. Grasses that survived intensive grazing, temperature extremes, seasonal rainfall, changes in soil fertility and competition from other plants were selected. Unbeknown to the early agriculturalists, the selected grasses were also high in NSC content. All grass that survives to reproduce is undergoing selection and future generations are better adapted to the changing environment.

When a stand of grass, containing a mixture of species is overgrazed, only the more competitive species and individuals within a species will survive to reproduce. Keeping animals confined in a paddock will provide evolutionary pressure and grass will develop more efficient grazing resistance mechanisms, especially if the grazing pressure is intense. One such resistance mechanism is high levels of NSC, either in large seeds, or in storage organs (Humphreys, 1981). Such is the case for perennial (*Lolium perenne*) and annual ryegrass (*Lolium multiflorum*) that originated in northern Italy. The genus *Lolium* has been under the longest period of agricultural selective pressure and subsequently is one of the highest in NSC. In fact, perennial ryegrass can no longer be found in the wild; it is only found in association with grazing animals. Perennial ryegrass holds the record for high NSCs, in particular fructan, when compared to other species of grass, grown side by side under various environmental conditions. It is considered the best grass for intensive production of cattle and sheep wherever it is able to grow. It is highly palatable, high in nutrient content, fast growing and durable. It has rather large seeds, will reproduce vegetatively via increased tillering and stolon formation after grazing, and is capable of storing very large amounts of fructans. The fructans provide energy reserves to get it through the short term droughts that naturally occur late in the Mediterranean summer. The large reserves of fructan give ryegrass the ability to grow very quickly after rain in spring and autumn and give it a competitive advantage over its neighbours. Ryegrass forms dense sod that protects its roots and soil from damage by heavy hoofed animals. It is frequently found in pure stands, as it crowds out other grasses. Ryegrass is the logical choice for sustainable intensive grazing in the temperate regions of Australia and New Zealand (*Figure 7-1*). Unfortunately the high sugar and fructan content that give it the ability to withstand heavy grazing is dangerous for horses.

Most of the grasses considered useful for intensive grazing by cattle come from regions where grass co-evolved with large herds of hard-hoofed herbivores. Africa's vast herds of ungulate grazers provided the necessary grazing pressure for grass to evolve symbiotic reproductive strategies as well as grazing resistance mechanisms. When drought caused herds to congregate near water holes the process was amplified. Grass varieties that have undergone natural selection from grazing pressure in the wild are logically the best grasses for further 'improvement'. Adapting grass for grazing by confined domestic animals increases NSC content even further (Oram and Lodge, 2003).

This is why African grasses, which are nearly all C4, tend to be higher in sugars and starch. These imported, exotic grasses have become the basis for intensive grazing in topical and sub-tropical regions of Australia. Grasses of African origin include kikuyu, paspalum, Rhodes, green panic, and setaria. In a study comparing the carbohydrate fractions of 185 selections of grass, forage Pennistum (millet) and Paspalum were the highest in NSC of the C4 tropical group. Nearly 20% of their dry matter was sugars and starch when grown under 25°C days and 15°C nights (Chatterton et al., 1988).

Plants naturally selected for adaptation to extreme climates are higher in NSC. Under natural conditions in Iceland, varieties of clover that were better adapted to subfreezing conditions and ice encasement were higher in various sugars in the autumn (Dalmannsdottir et al., 2001). The starch that accumulates in Autumn hydrolyzes under freezing conditions to form sugars, which may act as a cryoprotectant in some species, keeping cells from rupturing during freezing. Environments with extremely cold winters require forages to be higher in NSC in order to survive.

Whilst techniques for forage 'improvement' have not yet utilised genetic engineering, the technology exists to insert genes that enable new plants to make fructan, or to increase the enzymes controlling NSC formation. (Zhang et al., 2006; Humphreys et a.,l 2006). These characteristics are seen to be an advantage to cattle and sheep producers and until horse owners become aware of this, it is inevitable that the 'improvement' of pasture crops will continue to increase the danger of carbohydrate overload to grazing horses.

Figure 7-1 Ryegrass growing on the Canterbury Plains of New Zealand.

Native Australian grasses tend to be lower in non-structural carbohydrates (NSC) than exotic imports

8. Why native Australian grasses tend to be low in NSC

Large herbivores never evolved in Australia. An intriguing theory suggests that this is due to deficiencies in the trace minerals required by large herbivores. The Australian landmass lacks the geological mechanisms of volcanism and land upthrust that brings fresh minerals to the surface (Milewski and Diamond, 2000). Grasses in Australia co-evolved with relatively smaller marsupials that have soft feet and different grazing techniques than Bovidae or Equidae. Australian grass never had to adapt to enormous herds of heavy animals with sharp destructive feet that ate grass close to the ground across wide swathes of the countryside. They never had to adapt to long periods of freezing temperatures. Native Australian grasses tend to be lower in NSC than exotic imports (Boschma et al., 2003). The predominant plant stress in Australia is heat and drought. Even in temperate Australia, the temperature is never as cold as that which northern hemisphere adapted grasses must withstand. While accumulation of fructan is a useful defense for the short term droughts common in the Mediterranean region, it is frequently not enough to allow grass to survive the very long droughts that are common in Australia.

Before the introduction of cattle and sheep to Australia, both native plants and animals were well adapted to the unpredictable rains and long term droughts that characterise Australia. Kangaroos stop reproducing under drought conditions. Many Australian native grass species go dormant under drought, and have tough seed coats that can seal precious resources away until better times. They do not accumulate NSC under stress like grasses from Africa or Europe. There is no reason to risk limited resources trying to store excess carbohydrates for a drought that can last for years. Life slows to an ebb, awaiting the next rain.

Native Australian grasses are lower in NSC than introduced, exotic species when grown under the same conditions. In a study done in Victoria, the fructan, starch and sucrose levels in grass stems (the region highest in NSC) from 48 different species of grass forage, including both native and introduced species, were analysed at various times from two different sites. From samples pulled mid-day in mid November, NSC ranged from a low of 6-7% DM for veldtgrass stems and a high of 47.8 % DM for wheat stems. The native Australian grasses overall were lower in NSC, especially fructan. Speargrass (*Austrostipa* spp.), Wallaby grass

(*Austrodanthonia* spp.), tussock grass (*Poa* spp.), weeping grass (*Microlaena stipoides*), rat's tail grass (*Sporobolus* spp.) were among the genera lowest in both NSC and fructan. The highest in NSC were the introduced species: Wimmera ryegrass (*Lolium rigidum*), barley grass (*Hordeum leporinum*), barley forage (*Hordeum vulgare*), wild oats (*Avena fatua*), perennial ryegrass (*Lolium perenne*) cocksfoot (*Dactylis glomerata*), and Yorkshire fog (*Holcus lanatus*). These species all had fructan as the major constituent of their NSC (Smouter and Simpson, 1989).

In 1990, 146 genera of native grass were recognised in Australia. Native grass is seen by forage experts as being an underutilised resource. While a few species have been researched and used commercially, many others with good agronomic and conservation characteristics have yet to be examined (Roberts, 1990). Current objectives in forage research focus on further improvement of exotic species (Gordon and Barnett 2005). Native grass has supported sustainable cattle and sheep production for two hundred years, when adequate rain permits. While the value of native grass may not be recognised by graziers looking for maximum production of meat animals or Thoroughbreds, horse owners needing to maintain mature ponies and horses have an untapped resource in the species of grass native to Australia. While research in native grass production has not kept pace with research on improved, exotic species, enough information exists about management systems for long term sustainable grazing of native grass in Australia to be a great value to horse owners seeking to provide the perfect free choice feeding system to horses at risk of laminitis. Owners of these horses should make their needs known to forage researchers. A niche for native grass production is being overlooked.

Long term droughts have renewed interest in native grasses, as introduced species have performed poorly. More interest in environmentally friendly and sustainable grazing systems inevitably lead to re-evaluation of the importance of native grasses for soil stabilization, improved hydrology (that may help to prevent salinization of soils) and sustainable grazing over long term drought. Native grasses being considered worthy of commercial improvement include: Wallaby (*Austrodanthonia* spp.), Red grass (Bothriochloa macra spp.) wheatgrass, (*Elymus scaber*), Weeping grass, (*Microlaena stipoides*), Mitchell grass (*Astrebla* spp.) and Kangaroo grass (*Themeda triandra*)(Brouwer 2002).

Native Australian grasses have already adapted to 200 years of intensive grazing. Populations of several species of *Austrodanthonia* (Wallaby grass) from intensively grazed sheep camps were found have shorter tillers, lower growth habit and more seed heads compared to populations where grazing was very light. These were found to be genetically transmitted characteristics, not just temporary adaptations (Scott and Whalley, 1984).

9. High NSC Weeds

Certain weeds can be very high in sugar, starch or fructans and some of these are palatable to horses. Forage researchers know that weeds are palatable and high in nutrients, and some of those are already being further improved for cattle forage. Some common weeds that can be high in sugars or fructan include:

Dandelion *(Taraxacum officinale)*

Dandelions are found around the world and are known to be highly palatable to horses (*Figure 9-1*). Dandelion has more fructan than grass (Chatterton, personal communication). It is the same type of fructan (inulin) that induces experimental laminitis when administered to horses (Van Eps and Pollitt, 2006). After long term drought has killed shallow rooted grass, dandelions, with a deep tap root full of reserves, may be the only thing left green in the pasture. The concentration of sugars and fructans may reach 25% DM in above ground parts under conditions of repeated frost and sunny days (Watts, unpublished data) and 12-15% of fresh weight as inulin in the leaves (Van Loo et al., 1995).

Figure 9-1 Dandelion (Taraxacum officinale), a palatable pasture weed may contain up to 25% sugars and fructans as dry matter in its above-ground leaves and stems.

Storksbill or redstem fillaree *(Erodium sp.)*

Members of the family *Erodium* have been anecdotally implicated in cases of laminitis. Well adapted to disturbed bare soil, it springs up in bare paddocks after autumn rains (*Figure 9-2*). It can be very high in trisaccharides, testing over 25% DM (K.Watts, unpublished data).

Figure 9-2 Storksbill (Erodium species) has a hairy circular stem and grows to about 70 cm in height.
The five petalled flowers measure at about 10 to 15mm in diameter and are pinkish/ purple in colour. The fruit has a beak (hence the common name) about 3-5cm long.

Wild oats *(Avena sp.)*

Oats gone wild are just as high in NSC as the domestic varieties. They can contain high levels of fructan and starch.

Quackgrass *(Elytrigia repens)*

Sometimes called English couch, twitch, rope or dog grass (*Elytrigia respens*, previously *Agropyron respens*), this aggressive, hard to kill grass weed becomes palatable under cool growing conditions when it accumulates fructan. Because of its spreading, sod forming growth habit, drought tolerance and palatability, it is being used as a parent for new grass hybrids in forage breeding programs.

Sago or plantain *(Plantago lanceolata or P. major)*

This common weed is known to be excellent forage for cattle production due to its high sugar content (*Figure 9-3*). It is frequently the only thing left green after drought has killed the surrounding grass. Forage scientists around the world are recommending this weed as an alternative forage for cattle due to high drought tolerance and high feed value (Brouwer, 2002). It is high in trisaccharides. This genus of weeds also includes *P. psyllium* which is high in mucilage and is therefore included in herbal remedies meant to sooth and lubricate the intestine and relieve sand colic.

Sowthistle *(Sonchus oleracea or arvensis)*

Sowthistle contains inulin type fructans and is highly palatable. Introduced from Europe sowthistle has become a troublesome weed especially in cultivated croplands. Dispersed by the breeze on parachuted seeds, the plants spring up everywhere in disturbed soil and bloom throughout most of the year. The plant contains a milky juice. The inelegant name comes from sowthistle's reported appeal to pigs.

Chicory (*Cichorum intybus*)

Varieties of forage chicory has been bred to stay in a vegetative stage for a long time, and look more like endive than the type we usually consider as the common weed (*Figure 9-4)*. Chicory is valued as a high quality feed for fattening meat animals (Brouwer, 2002). Chicory is the source of inulin, a type of fructan that is hydrolysed to make oligofurctose or fructo-oligosaccharide (FOS) that can be used to induce experimental laminitis (Van Eps and Pollitt, 2006). The roots are the storage organ, but forage will have some inulin.

Figure 9-3 Plantain (Plantago major)is the larger of the two common plantains.
Plantain can be found in lawns, gardens, most pastures and virtually all roadsides. Infestations can become quite dense in run down lawns and pastures, excluding desirable grasses. Plantain can access nutrients deeper in the soil than most grasses.

Figure 9-4 Chicory (Cichorum intybus) is cultivated for fattening meat animals.
Chicory roots are rich in inulin, a type of fructan can be used to induce experimental laminitis in horses (Van Eps and Pollitt, 2006).

10. Which horses are at highest risk?

Any horse is susceptible to hindgut carbohydrate overload from overeating at one binge. All that is required is for the horse to be given access to more non-structural carbohydrate (NSC) than can be digested before entering the hindgut. Horses at highest risk include those:

- that have access to unlimited amounts of improved, high NSC pasture
- being fed large amounts of grain for show condition and for maximum athletic performance
- that are obese and not getting sufficient exercise
- that are insulin resistant.

There is a genetic predisposition to laminitis that has been confirmed by work conducted on an inbred herd of Welsh ponies in America by researchers at Virginia Polytechnic Institute and State University (Trieber et al 2006). Farm records going back a hundred years were examined, seeking correlations between laminitis and pedigree. Ponies that developed laminitis all descended from two mares and a stallion imported around 1900. Blood analyses of all the ponies at the farm showed that the ponies developing laminitis had high concentrations of insulin and triglyceride. This also occurs in the condition in humans known as Metabolic Syndrome; a precursor to Type 2 diabetes. The researchers were able to predict with a fair amount of accuracy which ponies would develop laminitis in the spring, when the NSC concentration in the clover rich paddocks was high. The mechanism by which insulin resistance might cause laminitis is not known, although a strong association has been well accepted for some time (Jeffcott et al 1986). Experimentally, laminitis can be rapidly induced by infusing insulin into the bloodstream of a horse or pony (Asplin et al., 2007) leaving little doubt that insulin alone, at abnormally high blood concentrations is laminitogenic. As with the parallel human condition, exercise and a diet low in sugar and starch are the most useful tools to manage the condition.

Certain breeds seem more prone to laminitis and the breeds generally considered at higher risk from metabolic laminitis include:

- all pony breeds
- "easy keeper" breeds: Egyptian Arabs, Spanish breeds, Appaloosa, Morgan and some lines of Warmbloods, Norwegian Fiord, Icelandic

While the mechanism for laminitis associated with hyperinsulinaemia is still unknown, the physical characteristics and body profile of horses or ponies that are at high risk for laminitis are becoming recognised. Following is a list of characteristics that should trigger pro-active changes in management to minimise risk of endocrinopathic (hormone induced) laminitis:

- A tendency towards obesity on diets that maintain other members of the herd in moderate condition
- Presence of abnormal fat deposits, even when the animal is placed on a restricted diet such that ribs may show. These are often lumpy or corrugated and hard. Sites of abnormal fat deposits include:

- the crest of the neck, such that a dip forms in front of the withers
- the depression above the eye
- the sheath of a male, or the udder of a female
- the abdomen
- around the base of the tail *(Figure 10-1)*
- the withers or shoulder

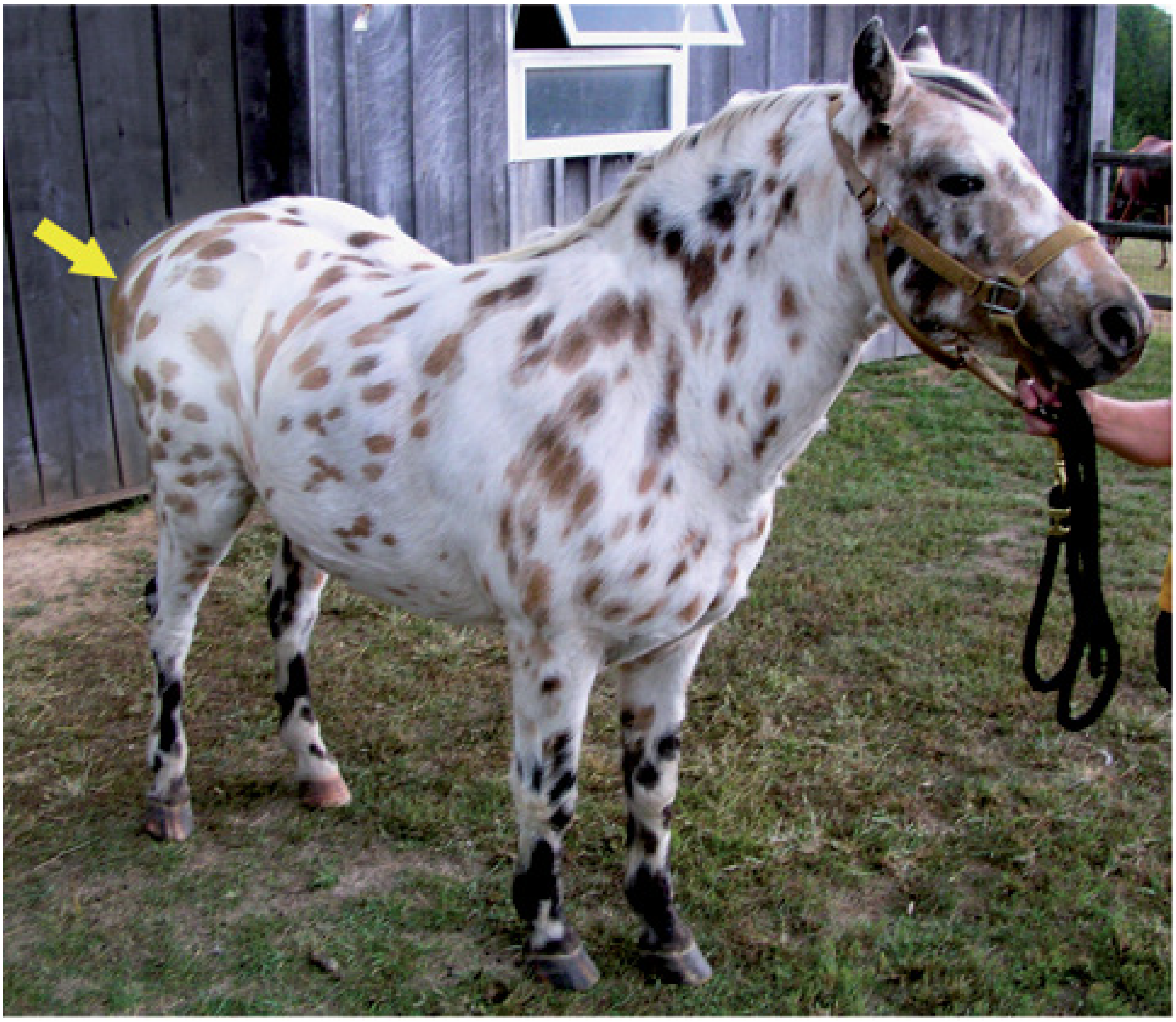


Figure 10-1 Laminitic pony with the cresty neck and abnormally large fat deposits around the base of the tail (arrowed) typical of insulin resistant, (hyperinsulinaemic) obese ponies.
Photo: Don Walsh.

11. Dietary changes during an acute attack

If the animal has foundered at pasture, remove it to an area where feeding can be tightly controlled. Access to even very short grass is not suitable, as the parts close to the ground can be very high in stored sugars, starch or fructan. Provide the horse with a comfortable, safe place to lie down. Remove all cereal grain from the diet. Some horses and ponies can worsen with even a handful of grain. For horses in performance condition with high metabolic demands, beet pulp with added oil can provide a safer form of dense calories than cereal grain. Keep the diet as simple as possible; right now managing the current laminitis episode is the priority. Worry about a shiny coat and proper show condition later. The horse cannot go to the next show if it is lame and lying down. While some horses are able to tolerate reasonable amounts of lucerne, during laminitis it may best to eliminate legume hay and chaff until the feet are stabilized. If oaten or wheaten chaff needs to be fed to give medicine or supplements, soak it first in lots of water to remove excess sugars and fructan. Do not feed bran, as it often contains considerable starch. Do not feed anything with honey or molasses. Feed no high sugar or starch treats, such as apples, carrots, bread, pasta, green grass or weeds of any kind. It is normal for a horse in pain to have a reduced appetite. No harm will be done if the horse does not eat much for a couple of days.

12. Soaking hay to remove excess WSC

Leaching excess sugars and fructan out of hay may be very helpful to a horse with active laminitis. While soaking hay may be inconvenient long term, especially during times of water restrictions, it should be included as a first aid treatment, and can minimise worsening of symptoms until more suitable hay can be obtained.

The concentration of sugar and fructan (collectively called Water Soluble Carbohydrates or WSC) can be reduced by soaking underwater for 1-2 hours. Using more water will increase the amount of WSC removal. In a study using 15 different hay samples, up to 56% of the WSC were removed after soaking for 60 minutes in cold water. The same amount can be removed by soaking for 30 minutes in hot water (Watts and Sirois, 2003). As starch is not soluble in water, forage samples that contain high starch levels are not affected by soaking. As the sugars will be left in the water, clean fresh water must be used every time and the ill horse must not be allowed to drink the water used for soaking. The water can be used in the garden, where the sugars may provide a useful source of carbon to stimulate microbial growth.

Practical suggestions for practical soaking set ups

In an emergency any water tub can be used, with a heavy weight on a piece of steel mesh to keep the hay submerged. Wet hay is very heavy, and you will need to improvise a better method long term to save your back. Creativity is essential to find a practical method, which need not require much expense. A wheeled plastic cart or wheelbarrow with bungee cords fastened across the top is easy for small amounts of hay. Tip the water out, and move the hay around easily in the cart (*Figure 12-1*). Another option is to place hay beneath weighted steel mesh in a plastic laundry basket and submerge it in water contained in a rectangular plastic tub (*Figure 12-2*). The water can be drained away via a tap fitted to the base of the tub (*Figure 12-3*).

Figure 12-1 Grass hay can be soaked in a flat bed wheel barrow.
A heavy weight on top of steel mesh keeps the hay under water. Inset shows the water being discarded; a bungee cord prevents the hay from slipping out of the barrow.

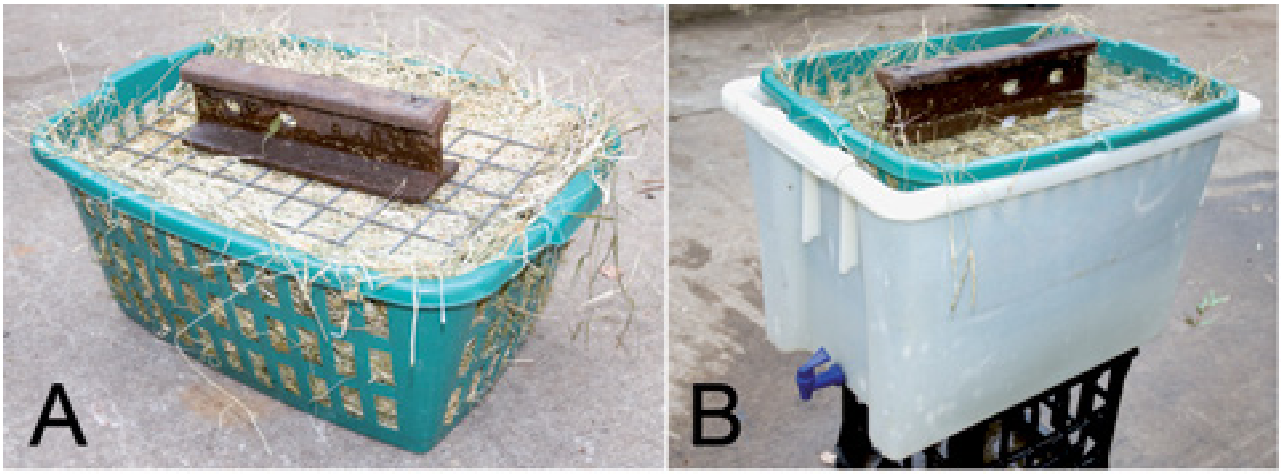


Figure 12-2 Grass hay weighted beneath steel mesh in a laundry basket (A) can be soaked in a tub (B) fitted with a tap for discarding the used water.

Figure 12-3 Tea coloured water draining from a tub is which grass hay has been soaked.
Soaking hay in cold water for 60 minutes will remove around 50% of the water soluble carbohydrate.

Some hays may be so high in WSC that while soaking may reduce levels significantly, it may still be too high for a horse with active laminitis. A second soak with clean water will remove more. Feed soaked hay until real improvement has occurred. It may take up to 2 weeks to see the full benefit.

Place wet hay in a tub or on a mat to keep it from gathering dirt, or feed from a hay net. Most horses accept wet hay readily. Those few with a very persistent sweet tooth may need to get really hungry before they will eat hay with sugar reduced. Do not give in too soon to finicky eaters. Wet hay may get mouldy very quickly in warm weather, so it is recommended that you only soak the hat to be fed within a 12 hour period. The amount of mould spores in each batch of hay will also determine how quickly wet hay will spoil. The soaking water will start to ferment and form alcohol quickly during hot weather. During cool, dry weather, you might be able to spread soaked hay out to dry on some mesh wire to dry for feeding later. Use your nose to decide. Do not feed sour or mouldy-smelling hay.

No studies have yet been conducted on what nutrients other than WSC and potassium are removed by soaking hay. Other water soluble nutrients including B vitamins, vitamin C, are probably reduced as well. These vitamins are important for overall health, but healthy horses can make Vitamin C in their livers and B vitamins are produced by micro-organisms in the gut. More research needs to be done to see if long term soaking of hay has any detrimental affects on equine health. If soaking the sugar out of hay assists in managing your horse during a laminitis episode, then you know, even without hay analysis, that the sugar or fructan content was too high. Try to find hay with low WSC content. It will be far more practical than soaking hay long term.

The important difference between horses and ruminants such cows and sheep, is where in the intestine they ferment their feed

13. A horse is not a cow

The important difference between horses and ruminants is where they ferment their feed. Cows and sheep have a compartmental forestomach with the rumen being the major fermentation compartment. Ingested feed is continually fermented by a vast and diverse symbiotic microbial population. Sugars, fructans and starch are readily available carbohydrates and are rapidly fermented to volatile fatty acids (VFAs) and lactate. VFAs are efficiently absorbed across the rumen wall into the blood stream and are delivered directly to the liver and processed as energy sources. The NSC feed the bacteria, and the bacteria feed the cow. Lactic acid or lactate is also formed by the fermentation of fructans, starch and sugars and lactate is a stronger acid than the VFAs. If produced in large quantities it can lower the pH of the rumen leading to acidosis, illness and laminitis. The end product of NSC digestion in ruminants is not glucose as it is in monogastic animals like humans and dogs. The rumen microbes ferment the NSCs into VFAs and lactate that the liver processes into glucose as needed.

Horses are hindgut fermenters. Food remaining after stomach and small intestine digestion is subjected to microbial fermentation in the enlarged caecum and colon. Although the stomach of the horse is relatively small, acidic and quick to empty, some fermentation does occur with lactic acid being the main fermentation end product (Al Jassim et al., 2005). In the small intestine enzymes are released that digest starch into simple sugars which are then absorbed into the blood stream. When blood sugar levels rise, this triggers release of insulin, which is needed to facilitate the entry of glucose into certain tissues where it can be used for energy.

The portion of the diet that escapes stomach and intestinal digestion is mainly in the form of structural carbohydrates (fibre). The diet of horses in their natural state is grass and legume based and consists mainly of complex, structural carbohydrates in the form of cellulose, hemicellulose and lignin. Non-structural carbohydrates (NSC) in the form of sugars, fructans or starch are also consumed. The structural carbohydrates and fructans are indigestible to mammals (Flamm et al., 2001; Roberfroid, 2004) and a large portion of the equine abdomen is occupied by the caecum and colon where complex carbohydrates and fructans are fermented to absorbable end products. Only bacteria can crack the chains of fructose that make up fructan, so fructan passes down the horse's small intestine to the hindgut unchanged. When it gets to the hindgut, it is rapidly fermented along with any excess starch.

Domestic horses and ponies sometimes encounter large quantities of starch and fructan in their diet when they consume cereal grain or the sward of certain cultivated pastures. Pony breeds, having evolved metabolic adaptations for survival in harsh, low nutrient environments, are particularly prone to laminitis if given unrestricted access to cultivated sugar, starch and fructan rich pasture. Most of the consequences of carbohydrate overload occur after the arrival of the carbohydrate in the hindgut and relate to the rapid proliferation of hindgut bacteria flourishing in the presence of excess NSC substrate.

Upon mixing with the normally neutral caecal contents, excess starch or fructan undergoes rapid fermentation to lactic acid. With the arrival of more and more substrate, fermentation continues and the unnaturally acidic conditions favour the rapid proliferation of Gram positive bacteria of the *Streptococcus* genus collectively described as EHSS or equine hindgut streptococcal species (Milinovich et al 2008). These microbes have other names; *Streptococcus infantarius* subsp. coli (synonym: *Streptococcus lutetiensis*, previously: *Streptococcus bovis*). EHSS activity results in very acidic conditions in the hindgut with pH as low as 4. Two isomers of lactic acid, D-and L-lactate, are produced in almost equal proportions by bacterial fermentation in the equine hindgut. However, only L-lactate is produced by the metabolic activities of mammals, so the concentration of D-lactate in venous blood can be used as an accurate indicator of bacterial lactic fermentation in the hindgut (Van Eps and Pollitt, 2006).

Low pH in the large intestine initiates a series of secondary events that often, but not always, culminates in laminitis. One of the most important consequences is the death and lysis of large numbers of bacteria and the release of the toxic components of their cell walls and genetic material (endotoxins, exotoxins and microbial DNA). Toxins absorbed from the gut into the bloodstream during developmental laminitis and toxaemia following alimentary carbohydrate overload creates a very severe illness for the horse. Interestingly, experimental administration of endotoxin itself has never been able to cause laminitis. In addition, endotoxaemia can be effectively controlled by a range of drugs (e.g. polymyxin B, flunixin meglumine [Finadyne]), but laminitis develops regardless of their use.

As early as 24 hours after carbohydrate overload, the epithelial cells lining the caecum undergo degenerative changes and the bowel becomes leaky. By 48-72 hours there is widespread desquamation and sloughing of caecal epithelial cells sufficient to allow passage of lactic acid, toxins and laminitis trigger factors into the circulation. The consequences can be catastrophic. Horses can die from cardiovascular shock after the accidental consumption of excess grain. High heart rates, rapid breathing, fever, sweating, colic, diarrhoea and depression are the signs of horses battling grain overload. Just when the horse turns the corner and responds to treatment and the severity of the clinical signs decreases, the signs of foot pain appear; laminitis has arrived on the scene.

In horses, problems start when too much sugar, starch or fructan is consumed in a system not designed or prepared to cope with it. If there is too much starch, it overwhelms the ability of enzymes in the small intestine to process it, and overflows into the hind-gut. Fructan can only be fermented in the hindgut. Both cause havoc with microbial population dynamics. It's widely recognised that when a horse breaks into the feed room and consumes excess grain, laminitis may result. Many people assume that if their horse is on pasture, its diet is steady and constant. But if the starch or fructan content of pasture grasses and weeds increases quickly due to a sudden environmental change, hindgut fermentation may induce a cascade of events similar to grain overload with laminitis as a consequence.

Some horse breeds will founder on the pastures designed for Thoroughbred studs

14. A pony is not a racehorse

While you can feed a Thoroughbred broodmare like a cow, and for the most part get away with it, recreational horses, especially those with pony genes somewhere in their ancestry, may have problems. Most research on equine nutritional needs has been conducted on performance horses especially racing horses. Thoroughbred and Standardbred horses have been genetically selected in relative dietary affluence. This is a far different genetic pressure than native pony breeds were subjected to. Smaller breeds originated in harsh environments with poor feed.

Recommendations by nutritionists regarding the 'best' forages for horses at pasture are usually based on the needs of Thoroughbred broodmares, weanlings, yearlings and race horses in training. The goal of Thoroughbred studs is cost effective production of large, saleable yearlings. Taller, heavily muscled horses sell well at the yearling sales and are thus more valuable. Satisfactory rates of weight gain in Thoroughbreds are feasible on pasture grass in Australia. Young thoroughbreds gained an average of 0.34 kg per horse per day in set stocked paddocks of introduced grass species; a moderate rate of growth (McMeniman, 2000). The pasture grasses most often recommended for horse pasture in Australia are perennial ryegrass, phalaris, cocksfoot, tall fescue and kikuyu with the legumes white or strawberry clover (Stubbs, 1998a). In several books, the order in which grasses were recommended was well correlated with their potential to make sugar and fructans (Avery, 1996, Kohnke et al.,1999). Growth rate of foals and sale dollars per acre are often seen as the best way to determine pasture quality (Avery et al., 2000).

Recommendations for horse pasture grass species are based on palatability and rate of intake which are necessary to maintain acceptable rates of weight gain in Thoroughbred horses. Many studies on nutrition of pasture grass infer that palatability is an important goal (Archer, 1973; Archer, 1978). Palatability studies are relatively easy and inexpensive to conduct, so they are common in equine science. This may make horse owners erroneously associate high palatability with good nutrition. Horse feed companies often encourage this misconception. While palatability may be important to maximise intake for dairy cattle and fast growing young horses destined for performance careers, it is far less important to recreational horses getting very little exercise and tending to obesity. Many horse owners do not want or need high rates of weight gain for their horses. There are many cases of obesity in horses grazing on grass alone. It may be necessary to limit grass intake. What kind of grass should be planted if our goals do NOT include rapid weight gain, number of live foals per acre, or financial returns from yearling sales. We are faced with the conundrum that laminitic or high risk for laminitis horses and ponies can no longer eat the grass that previously appeared to support them. Pastures are required that overweight, high risk and/or laminitic horses and ponies can graze all day, nibbling grass of low nutritional content.

Some breeds will founder on the pastures designed for Thoroughbred studs and intensive cattle and sheep production. In a study comparing dry matter digestibility of timothy, ponies had a higher intake rate per bodyweight than horses (20.7 and 16.1 g/kg bw, respectively) and a higher rate of dry matter digestibility, 0.447 and 0.423, respectively (Uden 1981). Recreational horse owners must learn that they cannot feed their sedentary animals like performance horses. They do not do the same amount of work, and even if they did, ponies would not need as much because of their more efficient digestion and metabolism. Recreational horse owners need to realize that when nutritionists talk of the increased nutritional demands of exercising horses they are not referring to animals that walk or jog for less than 3 hours per week. Even a Thoroughbred has lower requirements for energy when growth has stopped, maturity has set in or when injury prevents exercise. Just like older humans, geriatric horses are more prone to develop metabolic conditions that require dietary attention regarding the NSC levels in their diets. Even between animals of the same breed and age there may be individual differences in feed requirements or tolerance. Of course it is easier to feed each animal the same, but to prevent overfeeding and the resultant diseases, we must start evaluating each animal separately according to its individual needs. Some people may say 'but I don't have a place to separate individuals for special diets'. Building a set of pens that separate horses enables the feeding of individual rations (*Figure 14-1*).

Not every horse should be fed the same amount of concentrate, nor should every horse be fed the same pasture grass. There are huge differences between grain and chaff, just as there are huge differences between grass types affected in turn by changes in their environmental conditions.

Figure 14-1 Building a set of pens allows horses to stay separated long enough to eat their individual rations.

15. Haven't we always fed grass and grain to horses?

Grain or grasses used for fattening cattle are not a natural part of a horse's diet in the wild. The first animals to be domesticated were goats and sheep, around 7- 9,000 BC in the Middle East. This is also when wheat and barley were first cultivated. Cattle and pig domestication came later; around 5-6000 BC. At first, farmers and herders probably had separate operations in the same general area, but by 5000 BC, evidence of groups with both domesticated animals and cultivated plants are found. The first farmers did not keep horses, preferring cattle as beasts of burden.

Horses were first domesticated around 3000 BC by pastoral, nomadic herdsman on the high, arid steppes of central Asia (Isaac, 1970). They appeared never to have stayed in one place long enough to have had an impact on selection of grasses for grazing tolerance. Their lifestyle revolved around what was best for their animals. Their animals supplied food, fibre and transportation and horse numbers and quality were status symbols. Nomadic herdsman did not confine animals nor feed them grain. They moved on when grass was eaten down. The descendents of these horses survive today in Mongolia, where they are still tended in a natural state by nomadic Mongolian herdsman, eating the diet they evolved on (*Figure 15-1*). These are a rare example of domesticated horses living and eating the in a way that parallels their evolution.

Evidence of keeping horses in confinement came much later, around 2000 BC. Horses were kept by the nobility as status symbols and for war. The early horses pulled chariots and were not ridden (Clutton-Brock, 1992). No longer did their keepers wander seeking the best forage grasses for their stock. Horses now went where battles were being fought and were fed what their warrior masters could carry most easily. They were confined in camps and held ready for combat. Grain is very palatable to horses and a dense source of calories. Thus began the history of confinement and grain feeding of horses. Not only did grain feeding put 'fire in the belly', it was also most convenient during war. Grain feeding is a double edged sword however. The right amount works wonders, but too much can lead to the disaster of laminitis.

Very early in the history of establishing guidelines for the management of domesticated war horses, it was realized that it was necessary to acclimatize animals to new locations and husbandry regimens. A Hittite king, in a letter to the king of Babylonia asks for a new shipment

Figure 15-1 Mongolian horses thrive on the central Asian steppes.
They live outdoors all year (30°C summers to minus 40°C winters), without supplementary feeding, searching for food on their own (Photo: Alan Renner).

of horses, as the previous shipment had gone lame. "*In Hatti-land the cold is severe and an old horse does not last long. So send me, my brother, young stallions!*" (Drower 1969). With what we know today, perhaps it was less the winter cold, but more the seasonal accumulations of NSC in the cooler months that was making the horses lame.

The earliest unequivocal writings on laminitis come from Apsyrtus, the 'father of veterinary medicine,' who lived in the early 4th century. Apsyrtus refers to acute laminitis as 'barley disease' and treated it by dietary restriction, exercise and bleeding. The Roman historian Vegetius Renatus writing in *Digesta Artis Mulomedicinae* (a guide to veterinary medicine) (AD 480) refers often to problems from the over-feeding of barley. He likened laminitis to gout and, if the horse was not responding to purgation and bleeding, recommended castration "for gout seldom affects eunuchs" (Smith, 1976).

The 2000 years that horses have been confined and fed by mankind is but a blink of an eye compared to the time involved in the evolution of the modern horse *Equus caballus*. While it is difficult for us to adopt nomadic, pastoral lifestyles for the sake of our horse's health, it is possible to incorporate husbandry practices that produce better health outcomes for our horses.

Feed the work, work the feed

Feed free choice forage to every horse not maintaining condition during hard work. If you are training hard for intense competition, feed as little grain as possible to maintain condition and feed in several small meals instead of 2 large meals (*Table 15-1 Wrong and right reasons to feed grain to your horse or pony.*). Make use of other high calorie sources such as oil and fat. Maximise calorie sources found in more slowly fermentable fibres, such as pectin and hemicellulose, which are found in soy hulls, beet pulp and lucerne. Grain fed equine athletes, confined to stables, are prone to stomach ulcers (Al Jassim et al., 2008). Free choice pasture forage also minimises stable vices such as stall weaving, cribbing and coprophagia (manure eating) and sand eating, and should be a constituent in all horse diets. Horses in hard work can eat just about any kind of forage.

Table 15-1 Wrong and right reasons to feed grain to your horse or pony.

Wrong reasons to feed grain	Right reasons to feed grain:
Because he likes it	Horse cannot maintain healthy condition on free choice grass or hay
Because he was a very good boy today	Horse cannot maintain healthy condition in spite of feeding dietary oil
Because everyone else does	Your veterinarian has addressed all other reasons for unexplained weight loss (dental problems, parasitism, gastro-intestinal disease)
Because he won't love me anymore if I stop	Required for high level of competitive activity
Because Grandpa fed grain to his horses	
Because the grain salesman said it was good for him	

Recreational horse owners may consider that diets formulated for performance horses are somehow superior, or more science based. Race horse trainers are focused on getting their horse to run fast next weekend. Long term health may not be considered. Winning next weekend is what trainers get paid for and what racehorse owners expect. The average career length of an Australian Thoroughbred was 461 days for females and 1,013 days for males. The cited reasons for wastage in 2-3 year olds in training was respiratory illness and lameness (Bailey, 1998). Most race horses that do succeed in winning races rarely have careers that span more than 4 years. Many horse owners cherish their animals regardless of how fast they run, or how high they jump. They expect them to be sound, comfortable and healthy well into old age. Recreational horse owners have totally different goals, and recreational horses should have totally different diets.

16. Common myths busted

Lush grass is not higher in sugar concentration

In nearly every description of grass that causes laminitis, you will see the word 'lush' being used. What does 'lush' mean? Here's a dictionary definition.

Lush Source: *WordNet (r) 1.7*

adj 1: produced or growing in extreme abundance; "their riotous blooming"

2: characterized by extravagance and profusion; "a lavish buffet"

3: full of juice; "lush fruits"; "succulent roast beef";

"succulent plants with thick fleshy leaves"

n : a person who drinks alcohol to excess, habitually

When various people are asked what 'lush' means, they say things like 'green, full of water, thick, tender, and fast growing'. They suppose that lush grass is sugar rich and likely to cause laminitis. They may also assume that brown, dry, sparse, tough, slow growing grass is lower in sugar. **THIS IS TOTALLY INCORRECT!** Dry, brown, stressed grass can have a dangerously high sugar concentration.

Colour has nothing to do with NSC content

The green colour in plants is from the protein chlorophyll. Colour has no relationship to sugar content in forage. Dead brown grass can be high in sugar and can cause laminitis in high risk animals (*Figure 16-1*).

Figure 16-1 Dry, frosted grass, yellow in appearance, can have a dangerously high sugar and fructan concentration. *The grass illustrated is Phalaris photographed in a horse paddock near Canberra.*

Aged hay is not lower in sugar

It is commonly thought that the sugar content of hay will decrease during storage. Less than 15% moisture at baling is recommended for horse quality hay in Australia. Hay in this moisture range will not lose appreciable amounts of sugar during storage. Of course some horses will have problems when switching from one batch of hay to another, but the 'freshness' of the hay is not the issue, it's the large variability of NSC from one batch to the next.

Stemmy, high fibre hay is not always low in sugar

By now you are learning that stem tissue is higher in NSC concentration than leaf tissue. Coarse stemmy hay can be very high in NSC, or sometimes not. Soft leafy hay is frequently low in NSC unless cut when stressed by drought or sudden cold weather. Equine nutrition textbooks make an incorrect assumption that fibre content is always inversely related to NSC content. It is considered a golden rule that as forage matures, fibre content goes up, and nutrient concentration goes down. However, we cannot look at one factor in isolation. Forage maturity is only one factor of many that affect NSC of forage.

In Colorado, USA, oats were planted side by side, one planting in early spring that was subjected to freezing temperatures at early stages of growth and the other planted in early summer and subjected to freezing temperatures in late maturity. Samples were taken at eight different stages of growth and field dried to make oaten hay. The study was repeated over two years and the samples accurately analysed for NSC. The oats that matured when nights were freezing in late autumn had very high levels of sugar and fructan, even when fully mature and fibre content was at its highest. Levels of NSC of mature forage in autumn were similar to those found at boot stage in spring which is considered the stage when nutritional content peaks. Similar results were obtained with stem material reaching a WSC content of 250 g/kg^{-1} DM in autumn (Contreras-Govea and Albrecht 2006). These studies show that environmental effects contribute more to high NSC concentrations than stage of growth. Thus high fibre hay can still be high in NSC.

To determine if this effect occurred in other species, another study was conducted in Colorado under optimum conditions for accumulation of NSC (*Table 16-2*). Thirteen different varieties of grass were tested for WSC, starch and Neutral Detergent Fibre. These were cut a full month after optimum stage for hay production. Samples were frozen within 15 minutes at

Table 16-1 The NSC content of dry, yellow grass killed by winter cold and drought can still be dangerously high for laminitis high-risk horses.
Sugars remain in dead grass until rain or melting snow leach them out.

Grass species	NSC (% dm)
Cocksfoot	20.7
Perennial ryegrass	39.7
Tall fescue (1)	31.7
Tall fescue (2)	29.6

-20°C, and shipped to Dairy One, Ithaca, NY, overnight on dry ice.

The results show the negative correlation (r) between NSC and NDF is only 0.66. In plain language, this means that while fibre content is a large factor in the NSC content of forage, it is far from the whole story. The growing conditions during this study were not particularly conducive to accumulation of NSC, as the weather was warm and the plots were properly fertilised and irrigated for maximum growth. In light of previous studies, it is conceivable that under cold conditions this correlation might be even weaker.

Since nutritionists frequently rely on proximate analysis, it is easy to see how it might be mistakenly assumed that NSC and fibre are inversely related. Using proximate analysis, components are subtracted to estimate remaining fractions. Hence when one fraction is high, the others are lower. However this does not work with plant cells. Sugar, starch and fructan are found inside plants cells, whereas fibre is found in the outside of cells. This is the basis of the definitions of NSC and Structural Carbohydrates. NSC and fibre are not mutually exclusive because they do not occupy the same space. A useful analogy is to consider a plant cell like a warehouse full of bins. The bins can be empty or the bins can be full, but it has no impact on the mass of the walls. Plant scientists acknowledge the variable relationship between NSC and fibre. They prefer to present NSC data as g NSC per kg of structural DM, rather than as a percent of total dry matter as favoured by nutritionists.

Fast growing grass is not higher in NSC

Grass that is growing fast is *lower* in NSC concentration because sugars are being used up for raw materials and energy. This myth probably came about because so many horses are kept in paddocks that are continuously grazed so short that they eat it as fast as it grows. Then when it rains, or fertiliser is added, or another limiting factor is removed, the grass grows enough that the horse finally has an opportunity to overeat. The fact that the grass is growing faster is not germane. The important aspect is that intake is no longer limited by growth rate. As hard as we try in agriculture, we cannot totally control pasture growth rate because the weather is beyond our control.

What we *can* do is control intake, by controlling access, using grazing muzzles, strip grazing or using a bare dirt paddock. Then we can focus on growing healthy grass that is lower in NSC per mouthful, and have a sustainable, horse friendly pasture. Healthy grass will also prevent erosion and encroachment of weeds, the basis of an environmentally responsible land stewardship program.

Table 16-2 The relationship between and NSC and fibre content of forage.
Mean of 4 replicates (values followed by the same letter do not differ significantly).

Variety	NSC (%DM)	NDF (%DM)
Roadcrest crested wheatgrass	20.2 a	61.7 cd
Garrison meadow foxtail	19.9 a	57.3 e
Climax timothy	17.2 ab	59.6 de
Potomac orchardgrass	15.4 bc	61.9 cd
Cache meadow brome	13.8 bcd	66.5 abc
Sherman big bluegrass	13.4 bcd	67.5 a
Regar meadow brome	13.0 cd	64.7 abc
Ginger Kentucky bluegrass	12.8 cd	63.8 abc
Fawn tall fescue	12.8 cd	62.3 cd
Wideleaf orchardgrass	12.4 cd	61.9 cd
Manchar smooth brome	12.0 cd	63.3 bcd
Redtop	10.7 d	64.5 abc
LSD (p = 0.05)	3.55	3.37

17. Limiting access to reduce intake

Some horses and ponies can consume pasture with surprising speed. In one study, it was estimated that ponies consumed 40% of their daily dry matter intake during 3 hours of pasture turnout (Geor and Harris, 2009). Animals with access to round the clock grazing, when pasture growth is optimum, can easily consume excess to their requirements and become obese. Reduction of intake is thus an important component of any strategy designed to minimise the risk of pasture associated laminitis.

Grazing muzzles

A grazing muzzle may be a good option for horses that can tolerate some grazing (*Figure 17-1*). They must be fitted with care to prevent rubbing. Make sure it has a breakaway feature to prevent injury if it gets caught on something. It may need to be used all the time, or in some cases just to limit intake during periods when stressful conditions have caused NSC to increase. Owners sometimes feel that their horse cannot adapt or cope with wearing a grazing muzzle. However, most horses will eventually accept the limitation and do just fine. If the horse seems frustrated at first, and unwilling to graze, sometimes poking some grass through the hole in the muzzle will spark their interest. Some clever animals are so successful at grazing in a muzzle that you may still need to limit access to the grass. A hand made plastic insert with a smaller hole may be an option for clever ponies, or those that chew the hole larger in rubber muzzles.

Strip or cell grazing

This concept requires the use of portable electric fencing using highly visible, white tape and step-in posts (*Figure 17-2*). Solar charging or battery operated units can be used for paddocks away from mains electricity. Move the fence daily to enclose the daily allotment of grass. Once the grass is shortened by grazing, more sunlight will hit each blade and the sugar content may increase significantly the next day. Do not allow overgrazing as this may stress the pasture and increase the NSC concentration in surviving stems (*Figure 17-3*). Continuous grazing depletes nutrient reserves, weakening grass plants until eventually they die, especially those without successful grazing resistance mechanisms. Continuous grazing encourages the growth of weeds and causes unwanted soil compaction.

Figure 17-1 Grazing muzzles limit grass and thus NSC intake by horses at pasture.
Holes in the rubber base-plate (inset) allow access to some pasture (photos: Darrin Hatchman). Grazing muzzle (VET2295X) from Saddlery Trading Company, 124 Tennyson Memorial Avenue, Tennyson Qld, Australia 4105. www.saddlerytrading.com

Figure 17-2 Pasture intake can be managed by strip grazing paddocks using portable electric fences.
It is important to move the fence on both sides of the strip to prevent overgrazing

Figure 17-3 Rotational grazing using portable electric fencing.
This paddock has not been allowed to recover sufficiently and is being grazed too heavily. The pasture is stressed, nutrient depleted and with sunlight striking so much of the shortened grass the NSC concentration in surviving stems may be higher than in the adjoining, longer pasture. Dividing the paddock into more sections to allow a longer recovery period would be more sustainable over long term.

Limiting grazing time

Obese or laminitic animals may need to be moved to a bare, dirt yard. Moving from grass to a bare sacrifice area is the safest way to assure that grass intake is limited. Many people have to be away all day, and worry about muzzles coming off or temporary fencing not being substantial enough to contain clever animals. It may be hard to convince a fat pony that coming into a dirt yard from grass is in his best interest. You will be required to be more clever than the pony. Horses are creatures of habit, and you must enforce a new habit. You may have to persevere over a period of several weeks, giving the animal a handful of lucerne chaff or some other low sugar treat when you catch him. Then lead them to the sacrifice area and reward them again. They will learn to come in when you want. If you train several times a day with bell or a whistle that accompanies presentation of the treat in the sacrifice area, this may provide a stimulus to elicit the desired response. This is also a good time to scratch their favourite places or groom if they enjoy it. Make coming into the sacrifice area a rewarding occasion. You may even be surprised to find them waiting in the sacrifice area for their treat after their allotted grazing time is over.

Essentials of a sacrifice area

Whether called a dry lot, round yard, corral, or dirt paddock, a sacrifice area is useful for the management of healthy horses and absolutely essential for those at high risk for laminitis. The reasons are many:

- For quarantining new horses coming on the property
- Introductory socialization with protective fencing to minimise injury
- To keep horses safe during or after pasture management practices such as weed spraying, fertilisation, slashing/mowing, or harrowing manure
- To limit exercise for horses recovering from laminitis or injury
- To protect pasture from damage when it is too wet or muddy
- To prevent overgrazing and death of grass when drought has reduced the amount of available forage
- To keep horses available for work, shoeing, foot trimming or veterinary attention
- To limit grass intake to manage weight loss in horses with a tendency towards obesity
- To limit or eliminate grass intake in high risk horses during periods when environmental conditions produce dangerously high NSC in grass

Fencing of the sacrifice area

This area will need the best fencing on your property. Confined horses are inventive, destructive to fencing, and prone to injure themselves testing the limits of the fencing (*Figure 17-4*). If there is grass around the perimeter, either prevent the animal from getting to it with an electric wire, or use solid steel mesh fence to ground level. Other options include killing the grass with herbicide or smothering it with black plastic. Animals at high risk can ingest enough grass under the fence, grazing on their knees, to trigger another laminitis attack.

Figure 17-4 Horses in dry yards are inventive and grazing on their knees may consume enough grass under the fence to trigger laminitis.

Footing

The area should be flat, to minimise potential erosion. The footing should be supportive, comfortable, well drained and not too dusty. Sand is suitable if fairly coarse. Stone dust, or small rounded river pebbles can make comfortable, supportive footing (*Figure 17-5*). If the subsoil has clay and swallows the top footing when wet, this can be prevented by putting a layer of Geotextile fabric underneath the top layer. This is used to keep road base from sinking in clay soils.

Shade/shelter

The sacrifice area must have shade at least from the midday and afternoon sun. This can be from a neighbouring building, shed, trees, or free access to a stall. Old or sick horses may require shelter from cold, stormy, wet weather. Horses separated from the herd will be understandably upset. They may do better if other horses are visible close by. If a horse has laminitis, efforts should be made to minimise stress. Consider having a favourite companion share time in the sacrifice area. Horses with acute laminitis should be encouraged to lie down by offering them comfortable bedding in an area where they feel safe and secure.

Managing pasture to minimise NSC concentration

If you have horses at grass, whether you realize it or not, you are a grass farmer. How much do you know about growing grass? You would expect your hay producer to be educated about how to grow better quality hay for your horse. As a horse owner you should take the time to get educated on how to grow better quality grass. If your horse is only out there for a few hours or you only have a small area perhaps it's not so important. However, if you are expecting your animals to derive a major portion of their diet from your pasture, it is appropriate that you spend some time and effort learning how to grow the best grass for the needs of your horse(s).

As discussed above stressed grass may be dangerously high in NSC (Watts 2004). To minimise NSC accumulation, we have to nurture the grass to keep it healthy and growing at a steady rate. Remember, the concentration of each mouthful of grass is less in NSC when it is properly nurtured, even though the total NSC per acre may be higher. You may have to limit access for animals at high risk for laminitis by one of the methods given previously. With good grass husbandry, you will have healthier grass, more grass, fewer weeds, less soil erosion, better water infiltration and retention in the soil. You can have your cake and eat it too; lower sugar grass and a healthier, sustainable pasture ecosystem that is better suited for the needs of your horse(s).

In agriculture we cannot control the weather, or the type of soil, but there are some things we can control. Drought is not a good time to fertilise or spray weeds, for reasons we will discuss later. Everyone will want to fertilise and spray weeds when drought breaks, so it might be a good idea to have the correct products on hand and application equipment readied to make best use of time during optimum conditions.

Figure 17-5 A well constructed sacrifice area is useful for the management of healthy horses and absolutely essential for those at high risk for laminitis. *Small rounded river pebbles make comfortable, supportive footing.*

To boost production of milk and meat, elaborate and detailed pasture management plans, that maximise NSC in specific species of grass in specific environments, have been developed (Fulkerson and Donaghy 2001; Jones and Lazenby1988). Pasture management experts, using computerized mathematical models, know how to get the most milk from dairy cows in a paddock of perennial ryegrass and clover. Unfortunately, this model is optimised for maximum returns from production animals. As discussed above, "***a horse is not a cow***", and "***a pony is not a racehorse***", so we need different plans for horses with health problems. No research has been done on sustainable grazing systems that minimise NSC. It will be complicated and difficult to devise plans to graze grass when NSC reserves are low because intensive grazing kills such grass. A sustainable pasture management plan for grazing grass while minimizing NSC intake is within the grasp of agricultural science, but at this time, this is not a research priority. A successful management strategy would need to be worked out in every bioregion, on every specific type of pasture. Care must be taken to keep pasture management advice into the context of your soil, weather, grass species and the available resources. All we can do at this time is to use our understanding of the factors affecting NSC accumulation and strive to minimise NSC content. With a healthy, vigorous stand of grass you will not only have more grass, lowering feed costs appreciably, but your pastures will be more self sustaining.

Many things affect the health and growth of plants. The one that is most important at one instant in time is called the 'limiting factor' which overrides all other factors. If drought is the limiting factor, putting fertiliser on will not increase growth. If the soil is packed hard, the best fertiliser program may not work until you get the soil properly aerated. Limiting factors in agricultural systems are constantly moving targets. Correcting one limit to growth allows a different limit to come into play. After rain, the limiting factor changes from drought to weeds, or temperature, or any number of things. Farmers are constantly chasing the most limiting factor and frequently it takes expert advice to decide which aspect of pasture management is the most cost-effective to treat at any particular time. Horse people tend to not consider expert advice in pasture management, citing inability or unwillingness to pay the fees that professional pasture management consultants charge. In fact, however, professional agronomists charge about the same as an electrician or your next riding lesson, and probably less per hour than your farrier.

While it is impossible to dictate which limiting factor needs addressing first in your pasture situation, the following discussion should be useful.

Paddock placement

If possible, choose a paddock that has some shade during part of the day. The longer the grass is shaded, the lower its ability to make NSC. Utilise hedges, trees, or buildings (*Figure 17-6*). Grazing in the forest is an excellent option to minimise sugar consumption and increase exercise, but take care to avoid overgrazing that can cause erosion on steep slopes.

Figure 17-6 The pasture in paddocks shaded from direct sunlight produce less NSC.

Avoid paddocks with newer plantings of improved varieties of grass and clover developed for fattening animals. A better choice would be a stand of native grass, or seedings from older varieties developed before grass breeders became so accomplished at increasing sugar content.

Restrict grazing when nights are cold

When night time temperatures dip below 5°C, the chances of NSC being very high the next day are just too great to gamble on allowing a horse with a history of laminitis to graze. Temperature overrides other factors, so even if you have everything else right, it's just too risky to graze when it's cold at night. Wait until you have several warm nights and good growing conditions before you allow access to this grass. This advice supersedes all in following sections. No place in Australia gets cold enough long enough to force grass into dormancy so it all turns brown down the crown. Under near freezing conditions, both sugar and fructan will increase in green tissue. Data gathered in NSW show sugar and fructan in ryegrass was highest in the winter month of July, regardless of stage of growth (Fulkerson, 1998, Fulkerson and Donaghy, 2001). Studies conducted in Colorado and Wisconsin, USA. on oat hay both showed that cold nights caused NSC to increase in oat forage regardless of the stage of growth (Chatterton et al., 2006; Contreras-Govea and Albrecht, 2006).

Rotational grazing

This is addressed early because not only is rotation of pastures one of the most important aspects of all good pasture management programs, it also needs to be in place to facilitate other management practices that minimise NSC accumulation. Basically, we graze grass when it's in a stage of growth low in NSC, however we can't do it for too long or the most desirable species will die. Grass needs R & R (Rest and Regrow). So we graze, move on, and then nurture the previously grazed paddock to prepare it for the next grazing period. When herds of migratory animals graze in nature, they cut swaths through the best areas of grass and move on, allowing that grass to regenerate. Rotational grazing is based on this natural system and is essential to a sustainable grass ecosystem. Continuous grazing of confined animals kills grass by a number of mechanisms, encourages weeds, causes internal parasites to build up and creates 'horse-sick' pastures. However much land you have to graze it must be split at least into two, or preferably 6 different paddocks. If you have more horses than grass, which is generally the case, this will help you grow a lot more grass and will lower your feed bills. Some horse people have a romantic vision of horses galloping free across the prairie as Nature intended and hate to chop up their large fields into smaller paddocks. Unless you have hundreds of hectares of bush, forest, and open plains, you cannot come close to simulating a natural horse ecosystem that will take care of itself.

If you have more grass than horses (which is fairly rare), rotational grazing will help you control the concentration of NSC in the improved varieties of grass. If you have the good fortune of having native grass pastures, rotational grazing is an essential tool for preventing the overgrazing that will kill it. In the next section, we'll talk about the perfect time to mow or slash to remove developing seed heads. Slashing stimulates the production of new tillers and leafy regrowth. Paddocks are best kept in a vegetative stage of growth. Remember that leaves are lower in NSC than stems and heads. We do not want to give laminitis prone horses the opportunity to selectively graze developing seed heads that accumulate sugar and fructan, or mature seed heads that are high in starch.

Portable electric fencing and a solar fence charger are handy for cross fencing if separate paddocks with permanent fencing are not available. You will be grazing small sections, or cells (*Figure 17-2*). Be prepared to move the horses to another cell frequently, perhaps every two weeks during peak growing conditions. You will need to be mowing, or topping the cells at a schedule dictated by your grass, and the number of horses it supports. Every horse property with grazing land should have its own mower or slasher. It's an essential tool for pasture management. You may think this is a lot of bother, but once you get the system set up, it will be easier to keep everything maintained properly because only a small section needs attention at any given time. The real bonus is how much more feed you will have for your horses and the control you will have over its quality.

For C3, cool season grasses such as ryegrass, cocksfoot and phalaris, start grazing new regrowth when it has at least 2 leaves and when night time temperatures are above 5 C. Grazing before this stage will diminish reserves and weaken the grass. Avoid offering your horse the stubble after slashing, as this may be high in NSC. Move the horses off the paddock when you can feel the second node starting to move up from the base of the plant, indicating elongation of the stem prior to heading. Slash just below the topmost node to remove the developing seed head. The horses should be moved to a cell that has leafy regrowth.

Depending on how good conditions are for growth, the proper stage for grazing may be 2-4 weeks from the time it was mown or slashed. Nitrogen levels and temperature are the most critical factors for growth rate. You may find you need a 4 week rotation under limiting conditions, and only 2 weeks under optimum conditions. Phalaris and prairie grass *(Bromus wildenowii Kunth)* require an opportunity to be left alone and go to seed and replenish reserves at the end of the growing season or they will die out and weeds or clover will take over.

Graze the paddock until the horses have eaten it down no lower than 4-5 cm then move on to the next paddock in the rotation. Mow any latrine areas or tall, rank areas that have been left behind. Harrow manure, apply fertiliser or herbicide as needed, and rest and regrow.

C4 grasses like Rhodes, couch, paspalum may have to be grazed late summer in a 14 day rotation to keep them from heading. Kikuyu does not head, but the stolons may be high in starch, so care should be taken to graze leafy growth. Graze a section, slash the remainder and come back after you get new leafy regrowth. In warm weather, with good moisture, regrowth can occur within a week. In cool or dry weather it may take 3 weeks.

Timely slashing and grazing

Constant mowing is counterproductive and unnecessary. It may seem that limiting intake by constantly mowing, or overgrazing a paddock is a useful strategy, but this practice may actually increase NSC concentration in the short term by exposing stem bases high in NSC to grazing. Short grass is also more exposed to sunlight, which produces sugar. While mowing is a good way to control tall annual weeds, it gives a competitive advantage to certain plants whose leaves lay flat on the ground out of reach of the mower blades. Some of these prostrate plants, like clover, dandelion and plantain (storksbill) can be very high in NSC (Watts 2005). Other high NSC weeds like thistle may be stimulated into putting out new shoots by mowing. Like constant grazing, repetitive mowing may help select for those species of grass that are high in NSC because they are more competitive and tolerant of constant removal of top growth. Constant mowing is just like constant grazing; in the long term it may select for plants that are high in NSC.

Mowing and intensive grazing have the same effect on grass. If there are animals on the farm that have a high nutritional requirement, like broodmares, growing young stock, performance horses in need of more condition, cattle or sheep, a session of intensive grazing can accomplish the same goals as mowing and is far less wasteful of valuable resources. In any of the following discussions regarding optimum time for mowing, a session of intensive grazing can substitute. Tidy up as needed with a slasher after animals have moved on.

It is possible to keep C3 grass in a leafy, vegetative stage all growing season with 2 or 3 timely passes with a mower or slasher. The trick is to pay attention to the height of the developing seed heads inside the stems as they rise above the ground, and cut them off before they waste valuable resources by forming seed that your horses doesn't need. By removing the heads before seeds form, the grass will put that energy back into growing more tillers thus making the grass thicker, with a higher leaf to stem ratio.

To review our understanding of grass morphology: Growth points in grass are called meristems. The terminal (apical) meristem forms a bud, or embryonic grass head. There are also meristems at root tips, and new tiller initiation points. Meristematic tissue is actively differentiating and growing and has high demands for sugar, just like a mammalian embryo. Meristematic tissues exert hormonal control and receive priority allocation of sugars.

The apical meristem in grass forms in the crown. If you have a good magnifying glass you can see a primordial seed head with buds for all the parts starting to develop before the stem even starts to elongate (*Figure 3-2*). The meristem is arranged with the bud on top, and all the future nodes and internodes stacked inside one another like a collapsed telescope. When conditions are right, the meristem starts to develop into a seed head, and the bottommost section of stem raises up from the crown, pushing the meristem up. This is the start of the stem elongation phase of growth. You can feel the node inside the grass stem. Some farmers may refer to the node as a 'joint' and may call this the 'joint phase'. After the first section elongates fully from the bottom, the next section starts to grow. Now you can feel 2 nodes or joints in the stem, one visible and the other palpable underneath the leaf arising from the first node. Then the third node elongates, and so on, just like an elongating telescope. The meristem will always be found just on top of the topmost node. You can cut this section down the middle with a sharp knife and see with a magnifying glass the little seed head perfectly formed (*Figure 2-2*).

The reason why it's so important to understand how to find the orientation of the apical meristem inside the stem is because this is what you need to remove when you slash. By removing the developing seed head, you remove the source of hormonal control for allocation and concentration of NSC. Removal of this source of hormones also triggers growth in the tiller meristems that have been laying quiescent waiting their turn for resource allocation. In one timely mowing, you both remove a concentrated source of NSC held up in a handy position for your horse to selectively graze and trigger growth of new leafy tissue to use up NSC and spread them around in more biomass.

If you wait to slash after the grass has headed, you will still remove seeds but the plants will have already put valuable resources into making them and fewer tillers will result.

To determine the height to set your mower, take a ruler out to the pasture and find the topmost node inside the stems and set the mower so it will cut most of them off, while allowing as many lower leaves to remain as possible. If you have a tractor mower that sets fairly high you might get away with one timely mowing. If using a garden tractor with a maximum blade height of around 10 cm, you may need to mow again 10 days later at the same height to get all the growth points cut off. Don't be concerned if you miss a few heads. If you get 90 % of them off, you've done a good job. A few late-growing, secondary tillers going to seed over the summer will make little difference.

After mowing or topping, it's time to fertilise to allow this section of paddock to regrow new tillers and leaves. If you need herbicide to control weeds this is also the best time in the rotation, if conditions permit.

Fertilise for optimum growth

It may be a surprise, but standard advice for pasture fertility to produce optimum but not excessive growth will generally be the same whether your goal is high NSC per acre or low NSC concentration per mouthful. As we learned previously, these conditions frequently occur simultaneously. Tell your agricultural consultant that you are looking for a conservative rate of nitrogen and optimum phosphorus and potassium. The effect of micronutrients on NSC content is unknown. To maximise overall equine nutrition and health, this is also the time to have a soil test done to determine if trace elements need to be applied.

The first step will be to obtain a representative soil sample. As soil is quite variable, multiple samples are obtained with a special soil sampling tool, and mixed well to get an average. Soil types, and therefore soil fertility can vary throughout a pasture, and sometimes it is necessary to get separate samples if the variation is great. Soil at the top of a hill will vary from soil at the bottom of the hill where erosion has deposited topsoil and increased moisture has produced more organic matter. Clay areas should be sampled separately from sandy areas, as these soils may vary greatly in water soluble nutrients that are prone to leaching (like nitrogen and potassium).

The analysis varies from one soil lab to another. As with most things, you get what you pay for. Make sure you get at least pH, organic matter, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, sodium and soil texture. If you have expert advice to help you interpret results, additional useful information can be derived from Cation Exchange Capacity, Electrical Conductivity (measures salt content), free lime, and lime requirement.

Available fertilisers may vary locally, so this discussion will be very general. Fertiliser dealers sometimes have knowledgeable people who can help you choose the most appropriate materials, and may offer soil sampling and application services. Look in the phone book or the Internet for Agricultural Services.

There is much interest in organic sources of fertiliser. No research exists that proves that one source of nutrient is more beneficial to grass or your horse, than another. A nitrogen molecule is the same when found in ammonium fertiliser purchased at a farm supply store or when found in fish emulsion or manure. Of course fish emulsion has other nutrients in it that commercial nitrogen fertiliser may not contain, however if nitrogen is the limiting factor, the additional nutrients in fish emulsion can not be substituted, regardless of their value. Organic sources of fertiliser are broken down and made available to the plant by micro-organisms in the soil. Top dressings of organic fertilisers may not be as readily available, especially under dry, hot conditions or cold conditions that are not optimum for the growth of the micro-organisms that recycle organic matter. Excess amounts of organic fertilisers may create problems with water contamination if more is applied than can be utilised by grass growth. Do not fall into the belief that they are totally safe to the environment and do not require attention to nutrient composition and application rate. Best to smell fish emulsion and fertilisers based on poultry manure before purchase, and consider how your neighbours may react. It is recommended to wait 3 weeks after applying poultry manure to prevent possible problems with salmonella or botulism, so it should be applied at the start of the rest period for the grass in your rotational scheme.

Correct soil pH

While no work has been done on the affect of soil acidity on NSC content of pasture, correcting soil pH is probably the most cost effective way to maximise plant health. If uncorrected, acidity will cause a lot of problems. Application of proper amounts of lime, as indicated by soil testing, should be the cornerstone of any program to maximise health and vigour of any crop, grass included.

Nitrogen

Nitrogen is the cost effective nutrient that can be applied to improve pastures. Nitrogen deficiency is the most frequent cause of clover takeover, because clover can make its own nitrogen. Proper amounts of nitrogen applied early in the growing season will remove this competitive advantage and allow grass to grow tall enough to shade clover out.

Grass has the luxury of indulging in vegetative reproduction in times of plenty. Fertiliser or water shortages may cause grass to give up tillering altogether, and cause earlier formation of seed. If grass has plenty of nitrogen BEFORE the stem elongation phase it will induce more profuse tillering. It's too late after stems form; nitrogen will then encourage elongated stems. That's why the best time to fertilise pastures with nitrogen is early spring, just before or as the grass becomes active and starts to grow. In areas without a cold winter season this time will be after a drought breaking rain, or just before the warm season when grass growth increases.

Nitrogen deficiency causes NSC to accumulate in improved species of grass. Native grass generally has less need for nitrogen but certain Australian native grasses do respond to nitrogen fertilisation with increased growth and vigour. Remember, our objective is to maximise growth and use up sugars as they are produced. The amount of nitrogen applied must be balanced with the amount of available water. If water is limiting, there is no use to adding nitrogen. Under drought conditions nitrate accumulation will occur if nitrogen is in excess of the needs for growth. The salty nature of some nitrogen fertilisers can make drought stress on the plants even worse. In general, drought conditions are a bad time to apply fertiliser.

The texture of the soil and the anticipated rainfall after application are important factors for determining the maximum amount of nitrogen that can be applied at one time. Nitrogen is not held by soil particles and is very water soluble. It will go where excess water goes. Sandy soils may leach excess nitrogen into ground water. Clay soils with a slow rate of water intake may cause excess nitrogen to run off and contaminate surface water. Excess nitrogen may cause nitrate toxicity if heavy doses of nitrogen fertiliser are applied before drought or frost. For all these reasons, it is safer to apply nitrogen in 2 or 3 smaller applications through the growing season rather than in one large application. Applying at the start of the rainy season is a good time, and then in the middle of the growing season, just after a rest period in the grazing rotation. Do not apply nitrogen too late in the season on grass that will become dormant. Excessive growth at this time will deplete carbohydrate reserves that may be needed to survive the following season of cold or drought. Excessive nitrogen late in the season may delay senescence in areas with frost, keeping grass alive longer in temperatures most conducive to NSC accumulation. In regions where grass grows all year round, small amounts of nitrogen may need to applied throughout the year in balance with the amount of growth expected.

For large operations, commercial application is often most efficient. Measure your pasture gates to make sure equipment can enter. For smaller operations, consider getting a dry or liquid fertiliser applicator made to mount behind a 4 wheel drive vehicle or utility. Dry fertiliser is usually broadcast by a spinning device that is either ground driven or powered by a motor. Liquid can be sprayed from a boom fitted with nozzles. For really small paddocks, similar units are made to be carried or pushed by hand. Call your local fertiliser dealer for the most cost efficient, effective products in your area.

Other valuable soil nutrients

Many soils in Australia are deficient in phosphorus, potassium, calcium, sulphur, magnesium, silica, copper, zinc and cobalt. Fertilise with phosphorus to maintain levels within a medium to high range as dictated by soil analysis. Phosphorus is very important for vigorous root systems. Excess phosphorus can tie up other essential nutrients, so it should not be applied haphazardly or without carefully calibrated application equipment. Potassium is important in giving a plant drought tolerance. Sulphur is important for the production of certain proteins.

Irrigate as needed for optimum growth

Many of us don't have the luxury of watering as needed. If you have irrigation available it will greatly improve your ability to grow lower NSC grass during times of drought. It's also far easier to grow thick, healthy grass that chokes out weeds and you can grow a lot more grass in limited space. For some reason, it is assumed that irrigated grass is higher in NSC perhaps because of the incorrect interpretation of the 'lush' word. Increased water content in grass does not cause laminitis.

Spray weeds

While your agronomist is collecting your soil sample, also have him identify weeds and recommend a product that will clean them up, especially the ones that can be high in NSC or are toxic. Do not mow perennial weeds if you intend to use herbicide. Some products work better if there is a large surface area of leaf tissue to absorb the chemical. If you have to mow close to help control annual weeds, you may need to give the pasture a slightly longer rest period to replenish reserves. Always use herbicide at the very start of your R & R period, as some require that you hold animals off the grass for a certain period of time. This is called 'grazing interval' and should be listed on the product label, or provided by your agronomist. It is very difficult to kill weeds under drought conditions as they tend to not absorb enough chemical to kill them. Fast growing weeds are easier to kill. Some herbicides work better if fertiliser has been applied prior, or even in addition to the herbicide.

Managing under drought

It's impossible to manage drought. Drought manages us. Drought puts pastures under extreme duress. Experienced grazers know that to prevent complete, permanent elimination of grass and the resultant environmental disaster, destocking of pastures is the only option. Get the animals off. Hand feeding can decrease the amount of overgrazing but horse hooves in search of a green titbit do damage as well.

As horse owners are more reluctant to decrease animal populations when drought persists, the only viable option is to limit the amount of land that is decimated. Remove animals to the sacrifice area. A small sacrifice area and a large, resting pasture are better than producing a very large bare sacrifice area by over-grazing everything during drought.

After the rain

When you see the first green tinge of new grass, about 2-5 days after drought breaking rain, remove animals to the sacrifice area. Do not graze grass after a drought breaking rain until there are at least 2 leaves per tiller on the new growth. Levels of nitrates will be very high until growth has used it up to make protein (Fulkerson, 1998). Animals will forgo eating plentiful dead grass to seek out the first green shoots. They may also ingest a large amount of stubble and crown material, which are storage organs for NSC. This is a very dangerous time for horses with a history of laminitis.

Drought puts pastures under extreme stress and to prevent complete, permanent elimination of grass from overgrazing and soil erosion, paddocks should be destocked. The amount of land that is damaged can be minimised by hand-feeding in a sacrifice area.

18. Replanting paddocks

Everyone would like to have a recommendation for some kind of grass that their obese or laminitic horses can graze free choice, year round, all day. There are very few Australian studies that compare the NSC content of grass grown side by side under the same growing conditions. The data that is available is generally focused on optimising NSC in species known to have a high genetic potential to make NSC. There is very little information about the nutrient content of grasses considered 'of lower quality'. Forage research is directed by the cattle and sheep industry and its goal is different from owners of laminitic horses and ponies. There are studies underway to reselect grass for lower NSC content (Watts and Chatterton, unpublished data) but these grasses are most suitable for the intermountain west of the United States, so this data may not apply to Australia.

The kinds of grass that will suit our needs will probably be described by forage specialists using words such as 'unpalatable, low or poor quality, low nutritional content, or undesirable'. Without field research, the best we can do is look to some of the grasses that the cattle industry finds 'inferior', and avoid those that are considered 'superior'. The following categories are far from being a complete listing of the possibilities.

Highest potential to accumulate NSC under certain conditions

Annual or Italian ryegrass, perennial ryegrass, tall fescue, oat forage, barley forage, wheat forage, kikuyu, buffel, cocksfoot, clover, panic, paspalum and setaria. Annual or Italian ryegrass has the highest genetic potential for sugar and fructan concentration. Clover is a poor choice for laminitic horses due to high starch content. Clover may be removed from pastures with herbicides.

This mixture of perennial ryegrass, plantain and red clover planted for dairy cattle is deadly to horses prone to laminitis.

Medium potential

Yorkshire fog, prairie grass (*Bromus* sp), Teff , Mitchell grass.

A mixture of Yorkshire fog and Phalaris would be a better choice of grasses for laminitic horses than ryegrass-clover paddocks that are planted for cattle and sheep production.

Low potential to accumulate NSC

Many native grasses are lower in sugar and fructan. Their low NSC content makes them less persistent under intensive grazing therefore it is imperative to manage them very carefully. Some lower sugar grass native to Australia include *Bothriochloa* (red grass), *Microlaena stipoides* (weeping grass), *Heteropogon* sp. (Speargrass), Kangaroo grass, and Wallaby grass.

Silver tussock grass (*Poa cita*), native to New Zealand, is low in sugar.

Lucerne that grows quickly in warm weather tends to be low in sugar. Take care, as some laminitic horses seem sensitive to lucerne. If adding lucerne to the diet of a laminitic horse causes it to worsen, eliminate it from the diet.

Clover is a poor choice for laminitic horses due to its high starch content. This mixture of perennial ryegrass, plantain and clover, planted for dairy cattle, is deadly to horses prone to laminitis

19. NSC content of some common horse feeds

When access to pasture must be limited, you'll need to rely more on purchased feeds. Unfortunately, When access to pasture must be limited, you'll need to rely more on purchased feeds. Unfortunately, the amount of NSC is not currently available on feed labels, because regulatory policies have not kept pace with new technology in feed testing. Unless the feed company can be persuaded to get an analysis for NSC done, or you get one done yourself, you will have to look at ingredients and make an educated guess about the appropriateness of any commercial feed product.

Fine tuning a successful diet for each animal will require careful experimentation and observation due to individual sensitivities. A veterinarian or equine nutritionist can make suggestions, but the owner of the affected animal will have a better opportunity to decide which feeds each animal does best on because they are there to watch for subtle changes. Only change one feed or management practice at a time. If after a few days there is no worsening of symptoms, proceed with caution to increase the amount of new feed. Because there are many different types of testing procedures, we cannot compare amounts of NSC in feeds from one laboratory to another. All of the data given here (*Table 19-1*) is from Dairy One, a lab that does NSC analysis from all around the world, including for Australian feed companies and government research institutions.

Keep this data in proper perspective. Frequently, the average content of a nutrient in a particular kind of grass or feed is incorrectly assumed to be absolute. The more samples that are analysed for each type of feed, the more significance we can place on the average NSC content. We must question the validity of data with low 'n' numbers. The nutrient content of feeds, especially its NSC content, is very dependant on environmental factors. Please note the wide range of what is considered 'normal'. Normal range in this database is considered to be one standard deviation from the mean. It does not include outliers. There's a lot to be learned from this database; more than we can do justice here, however some highlights are:

Grass pasture

The data for NSC content of fresh grass is slightly higher than grass hay; 14.8 and 13.1, respectively. NSCs are very unstable in fresh forage, as the grass will continue to respire and use up NSC after it is cut. In a study conducted by Rocky Mountain Research, Inc., sample handling and shipping methods made large differences in NSC content of fresh, annual ryegrass forage (*Table 19-2*). Samples frozen immediately were in the freezer within 15 minutes of being cut. One set of samples were kept ambient in the back of a car for 3 hours before being frozen. Overnight shipments were received 19 hours after removal from the freezer (-20°C) and were still very cold. Priority mail shipments took 2.5 days to reach the analytical lab.

Because shipping overnight on dry ice is costly and inconvenient, it seems probable that the data generated by Dairy One on fresh forage is lower than what actually occurred under field conditions. Suffice to say that fresh forage is generally higher in NSC than hay.

Note the wide range for what is considered 'normal' for both fresh grass and hay; greater than a two fold difference. While this would not matter to most horses, it can matter a lot to a horse that has or is high risk for laminitis. When you find a batch of hay that a laminitic horse does well on, buy in quantity. Before you run out, test the suitability of the new batch in case it is not appropriate and you have to find something else. If unable to send to a laboratory that does analysis for NSC, you'll have to experiment on the horse. Proceed over the course of 2 weeks to replace the previous batch of hay with the new batch. Neck circumference is correlated with insulin resistance in horses (Frank et al., 2006). Observe the look and feel of the neck daily. Trot the horse out in hand or in a round pen, if he is currently sound. If at any time you see the neck or other areas of fat deposition getting larger or harder you know the new batch of hay has NSC too high for that horse and you should seek other hay or start to soak to reduce the WSC content. Any time a high risk animal gets reluctant to trot out, or moves stiffly or with a shorter stride, or refuses to pivot the front feet while turning in hand, you need to act quickly. Reduce NSC in the diet, and proceed with first aid measures

Grass hay

In light of the very different requirements for optimum health in recreational horses compared to performance horses, it is important that the grass or hay, constituting 95% of our horses diet, should be tailored to their needs. If the normal range of NSC content of hay, is from 8-18%, it is appropriate that horses doing less work should be fed hay from the lower end of this scale (*Figure 19-1*).

While no research has been conducted, on at risk horses or those with laminitis, they should benefit from hay lower in the range (about 13% NSC on a

Table 19-1 Range of NSC as a percentage of total dry matter (DM) in horse feeds (n = number of samples tested). *From Dairy One feed composition library, Ithaca, NY. http://www.dairyone.com/Forage/FeedComp/disclaimer.asp 2006. .*

	Mean NSC (% DM)	Normal range (% DM)	n
Roughage (Forage)			
Fresh grass forage	14.8	8.8 - 20.7	1919
Grass hay	13.1	8.2 - 18.0	12,274
Fresh lucerne or clover	14.5	10.9 -18.2	75
Lucerne hay (or chaff)	11.1	8.8 -13.4	30,231
Oat hay (or chaff)	22.1	15.0 - 29.1	2,139
Barley hay	19.4	12.8 - 26.1	63
Wheat hay (or chaff)	17.3	10.3 - 24.3	384
Millet hay	9.6	6.7-12.5	29
Straw	9.6	3.1-16.1	436
Supplementary Feeds			
Beet pulp	12.2	7.0 -17.5	164
Soybean hulls	5.4	2.2 - 8.5	58
Soybean meal	15.1	12.3 - 17.9	195
Wheat bran	29.9	21.7 - 38.0	54
Wheat pollard (middlings)	32.1	23.1- 41.1	61
Distiller grain	10.0	5.7- 14.3	672
Rice bran	24.8	15.8 - 33.9	53
Copra (coconut meal)	10.6	6.6 -14.7	22
Flax (linseed)	4.8	3.9 - 5.7	7
Molasses	60.7	48.5 - 72.9	41
Grains			
Oats	49.7	37.5 - 61.8	44
Barley	60.1	53.8 - 66.3	58
Corn	73.0	68.5 - 77.5	189
Sorghum (milo)	61.3	39.3 - 83.3	18

dry matter basis). Because individual horses vary, for both alimentary and metabolic reasons, the amount of NSC that can be tolerated differs from one individual to another. The amount of current exercise will also impact the amount of NSC tolerated. Regular exercise is strongly advocated to counter insulin resistance and laminitogenic effect of high blood insulin concentrations. As much as we would like to have a recipe for the perfect diet for every horse, it is just not possible.

Clover and lucerne

The data in *Table 19-1* is a combination of mostly lucerne with some clover as well. As you can see, these forages average slightly lower NSC (14.5 and 11.1% DM for fresh vs. cured, respectively) than fresh grass (14.8% DM). When pastures are overgrazed, horses may eat clover patches down to the dirt. They then may be eating relatively more of the portion of the plant in which starch or sugar, depending on environmental conditions, is more concentrated.

Feeding lucerne (alfalfa) to laminitic horses is controversial and until clinical studies to induce laminitis under field conditions have been conducted, opinions will differ. There are anecdotal reports implicating clover or alfalfa as laminitis triggers especially in the US. On the other hand laminitic animals are reported to do well on lucerne in Australia. There is always the chance that any one batch of a feed has more starch than those previously analysed. Lucerne and clover are sometimes referred to as ‘legumes’. They

Table 19-2 Effect of sample handling on NSC content of fresh grass.
Mean of 4 replicates, analysis by Dairy One, Ithaca, NY. Numbers followed by the same letter do not differ significantly at p = 0.05. Study funded by the Animal Health Foundation. Missouri, USA.

Treatment	Sugar	Starch	Total NSC	change
Freeze, ship overnight on dry ice	14.0 a	1.55ab	15.55 a	
3 hour to freeze, ship overnight on dry ice	11.1 b	1.7 a	12.9 b	-17%
Freeze, priority mail, no ice	9.3 bc	2.1 a	11.3 bc	-27%
Never frozen, priority mail	28.8 c	.8 b	9.6 c	-38%

both have symbiotic bacteria in their roots that fix nitrogen. As nitrogen is the limiting factor for protein production in plants, legumes are higher in protein than grass. Legumes have bioflavinoids that make them very tasty to animals. They are not necessarily sweet. Perhaps 'savoury' is a better description of the flavour. Because clover and lucerne are very flavourful, animals at pasture may seek them out and eat them exclusively if given the opportunity. Clover stolons are starch storage organs. After 4 weeks of simulated late Autumn weather, with near freezing night time temperatures, stolons of various varieties of clover contained 15-18% DM as starch and over 20% WSC (glucose, fructose and sucrose). After long term simulated 'winter' conditions, with subfreezing temperatures the amounts of starch and sugar decreased over time (Frankow-Linderg 2001). Thus the potential exists for clover in pastures to become high in starch or sugar under long term freezing or near freezing conditions accompanied by sunny days. If lucerne or clover hay is cut just before or after cold weather, it may be considerably higher in sugar than if cut during warm conditions. More sugar or starch will be present in leaves than stems. When choosing lucerne hay for a laminitic horse, seek out batches that have less leaf and more stems. Feed small amounts at first and if, after a few days, there is no development or worsening of symptoms, proceed with caution but keep amounts reasonable to ensure adequate but not excessive protein intake.

Figure 19-1 Obese, hyperinsulinaemic ponies are at high risk of developing laminitis especially if given unrestricted access to high NSC hay.

Grain hays

Table 19-1 shows that oat, barley and wheat hays are higher in NSC than the average grass hay. Since chaff is nothing but chopped up hay, we can assume that oat or wheat chaff is also NSC rich. These are all C3 plants that accumulate fructan. There is a common belief that the absence of grain kernels in grain hays makes them less of a problem for high risk horses and those prone to obesity. This is not so. Cereal grains have been selected for their ability to produce enough sugar to make large, starch filled seeds. Just before the seeds start to form, the sugar and fructan gathers in the stem, ready to be turned into starch as the heads fill. Producers of grain hay and chaff know that just prior to seed filling is when the nutritional content and palatability is highest, so they strive to cut just at this stage. High levels of WSC, mostly as fructan, will be found in the stem at this time (Schnyder, 1993). Whole barley plants peaked in WSC content (318 g/kg) at the milky, ripe stage just as kernels had filled. Oligosaccharide content was 76 g/kg, fructan content was 128g/kg, total sugars were 94 g/kg (McDonald et al., 1991). If the sugar and fructan that was poised in the stem are not processed into starch for seed formation, it remains in the stem. No wonder it tastes best at this stage.

High concentrations of unused sugars, fructans or nitrate may occur in grain hays subjected to drought, frost, lodging (falling over, with broken stems) or infestation by insects such that the development of the seeds is impaired. When grain crops fail due to these conditions, the stems are harvested for hay and chaff. Beware of these hays for horses with or at high risk for laminitis.

The ratio of sugar to fructan may differ under water stress. Well watered wheat stems had DM up to 35 % NSC mostly as fructan. Wheat stems subjected to slight water stress had overall less NSC. Under moisture stress sucrose was the main carbohydrate, fructan levels were lower, and the fructan chains were shorter (Yang et al 2004).

Straw

From the previous discussion, you should be starting to understand why straw can be too high in sugar and fructan for high risk horses. The Dairy One database shows straw NSC averages from 3.1-16.1 % of dry matter, well within the range of average grass hay. We've always heard that straw has very little nutritional value and it is true that when tested by routine analytical procedures, it tests low in protein and minerals. Until recently, commercial testing for NSC has not been available. Now we can see that while straw is low in other nutrients, it can still be high in sugar or fructan. If your laminitic horse or pony is eating his straw bed, take it away and get something non-edible such as sawdust, shavings, sand or chopped paper.

Other feeds

The extremely high level of NSC in any type of grain explains why a horse with laminitis should not receive ***any*** grain; not even a handful. If you need to coax a horse to eat supplements, a handful of lucerne chaff is more appropriate.

Some feed companies are attempting to correct the adverse affects of fermentation of grain in the caecum by making grain more digestible in the small intestine. While micronizing or steam flaking may make grain more digestible, it will also have a higher glycaemic index, making it even more dangerous for a horse with the laminitis associated with insulin resistance and hyperinsulinaemia. If corn, oats, or wheat products are listed as ingredients in a prepared feed, feed with great caution to horses with laminitis or prone to laminitis. Discontinue immediately if any development or worsening of symptoms occurs.

Wheat pollard is too high in starch to be fed to at risk horses. Small amounts may only be included in feeds if diluted with a large amount of very low NSC feed.

Beet pulp is usually appropriate for horses at risk, or with laminitis. The NSC ranges from 7-17%. Some batches may be too high for some horses. Sugar is extracted from beets using a very simple water extraction method. The amount of sugar collected determines when the extraction process is stopped. The amount of sugar in any particular batch of sugar beets will vary and the amount left in the pulp will vary as well. Sugar beet pulp is best fed after soaking with water. If the water used for soaking is sweet tasting, pour it off and rinse the beet pulp with additional clean water to wash away any excess sugar.

Copra, or coconut meal, is palatable to some horses and suitable as a carrier for supplements. Ground flax, small amounts of soy meal, distiller's grain, or rice bran are also suitable. Soy and lupin hulls are the outer seed coat and contain high levels of pectin, a good calorie source but slow to ferment, having a low glycaemic response and therefore a valuable addition to feeds formulated for horses prone to or with laminitis.

20. Other considerations for management of horses with or at high risk for laminitis

While the focus of this booklet is on pasture and dietary management to minimise risk of laminitis, we would be remiss if we need not briefly mention the other management aspects. Remember laminitis is triggered when pasture conditions exacerbate pre-existing insulin resistance or hyperinsulinaemia. Thus grazing pasture with high NSC content (e.g., during spring and autumn or when pastures are stressed by drought or frost), consumption of other feeds rich in starch and sugars and overfeeding that induces or worsens obesity promote insulin resistance, raise blood insulin and may trigger laminitis.

Daily observation

The best way to avoid full blown laminitis is to catch it early and nip it in the bud. If you have an animal with chronic laminitis that is currently sound, make sure you encourage it to trot or canter every day. Signs of laminitis may be subtle. The walk may be perfectly normal, but they may be reluctant to trot, looking stiff legged or short striding. Look for abnormal behaviour or movement for that animal. Mild laminitis may be mistaken for arthritis, or laziness. They just don't move out like they normally do. They will not want to put torque on their front feet. They may resist pivoting on the front feet, and rather carefully step around sideways. If this happens, it's time for the dry lot and first aid measures.

For those horses with endocrine dysfunction, diligent observation of areas prone to abnormal fat deposits can indicate that grazing time needs to be decreased or curtailed. The size and hardness of the crest of the neck will increase with increasing metabolic dysfunction. Neck circumference has been correlated with insulin resistance (Frank, 2006). A diary of weight tape or neck circumference recordings may give you an earlier indication of when the diet needs to be changed.

Lean body weight

It is irresponsible to allow a horse that has had laminitis to become or remain in an obese body condition. Allowing any horse to become obese will dramatically increase its risk for laminitis. In some disciplines, it may be fashionable for horses to be over conditioned, and show ring judges should reconsider this dangerous trend and instead reward horses that have well defined muscles derived from proper exercise. Do not allow conformation flaws to hide behind excess fat.

Crash diets are contradicted in horses already ill, especially in ponies that may be prone to hyperlipidemia. Reducing the amount of NSC by soaking hay or changing to hay with lower NSC content is better than reducing intake too drastically. An empty belly and gut is prone to colic and gastric ulcers. Horses and ponies should always have at least 1.5% of their bodyweight per day of dry matter intake in a combination of low NSC hay, chaff or beet pulp.

Exercise

As in the human version of insulin resistance (Type II diabetes), exercise is absolutely vital for the horse prone to laminitis. Eating less and exercising more is the key to weight loss. Start with two to three exercise sessions of lunging or riding per week, lasting 20 to 30 minutes. Gradually increase the intensity and duration of exercise per session to four to five times per week (Geor and Harris 2009). After only 2 weeks of daily exercise for 10 minutes, hyperinsulinaemic ponies had significantly improved insulin sensitivity. The effect on improved metabolism lasted 6 weeks after the exercise program was stopped (Freestone et al 1992). Set realistic goals and monitor progress regularly. Body weight can be measured using stock scales or by using a weight tape. Also measure neck circumference and score body condition monthly. Be prepared to increase dietary restriction and exercise if improvement is not occurring. Aim for a loss of 25-30 kg over a 4-6 week period (*Figure 20-1*). Exercise will improve the insulin status of most horses even if weight and adiposity loss is not dramatic. When blood insulin concentration returns to normal maintain the hard won life style change with a programme of ideal diet and regular exercise.

Of course no horse with laminitis should be forced to walk, but after an acute attack, when all signs of tenderness at the walk are gone with no pain medication for at least two days, the horse should be allowed to move about in a small dirt paddock with good footing.

Clinical evaluation

Veterinary consultation is needed to take a blood sample to assess the insulin status of your horse or pony. The simplest measure is the "resting" (basal) insulin and glucose concentrations. Often insulin resistance can be diagnosed on the basis of hyperinsulinaemia (higher than normal blood insulin) and normoglycaemia (normal blood sugar). In the insulin resistant situation normal blood sugar is maintained by secreting greater amounts of insulin from the pancreas (compensated insulin resistance). A serum insulin concentration greater than 30 mU/L is diagnostic for insulin resistance and the increased risk of laminitis (Geor and Harris 2009). Furthermore, a positive correlation between hyperinsulinaemia (insulin resistance) and laminitis severity was found in a USA field study (Walsh et al., 2009). It is important to use a recognised laboratory for insulin measurements preferably one with in-house equine reference ranges. Geor and Harris (2009) recommend the following sampling protocol: all feed should be withheld for a minimum of 8 hours overnight, blood is taken between 7:00 and 10:00 AM the following morning and animals are removed from pasture and housed on dirt or in a stable.

A more accurate insulin resistance test is the combined glucose-insulin test developed by Eiler et al., (2005). An intravenous catheter is inserted in the jugular vein and a baseline sample is taken. A glucose solution (50% dextrose) at the dose rate 150 mg/kg, followed by insulin (regular insulin, 0.10 units; Humulin R; Eli Lilly, Indianapolis, Indiana) is injected through the catheter. Blood samples are then collected at 1, 5, 15, 35, 45, 60, 75, 90, 105, 120, and 150 minutes and analysed for glucose concentrations using either a handheld glucometer or subsequently in a laboratory. The animal is insulin resistant when plasma glucose does not return to the baseline value within 35 minutes.

Figure 20-1 The same pony as in Figure 10-1 after 6 months of regular exercise and the dietary restrictions outlined above. *The cresty neck and other abnormal fat deposits have diminished and the pony has clinically recovered from laminitis. Photo: Don Walsh.*

21. Medication for insulin resistance

Medical therapy with a thyroid supplement (levothyroxine) or metformin may benefit animals that fail to respond to conservative dietary and exercise regimens. In healthy horses, a 6-month period of levothyroxine treatment resulted in weight loss and increased insulin sensitivity. A recommended dosage for weight loss in mature horses was 48 mg/d orally for 3 to 6 months (Frank et al 2008). Metformin, a drug commonly prescribed for treatment of human insulin resistance, dosed at 15 mg/kg twice daily, decreased insulin resistance and insulin pancreatic secretion in hyperinsulinaemic horses and ponies (Durham et al., 2008). The effect of this metformin regimen had waned when assessed at later time points (23–220 days) and further trials to define the potential of metformin in the treatment of insulin resistance and prevention of laminitis are a priority.

22. Conclusion

After reading this booklet you will appreciate the potential of pasture to trigger laminitis. The sudden appearance of laminitis in an individual horse or pony is now less of a mystery. The unfortunate conjunction of season, pasture and pony may have combined to trigger the problem. Perhaps armed with new knowledge you and your pony will never experience laminitis again. We certainly hope so. A better understanding of the links between pasture consumption and laminitis will lead to a more unified approach and rational preventive and treatment strategies, by owner, veterinarian and farrier alike.

At the Australian Equine Laminitis Research Unit (AELRU) in The School of Veterinary Science of The University of Queensland, the search for the fundamental causes of laminitis continues. Using advanced biochemical and molecular biological techniques we continue to thoroughly investigate the link between bacterial overgrowth in the horse's bowel (particularly that induced by the key pasture carbohydrate fructan) and events occurring at the basement membrane of the hoof lamellae. We are conducting in-depth studies of the link between hyperinsulinaemia (and thus insulin resistance) and laminitis (RIRDC current project "Investigation of the mechanism of insulin-induced laminitis in horses" to help develop better diagnostic, preventive and treatment strategies.

The real hope for horses as they confront their crippling adversary, laminitis, is a means to effectively prevent it. Once the devastating pathological cascade of laminitis is underway, the anatomical dislocations are so overwhelming that there is little hope a foundered foot can be restored to normal. When the reason behind the failure of a normally robust, trouble-free suspensory apparatus between hoof and bone are understood, the way to develop effective preventive strategies will be clear. Prevention of this terrible disease represents a better option than trying to repair the gross anatomical dislocations once they have occurred.

A better understanding of the links between pasture consumption and laminitis will lead to a more unified approach and rational preventive and treatment strategies, by owner, veterinarian and farrier

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Equine Laminitis

Managing pasture to reduce the risk

by Kathryn A. Watts and Christopher C. Pollitt

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Laminitis is a leading cause of death in horses and makes a significant financial and emotional impact on the horse industry

This report explains how environmental conditions can trigger three-fold increases in the sugar, starch and fructan (collectively called non-structural carbohydrates or NSC) content in pasture plants and hay. Horses and ponies consuming pasture excessively rich in NSC can develop laminitis.

Strategies are provided to prevent laminitis, based on principles of plant science: growing grass that is under less stress to reduce NSC concentration, limiting access to pasture for high risk animals by use of a sacrificial area and preservation and re-introduction of native grass pastures that are inherently lower in NSC.

This report is targeted at the owners of horses and ponies so that they can make informed decisions about pasture management and to more safely feed animals prone to laminitis or obesity.

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