# Management and breeding strategies for improved forage quality

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## Introduction

Hay producers in Australia have traditionally been paid for the quantity, not the quality, of the hay they produce. By contrast, export markets are increasingly demanding a more uniform supply of a high-quality product from Australian suppliers. Interestingly, the definition of 'quality' for export and domestic hay destined for the high-input dairy industry is the same as it is for domestic broadacre feed supplement or drought feed. The requirements for fodder used in each of these instances is, however, very different. Issues of quality relating to feed preference, palatability, and digestibility will be discussed and related to management strategies to optimise hay quality and some of the physiological traits in cereals likely to affect hay quality.

## Components of forage quality

Performance of animals is a good indicator of the quality of the forage they are being fed. In most field situations, the animal's performance depends on forage throughput and digestibility. As digestibility goes down, animals struggle to maintain liveweight due to an inability to eat enough and pass enough forage through their gastrointestinal tract to extract the nutrients they need. At the other production extreme, high-input dairy cows are fed a mixed ration comprising only 25% conserved forage, but poor hay quality still reduces intake and performance. In this situation, however, quality has less to do with digestibility and more to do with preference and palatability.

### *Digestibility*

Digestibility of a forage largely depends on the chemical composition of the cell walls, or fibre, component of the forage. One measure of this is the neutral detergent fibre (NDF) fraction. If this is high, it tends to reduce digestibility. More importantly, as lignin (an indigestible component of cell walls) increases, it binds with other cell-wall carbohydrates to reduce digestibility further. The poorest of cereal straws or standing pasture in summer may be so low in digestibility that intake and throughput in the animals will be so slow that they can lose liveweight. As digestibility increases, lignin decreases; NDF tends to decrease; and other non-structural forage components, such as water-soluble carbohydrates (WSC) and protein, rise. This results in a more favourable balance between readily degraded and resistant carbohydrates and greater energy for the animals. Higher protein concentration of the forage allows for more complete utilisation of this energy and faster growth or higher output of the animals.

### *Palatability*

Current chemical analyses, such as NDF, digestible dry matter (DDM), and crude protein, can estimate the nutritive value of the feed; but they cannot predict feed intake. The chemical components that affect taste and texture of the forage are important in determining palatability. These components can have negative and positive affects on feed intake.

Henry *et al.* (1996) developed a measurement of forage 'shear energy'. This measurement reflects the time it takes an animal to break down feed into small particle sizes that can be easily digested. The higher a forage's shear energy measurement, or toughness, the less an animal will eat when offered the feed in a voluntary situation.

Metabolic byproducts of microbial growth can 'taint' a hay and result in 'off' flavours to the animals, which reduce palatability and thus intake. These taints can be produced by bacteria, fungi, and moulds due to rain on a windrow prior to baling or baling of forage of high moisture content. Positive effects on palatability are likely to arise from increasing WSC. Threshold levels of sucrose for taste detection are commonly in the order of 1.5 g/kg forage, and fructose and glucose are detected at lower concentrations. With WSC concentrations of hay commonly in the range of 50 to 250 g/kg, sweetness is likely to play a role in an animal's desire to eat a forage.

### *Preference*

Whether an animal wants to eat a forage and how much it wants to eat are also influenced by preference. What the animal can sense in terms of sight and smell are important, especially in a high-input production system. As an example of this, there has been a push in recent years to provide objective measurements for grading oaten hay destined for the Japanese dairy industry. In the Japanese production system, lactating cows are typically fed a mixed ration, with the addition of hay contributing around 25% of the daily allowance. A major issue for customer relations and marketing for the hay exporter is reduced intake of the ration by cows due to poor 'quality' of the hay component. Rejected loads are predominantly associated with low WSC concentration. Scientific studies (e.g., Fisher *et al.*, 1999; Ciavarella *et al.*, 2001) and industry observations have shown that animals select strongly in favour of herbage or hay with higher WSC concentrations. The authors are unaware of any work investigating the effect of colour on animal sensory perception.

## In-season and post-harvest factors affecting quality

### *High nitrogen status*

Our research has found that, as growers apply increasing amounts of nitrogen (N) to cereal crops to increase crop N uptake and growth, stem-sugar concentrations decline (Figure 1). This can reduce the DDM of hay made from forage of high-N status due to associated increases in NDF. Work in the United States, at CSIRO Plant Industry, and at Department of Primary Industries in Victoria has also shown that animals select strongly in favour of herbage or hay with higher stem-sugar concentrations. A reduction in stem sugars is correlated with a reduction in nutritive value, feed preference, and intake and, as a consequence, can reduce animal production.

The challenge is for hay producers in Australia to optimise the production system, primarily N supply to crops, so as to boost crop growth but not adversely affect WSC concentration and thereby feed preference, palatability, and nutritive value.

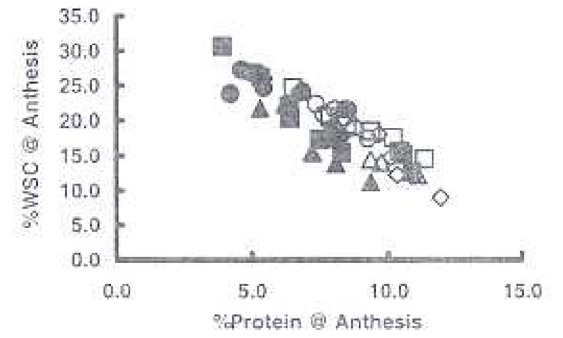


**Figure 1. Trade-off between WSC concentration and protein concentration in the above-ground biomass of wheat (*cv.* Janz) at anthesis[1] for (□) Ginninderra 1991, (■) Ginninderra 1992, (○) Barellan 1991, (●) Barellan 1992, (Δ) Pucawan 1991, (▲) Wagga Wagga 1991, (◇) Harden-Murrumburrah 1996, and (◆) Ariah Park 1996.**

### *Water status*

Severe drought will reduce biomass growth; but of the biomass produced, NDF will tend to be high and WSC low. Surprisingly, DDM can be reasonable.

In irrigated sugar cane, crops are managed to experience mild drought in the weeks prior to cutting in an effort to maximise sugar concentrations of the crop. This is because, under mild drought stress, new growth of a crop slows down but photosynthesis can be maintained, thereby leading to excess supply of sucrose. This is because the growth processes are more sensitive to drought than is photosynthesis. In this situation, there is a decrease in cell-wall growth and secondary thickening but an increase in WSC, resulting in decreased NDF due to a dilution effect of higher WSC.

In the absence of drought stress after flowering, growth of non-grain tissue due to cell-wall thickening and lignification (e.g., Pearce *et al.*, 1988) and continued stem elongation after anthesis (e.g., Borrell *et al.*, 1989, 1993) are common in many grass species. This continued growth and lignification reduces DDM due to the lignification. In contrast to the above example, NDF increases in conjunction with WSC. Thus, we sometimes have the paradox of producing lower-quality hay under optimum growing conditions than if there had been some mild drought.

### *Frost at flowering*

The effect of frost is difficult to quantify, as timing of the frost and environmental conditions prior to the frost result in varying damage to the grain. Generally, however, frosts just prior to and up to 5 or so days after mid-flowering result in death or abortion of some or all of the ovules or developing kernels. This type of frost results in an all-or-nothing response. That is, frosted grain dies, and there is a reduction in the number of grains that develop. As a consequence of the reduced grain numbers, WSC usually accumulates to higher concentrations than in non-frosted crops.

Frosts that occur during early grain filling usually result in shrivelled or collapsed grains of a dark greenish-brown colour or in deformed grains where damage has occurred to only part of the kernel. The later these frosts occur, the less of an effect they will have on WSC primarily and quality in general.

## Management strategies to optimise growth of crops and quality of hay

### *Budget crop inputs*

Getting the nutrition of crops right is important in making the most of the season. Fertiliser inputs of phosphorus (P) and N should be budgeted on crop demand for average farm or paddock biomass yields plus some allowances for soil tie up. Small to moderate amounts of N applied at, or close to, sowing have the least negative effect on WSC concentration.

Budgeting N and P fertiliser for a biomass yield of 10 t/ha is throwing money away if there are other constraints to production that can't be altered and that limit a farm average to 4 t/ha. Conversely, there is no point in fertilising for an average biomass yield of 4 t/ha if all it takes to lift your yield average to 6 t/ha is rectifying a trace element deficiency or rotating crops. A rule of thumb for optimising yield and quality is to apply moderate amounts of N fertiliser at or close to sowing. Deep soil-N testing at the start of the season, together with a spreadsheet budget, can be used to help make more informed decisions on crop fertiliser requirements.

[1] The period or act of expansion in flowers.

### Crop rotation

Rotating crops is the best way of reducing the risk of soil-borne pathogens that limit the vigour and biomass yield of crops (Table 1). Root diseases reduce biomass through a wounding response due to death of roots and by limiting a crop's ability to fully extract water from the soil. Trial work conducted by CSIRO in collaboration with the various state departments over the past 12 years has shown a growth advantage and an increase in N uptake of wheat crops grown after brassica break crops compared to wheat after wheat. Ensuring that stubbles are free of grass weeds over summer will also reduce disease risk and conserve soil water for forage crops or pasture.

**Table 1: Effect of crop rotation on WSC accumulation of wheat crops at Junee, New South Wales, 1996.**

| Previous crop | WSC accumulation (t/ha) | |
|---|---|---|
| | Uncovered | Covered |
| | (Foliar disease) | (Less foliar disease) |
| Wheat (root disease) | 2.20 | 2.98 |
| Canola (less root disease | 3.02 | 3.98 |

### Root diseases

In its simplest explanation, root diseases exacerbate the effect of drought because the diseased roots reduce the extraction of water from the soil and therefore amplify any drought periods. At a more complex level, the root disease also results in diversion of assimilate to the sites of infection in a response to wounding by the disease. The consumption of assimilates to try to fight off the fungal infection further reduces the supply of assimilate for growth and WSC accumulation (Table 1). Rotate crops and sow resistant or tolerant cultivars.

### Foliar diseases

Foliar diseases limit the supply of assimilate from the leaves to the growing points by reducing the photosynthetic area of the crop. In some foliar diseases, this limitation appears to be proportional to the reduction in leaf area caused by the disease plus a wounding response, resulting in higher lignin deposition and hence lower DDM. With other foliar diseases, the reduction in assimilate supply from the leaves is greater than the reduction in leaf area, due to production of the enzyme invertase in the leaves in response to infection. Invertase traps the assimilate in the leaf in the form of simple sugars, which prevents it from being transported elsewhere in the crop. This second type of foliar disease can have a devastating effect on growth and biomass yield. In an experiment at Junee, New South Wales, in 1996, rainshelters stopped raindrop splash from leaf to leaf, which reduced the spread of foliar disease and resulted in greater accumulation of WSC. Hay of low DDM due to high lignin and low WSC results, with the added negative effect of fungal staining and taint. Rotate crops and sow resistant or tolerant cultivars. Fungicides are becoming an option to minimise disease effects for crops of higher biomass yield.

### Timeliness of sowing

Sowing as early as the break of season allows, while taking into account cultivar selection, frost risk, and weather-damage risk, is one of the simplest and most effective ways to optimise crop growth and quality for particular environments. As a rule of thumb, earlier sowing of erect-leaved cereals will result in higher WSC but may also result in higher NDF and lower DDM as discussed earlier.

### Post-harvest effects on forage quality

We have been working on strategies to help growers assess the quality of their standing hay crops or pastures so they can make decisions about hay cutting and post-cutting management. As a rule of thumb, we suggest that growers focus on high-quality crops at cutting and baling. The use of such technologies as superconditioners has been instrumental in reducing the curing time and how long a windrow is in the paddock and subject to possible weather damage.

## Use of breeding to increase yield through more efficient use of resources

### Disease resistance

Ensuring that the varieties you grow have adequate resistance or tolerance to root pathogens and foliar disease is important insurance against losses in yield and quality caused by such problems. As discussed above, the major reason for losses in yield from root pathogens, such as take-all and crown rot, comes about through damage to the roots, which limits the crop's ability to extract water from the soil. Foliar disease limits the supply of assimilate from the leaves to the growing points by reducing the photosynthetic area of the crop. Current breeding programs are doing an excellent job of introducing resistance or tolerance to pathogens and are working towards incorporating multiple resistances into new varieties.

### Canopy architecture

Several years of experiments comparing unrelated breeding lines varying in canopy architecture indicate that cereals with erect leaves accumulate higher concentrations of WSC than floppy-leaved types. The advantage of erect types at moderate to high levels of soil N (soil N plus fertiliser N) is due to better light penetration into the canopy. Floppy-leaved types intercept most of the light at the top of the canopy while at the same time inefficiently maintaining lower leaves of high-N concentration.

### Reduced tillering and higher WSC

Reduced tillering is a trait currently being evaluated by the grains industry as a way of increasing crop reserves of WSC as insurance against drought. It may also have application in the hay industry as a way of reducing the investment into structural carbohydrates and increasing the concentration of readily digested WSC. In the past four seasons, we have evaluated reduced tillering wheats in a range of environments in South Australia, Victoria, and New South Wales. Despite the reduction in tillering, the early vigour of these wheats is similar to freely tillering wheats due to larger early leaves. In several experiments where we have taken detailed measurements, the best of the reduced-tillering crops had similar N uptake but had accumulated on average 20% greater stem sugars to flowering than the current cultivars. We have not yet evaluated these breeding lines for NDF or DDM.

### WSC accumulation and the effect of phenology

We have assessed variation in the accumulation of WSC in 80 spring wheats from Australia and overseas. There was significant variation for accumulation of WSC to anthesis. WSC varied between 15% and 25% of the above-ground biomass (Figure 2). Assessing WSC is time-consuming and labour intensive so breeding populations have been made with the aim of developing molecular markers to streamline the breeding for high WSC accumulation. We currently use near-infrared spectroscopy to speed up our analyses for WSC and other components but also hope to test in-field tools, such as the use of a refractometer, to score WSC.

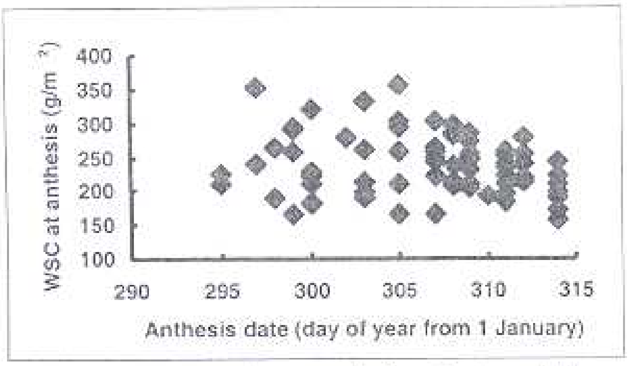


**Figure 2. Variation in accumulation of water-soluble carbohydrate to anthesis with date of anthesis for a collection of 80 wheats from Australia and overseas grown at Ginninderra, ACT, in 1998.**

The association between accumulation of WSC and anthesis date (-1.6 g/m$^2$/day) was not significant. That is, late-maturing cultivars do not appear to accumulate higher WSC concentrations that early-maturing cultivars.

### Conclusion

The definition of 'quality' for high-input production is the same as it is for broadacre feed supplement or drought feed. The requirements for fodder used in each of these instances is, however, very different. Environmental factors will ensure that we have suitable supplies for each of the end uses. Breeders are endeavouring to incorporate disease resistance and tolerance while targeting traits to improve forage quality in their breeding lines. WSC is emerging as one of the most important determinants of quality. Issues of quality relating to feed preference, palatability, and digestibility are all dependent on WSC concentrations to some extent. Growers can employ management strategies to optimise yield and quality, especially WSC, of their forage crops. Budgeting N supply is likely to result in the greatest improvement in quality of forage crops.

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