Farmer focussed research: the export oat hay experience

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Abstract
The export oat hay industry has grown from 100,000 t in 1989 to over 700,000 t in 2005. Initially productivity and visual quality characters were important criteria to ensure a consistent supply of hay for the Japanese dairy industry. It became apparent to the industry that other factors were affecting palatability, preference and performance. The continuing expansion of the export hay industry was dependent on determining important quality parameters for the market and the effect of variety choice, environment and management practises on these traits. The development of Near Infrared Spectrometry (NIR) calibrations for hay quality enabled rapid and efficient predictions of the traits. Research was conducted to determine how to implement and conduct cereal hay research so that the effect of time of sowing and cutting, yield, soil nitrogen, variety, and cutting height could be determined. *In vitro* digestibility (IVD), acid and neutral detergent fibre (ADF and NDF) and water soluble carbohydrates (WSC) were measurements of hay quality that could be rapidly determined using NIR techniques. The research included assessing the relative importance of these measurable traits and what management practices, cultivar choice and environmental conditions could influence their levels. All quality traits were influenced by the physiology and growth stage of the plant, changing soil moisture status, air temperature, and nitrogen status. In order to gain an understanding of the genetic variation and heritablility for IVD, ADF, NDF, WSC, and crude protein (CP), a study was conducted. There were significant year/location differences and genotypic differences in the group of varieties selected. The stability of performance for NDF, ADF, WSC, and IVD varied among the varieties. As the market grew and supply needed to increase, a concerted effort was initiated to understand the contributions of genetics, environment and management to produce satisfactory yield of a high quality product to build a new industry. Producing high quality hay ahas allowed the development of a strong export industry aligned to the needs of Asian dairy and beef production.

Key Words
experimental protocols, oat breeding, agronomy, anthesis

Introduction

The supply of oat hay to the Japanese Dairy industry had small beginnings. The challenge for the newly emerging export hay industry was initially to have a consistent supply of hay to meet the demands of the growing Japanese dairy market for oats hay. Productivity and visual quality of oats hay were the primary traits of importance for the industry at the outset. It soon became apparent from the Japanese dairy industry that differences in hay quality related to both variety selection and management practises used to produce the oat hay. At this time little was known about what plant characters affected hay quality and how management practises affected these quality characters.

It was identified that information was required to determine what the important quality parameters were for the market and how existing varieties could be influenced by management and the production environment. Industry needed to expand production and produce quality superior to its competitors to gain market share. In order to achieve these goals management practises and variety improvement for hay production were identified as key elements to meet industry objectives. Agronomists, plant breeders, and the export hay processors established linkages to address these new challenges.

Research was conducted to determine the influence of preference, palatability and performance of oat hay fed *ad lib* to dairy cattle whose main nutrient needs were being met by high energy, protein, and mineral rations. The results of research conducted by various organisations and individuals indicated that objective measurement of hay could be used to predict the quality of that hay.

Additionally, hay rejected by the market because of poor animal performance was analysed to determine the impact of genotype, production environment, and spoilage after hay cutting.

These results were used to identify breeding priorities for improved hay quality and yield potential and to investigate practices on farm that directly influence quality while maintaining or increasing hay yield.

Methods

Agronomy

Research into defining yield and quality attributable to genetics, on farm management, hay curing method and environmental impacts was initiated at the same time that animal feeding trials and NIR methodologies research were being investigated. A joint research project conducted by Gilmac, Agrilink and CSIRO produced hay samples from plots grown in different environments, with differing varieties and management inputs. The samples were analysed by Near Infrared Spectrometry (NIR) and subsequently fed to cattle in preference and intake trials. Initial research results indicated that quality was influenced by genetics, management, curing, weather, and climatic conditions during the growing season. The research also highlighted the need for protocols in the conduct of this research as the conduct of trials could create as much variability as the treatments themselves.

The most variability in results occurred because previously:

- Sampling of plots for quality used bulked samples from replicates or samples from one replicate only
- Inter-plot distances were much greater than row spacings and external rows of plots had access to additional water and/or nitrogen from inter plot areas.
- Sampling (ie cutting) occurred on a particular day and did not take into account maturity differences due to treatment effects
- Samples were taken from various heights above ground level from 2cm to 20cm depending on equipment used and method of sampling
- Samples were taken from different times of the day
- Samples were not consistently cured, dried and prepared for analysis.

Once protocols were developed that produced accurate results, field research was conducted at Mintaro and Balaklava in South Australia. Mintaro is characterised by an average 500mm rainfall, clay soil types and a long growing season while Balaklava averages 400mm rainfall, loamy clay soils and a shorter growing season. Sites were also used at Hart (SA) and York (WA) for validation purposes.

Replicated trials using a randomised block design were conducted to investigate the interactions that occur between cultivar, nitrogen rate and timing, seeding rate, time of sowing, the growth stage at cutting and curing conditions.
Samples were cut by hand from four or eight 0.5m lengths of internal rows. External rows of plots were not sampled. All samples were cut as close to ground level as possible and weighed. Sub samples were taken, weighed and micro waved within 20 minutes of sampling on high for up to two minutes and then either frozen immediately or oven dried immediately. Frozen samples were oven dried at a later date.

Hay produced from commercial farms was compared both subjectively and objectively to that produced in the research programme and for the first time it became apparent that practices on farm were a key driver of hay quality. In general those farmers producing the highest yields were also producing the lowest quality. Practices that could result in lower quality were identified and plans introduced by farmers to modify those practices.

Plant Breeding- Hay yield and quality

Hay trials with the most advanced breeding lines and varieties are designated Stage 4 (S4) and Stage 5 (S5). The S4 trial entry list varies between 36 and 50 lines/varieties and the S5 is a subset of the S4 representing 15 to 20 of the most advanced breeding lines/varieties. The trials have three replications. Current trial sites are located at Pinery, Kingsford, and Riverton in South Australia (SA); York, Williams, and Wongan Hills in Western Australia (WA), and Elmore in Victoria (VIC).

Generally it takes three or four visits to each trial site to cut the entries at Zadoks 71, watery ripe. Sites are checked from mid September to determine the growth stage of each line/variety and when the top floret is watery ripe, the hay cuts are completed. It is optimum to do the cuts in the morning, but this is not always feasible, so cuts between 10am and 3pm are acceptable. All trials at Kingsford are cut with a Wintersteiger Forage Harvester. Quadrats are cut from plots in all other trials. A $1m^2$ quadrat or two $0.5m^2$ are cut from each plot excluding the outside two rows. Quadrats are cut at ground level to ensure they are the same. Samples are weighed and data recorded and a sub sample of 200 to 400 g weighed and retained. The sub sample is kept cool until it is placed in a drying oven at 60°C for 24 hours or until dry. Once the sub sample is dry, it is weighed, data recorded, and hay yield is calculated. A representative sample is further sub sampled, chopped, and ground for quality analysis. NIR calibrations have been developed to assess *in vitro* dry matter digestibility (IVD), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), and water soluble carbohydrate (WSC). Table 1 shows the definition of these quality characters.

Table 1. Traits used to describe hay quality.

Quality trait	Description
ADF	% fibrous fraction composed of cellulose and lignin
NDF	% fibrous fraction composed of total cell wall composition including cellulose, hemicellulose, and lignin
WSC	% non-structural carbohydrate concentration composed of sucrose, fructose, glucose, and fructans
IVD	Lab estimate of the amount of feed digested by the animal as a % of intake
CP	% of total protein content

Statistical analysis

Models were developed for each quality trait and trial for the study conducted in 2002 and 2003. The model described sources of error in the trial, both natural spatial variation due to plot position and extraneous field variation across ranges and rows. Trials were also combined for a multi environment trial (MET) analysis with the following model: quality trait = trial + trial;entry + natural variation + extraneous variation.

Results and Discussion

Agronomy and development of experimental protocols

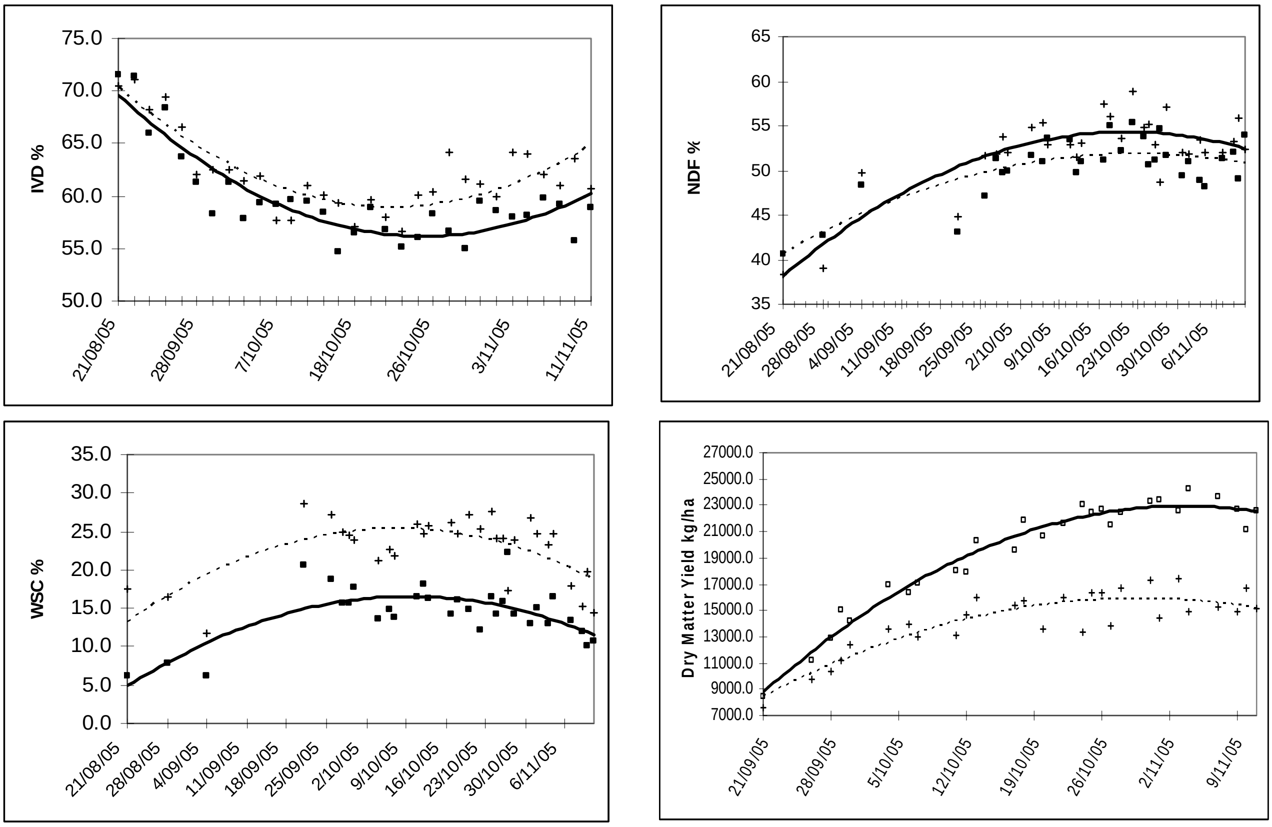
Hay trials were conducted from 1994 to 2000 to determine what parameters had an influence on hay yield and quality and how these experiments should be conducted to limit experimental error and produce accurate results. Research was conducted on time of sowing, time of cutting, yield and quality trade-offs, the impact of soil nitrogen and applied nitrogen, variety, cutting method and cutting height. The benefit of this multidisciplinary approach was that valuable information for the hay industry and research methodologies could be researched concurrently.

Results indicated that both yield and quality changed markedly for different plant growth stages and that a standard would have to be developed so that different treatments, especially varieties with different maturities could be compared in a valid way.

Hay yield accumulated in direct proportion to total above ground biomass (DM) yield. DM yield increases from the boot stage (Z45) to anthesis ranged from a low of 20 kg/ha/day in very dry conditions to 200 kg/ha/day when water was not limiting. In 2005 when conditions were cool, there was ample water and nitrogen and high biomass yields had already been achieved by Z40 the DM yield increased by 320 kg/ha/day just before and after anthesis.

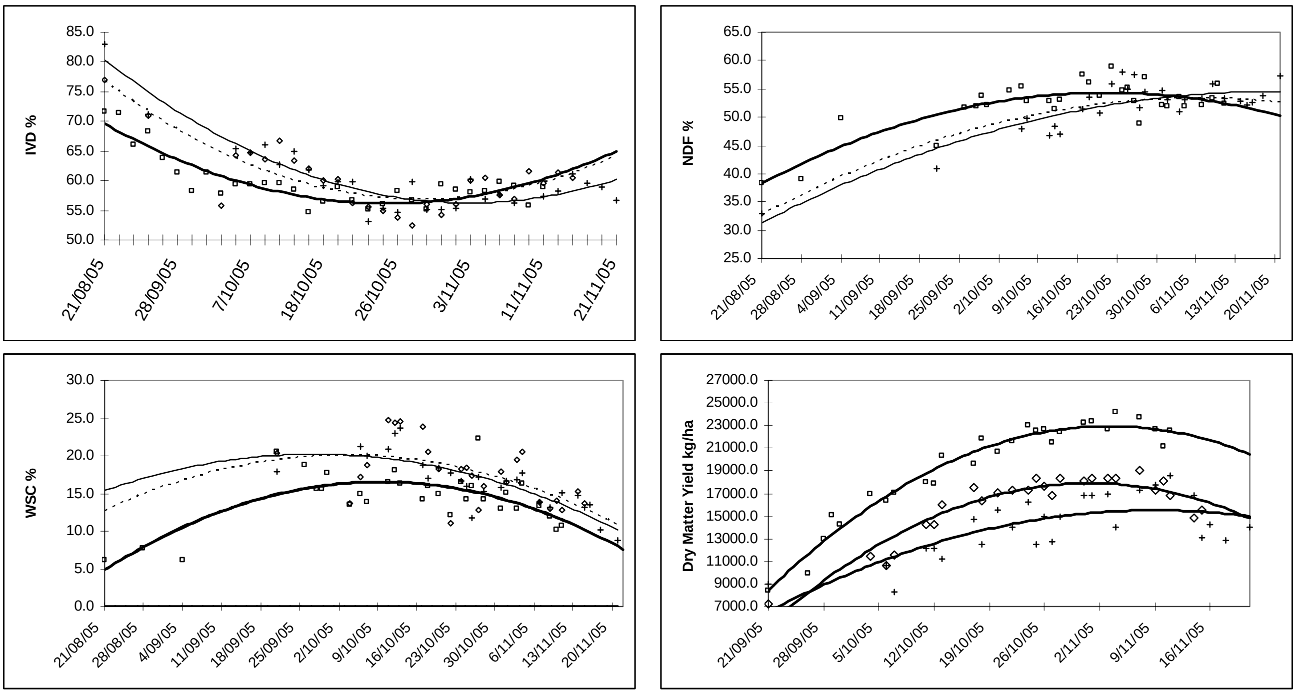
All quality parameters that are measured using NIR technology are influenced by the physiology and growth stage of the plant and the changing soil moisture status and air temperature that occur during this period of spring in southern Australia.

Figure 1. Change in IVD, NDF, WSC and DM Yield over time in variety Wintaroo 2005. Dotted line is where there was no added nitrogen and solid line has 100 kg/h nitrogen applied as urea.



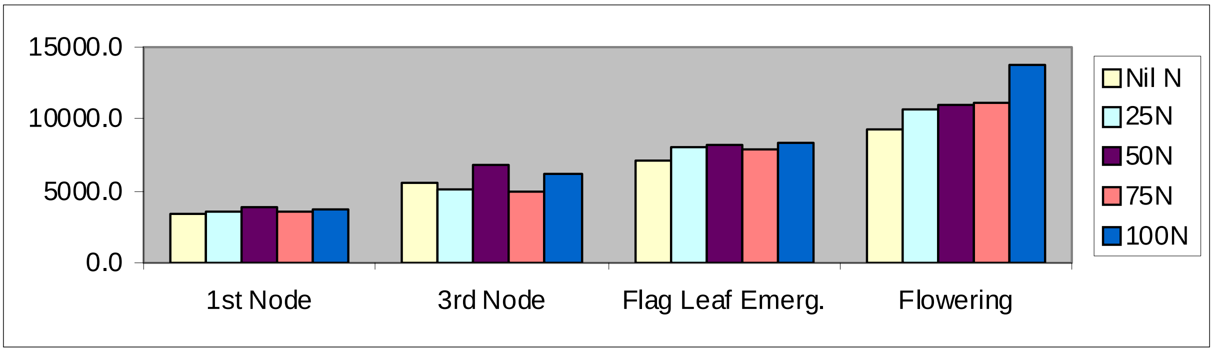
Anthesis occurred from 4/11 to 11/11 in the trial conducted for Figure 1. Many of the parameters measured are reasonably stable at, or around, anthesis but change markedly both before and after. Other research by Braun and Faulkner in less favourable years has shown lower dry matter accumulation rates but far more significant deleterious effects on all quality parameters after the completion of anthesis.

Figure 2. Effect of seeding date on changes in IVD, NDF, WSC and DM Yield over time in variety Wintaroo 2005. Open squares sown early May, triangles sown late May, crosses sown early/mid June.



Hay yield and dry matter yield are strongly influenced by seasonal conditions and nitrogen status. Figure 3 shows much lower dry matter accumulation in the relatively dry spring conditions of 2006 compared to the results from 2005 in Figure 2.

Figure 3. Dry matter accumulation of oats (cv Wintaroo) in 2006 at Tarlee SA.



In dry years total dry matter accumulation can be reduced substantially. In general terms hay from very low dry matter accumulation sites tends to have very good quality parameters.

Variety may have an influence on the quality parameters of oat hay but it is important to determine if the effects are innate or due to maturity. As quality declines fairly rapidly after anthesis it could be deduced that a variety that matures later will maintain higher quality later into the season until it reaches a comparative growth stage. This research is difficult to do and needs to be repeated over a number of years with varying spring conditions to accurately determine what is truly innate and what is due to maturity differences.
To investigate variety and environmental conditions initial research into anthesis dates was conducted. Table 2 is a recent example of this research.

Table 2. Comparative anthesis dates of cultivars sown in the Mid North of South Australia in 2005 and 2006.

Variety	2004 Sown 4/6/04 Start of Flowering	2005 Sown 29/5/05 Start of Flowering
Wintaroo	19/10/2004	17/10/2005
Wallaroo	9/10/2004	6/10/2005
Marloo	13/10/2004	25/10/2005
Brusher	11/10/2004	14/10/2005
Kangaroo	17/10/2004	27/10/2005
Possum	16/10/2004	
Riel	24/10/2004	7/11/2005
Buckley	13/10/2004	22/10/2004
Rufus	14/10/2004	15/10/2005
Jackie	21/10/2004	3/11/2005

The results (Table 2) indicate that maturity varies between cultivars and seasons and is not always predictable. For instance the mid-late maturing cultivar, Kangaroo, only flowered slightly later than the mid maturing cultivar, Wintaroo, in the drought year of 2004 but a substantial 10 days later in the favourable conditions of 2005.

Cereal hay is nominally cut at about 15cm from ground level in commercial practice depending on seasonal conditions and machinery used. Exceptions occur when hay is lodged and there may be up to 30cm of stem material left uncut or in low yielding, droughted crops where cutting is much lower to maximise yield. To determine if a standard cutting height should be recommended for trials and to give guidance to commercial hay producers, research to establish the relationship of yield and quality to cutting was needed.

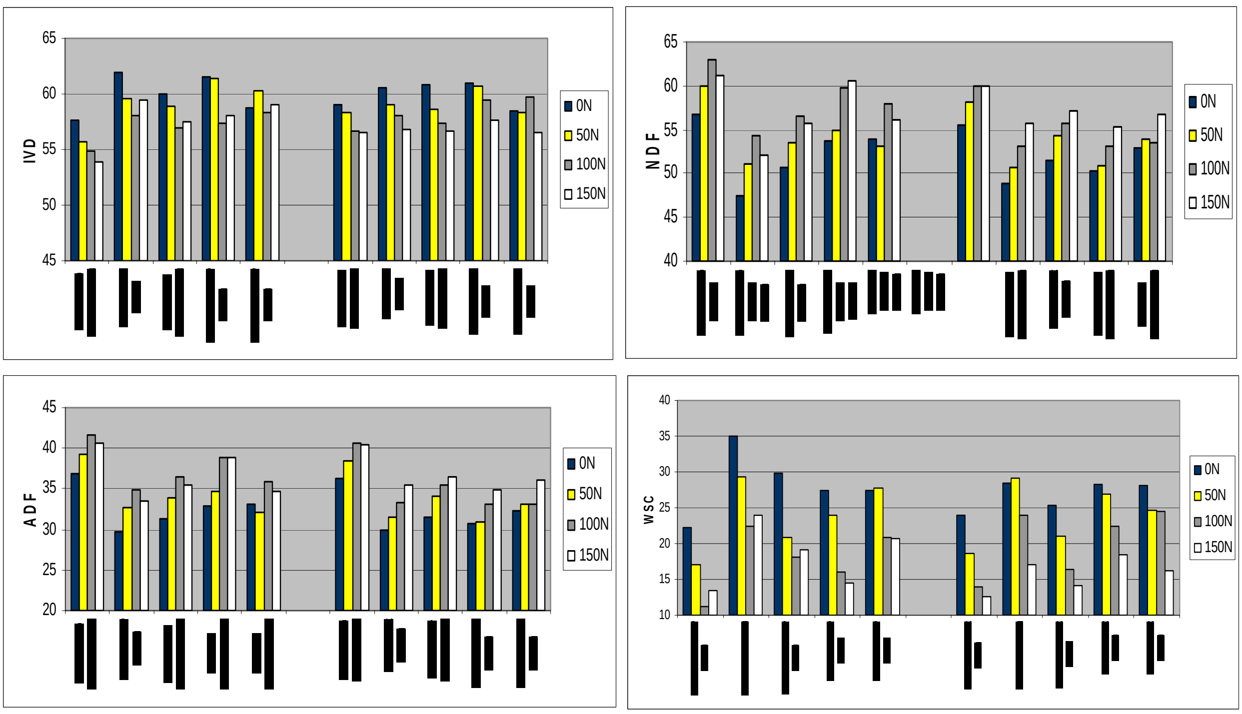
Table 3. Yield and quality of plant parts as influenced by height above ground level

Plant Part Sampled (above ground level)	% of Total Plant Weight	IVD %	ADF %	NDF %	WSC %	CP %	POTASSIUM %
0-5cm	4	50.3	44.1	62	17.9	2.6	1.6
5-10cm	4	52.3	44	61.4	20.7	2.7	1.6
10-15cm	4	53.5	43.7	61.2	21	2.7	1.6
15-20cm	5	54.6	43.4	61	21.4	2.9	1.6
20-25cm	5	55.3	42.5	60.1	21.4	3.3	1.7
25-40cm	8	56.4	41.7	59.2	19.2	3.7	1.7
40-55cm	12	60.7	38.4	55.6	22	5	1.7
55-70cm	18	65.8	33	49.5	23.8	6.8	1.6
70cm +	40	74	23	38.2	22.9	12.3	1.8
LSD 5%	3.5	1.6	1.3	1.5	NS	1.3	0.15

It is apparent from Table 3 that the lowest quality occurs towards the base of the plant and the quality increases up the plant. This also explains why cattle preferentially consume the tops of plants and reject material from the base when fed ad lib.

High soil nitrogen levels or high applications of nitrogen fertiliser generally increases dry matter yield unless additional winter growth results in depleted soil water, which in dry spring conditions can actually reduce ultimate yield. Low nitrogen status inhibits plant functionality and can reduce quality but as nitrogen status increases initially quality increases and ultimately plateaus before rapid deterioration. Deterioration of quality usually occurs before maximum yield is reached. This creates a dilemma for both researchers and hay growers in determining variety responsiveness and the yield / quality trade-off.

Figure 4. Effect of time of sowing, nitrogen rate and cultivar on IVD, NDF, ADF, WSC 2001.



Interestingly the responses to nitrogen vary between varieties and also sowing date. For example, high rates of nitrogen applied to early sown Wintaroo had more deleterious effects than when applied to the same variety when sown later.

These results indicate there is genetic variability for hay quality and therefore some scope to influence quality using a breeding programme. The environmental and management factors have a profound influence on any cultivar's ultimate yield and quality.

Modifying practices at the farm level

Samples of commercial hay taken from delivered consignments to Gilmac were objectively and subjectively characterised for quality. The objective measurements indicated hay rejected by the Japanese market also performed poorly in local feeding experiments and NIR analyses.

In general, the farmers who were perceived as successful producers of oaten hay (ie very high yields associated with early sowing, high nitrogen regimes and highly productive cultivars) were consistently producing the poorest quality. Where rainfall occurred during curing, the quality of these producers hay was very poor and usually rejected. The farmers involved realised there was a problem and that modifications would need to be made to production systems and curing methods.

These progressive farmers began understanding nitrogen nutrition and modifying its application and making cultivar choice on parameters other than yield. The farmers embraced super conditioning to reduce the risk of rainfall damage and many made modifications to machinery to reduce curing time.

Linking oat variety improvement with farmers, agronomists, and exporters

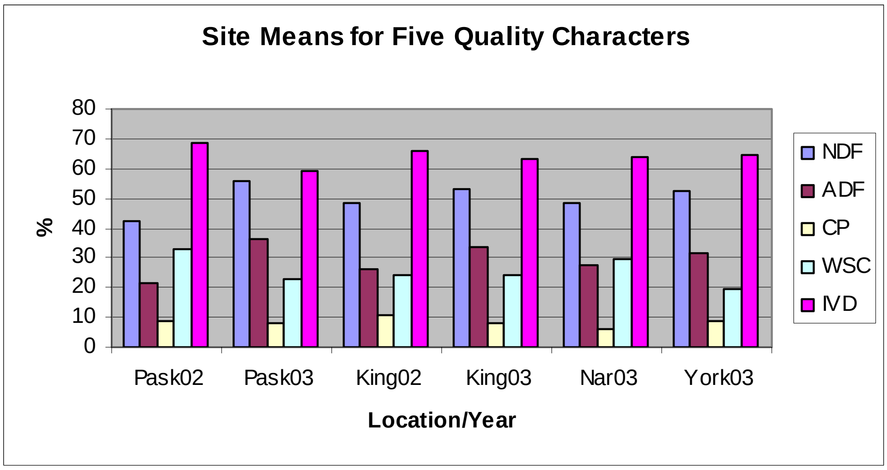
Hay trials to assess dry matter production in oat varieties released for grain production began as early as 1981 in the oat breeding program when five varieties, Swan, Coolabah, Saia, and NZ Cape were grown in a trial. At this time hay was cut at the milky dough stage. Seed became available of Wallaroo and Marloo in 1989 to growers providing the first varieties with cereal cyst nematode resistance and tolerance. The varieties were originally released for grain production, but in 1990 the potential of Wallaroo and Marloo for forage and hay production was identified. In 1995 the first hay trials were sown to evaluate hay yield potential in advanced breeding lines at Kingsford, Pinery, and Marrabel, SA.

An emerging new industry exporting hay to Japan was gaining momentum in 1995. Consultation with agronomist consultants, hay exporters, and growers quickly identified traits of importance that the breeding program needed to address. Hay quality emerged as a priority to ensure a consistent, palatable product. The measurable components of hay quality were IVD, CP, ADF, NDF, and WSC, but the relationship of these traits to palatability and preference had not been established. Furthermore, quality traits had not previously been evaluated in the Oat Breeding Program. Other breeding priorities identified were hay yield potential, maturity, hay colour, stem diameter, and disease resistance.

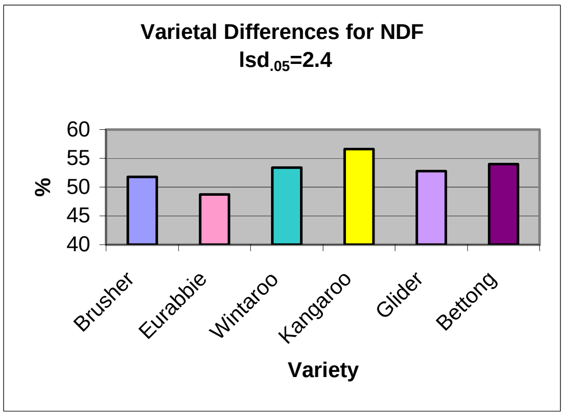
The hay variety improvement program gained impetus in 1997 when a research project to breed improved oat hay varieties was funded by the Rural Industries Research and Development Corporation (RIRDC). It was now possible to have the advanced breeding lines and varieties in the S4 and S5 trials evaluated for the five quality traits. Little was known about varietal differences for the quality characters. In order to gain an understanding of the genetic variation and heritability for IVD, CP, ADF, NDF, and WSC, a study was conducted in 2002 and 2003. Results of this study indicated there is potential for improving these hay quality traits.

The location and year means varied for NDF, ADF, CP, WSC, and IVD (Figure 5). Low values for NDF and ADF indicate good quality, whereas high values are desirable for CP, WSC, and IVD. Pask02 produced the highest quality hay compared to Pask03, King02, King03, Nar03, and York03. The poorest hay quality was found at Pask03. Values for NDF and ADF were 13.6% and 14.3% higher at Pask03 than Pask02. Water soluble carbohydrates and *in vitro* dry matter digestibility were 10% and 9 % lower at Pask03 than Pask02. The poor quality performance of varieties at Pask03 is directly related to the site mean hay yield. The mean site hay yield at Pask03 was 17.5 t/ha compared to 6.7 t/ha produced at Pask02. A similar trend occurred for NDF and ADF at King02 and King03. The location/year mean for NDF and ADF was 4.6% and 7.3% higher at King03 compared to King02. However, WSC levels were similar and IVD at King03 was only 2% lower than King02. The site mean hay yield for King02 was 8.0 t/ha compared to 15.7 t/ha for King03. Nar03 had similar NDF and ADF levels with King02, but WSC was higher and IVD slightly lower. York03 was similar to King03 for NDF and ADF levels, but was 5% lower in WSC compared to King03. York03 had a site mean yield of 9.5 t/ha. The site means for NDF, ADF, WSC, and IVD were significantly affected by location and year. Lower yielding hay crops produced in 2002 had higher hay quality than higher yielding hay crops produced in 2003. This is a key issue for hay producers and agronomists. Highly productive hay crops often have poor hay quality.

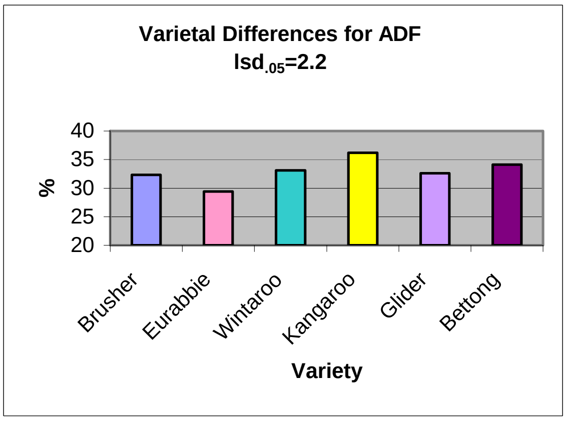
Figure 5. Site means of NDF, ADF, CP, WSC, and IVD for hay varieties grown at Paskeville, SA in 2002 (Pask02) and 2003 (Pask03), Kingsford, SA in 2002 (King02) and 2003 (King03), Narrogin, WA in 2003 (Nar03), and York, WA in 2003.



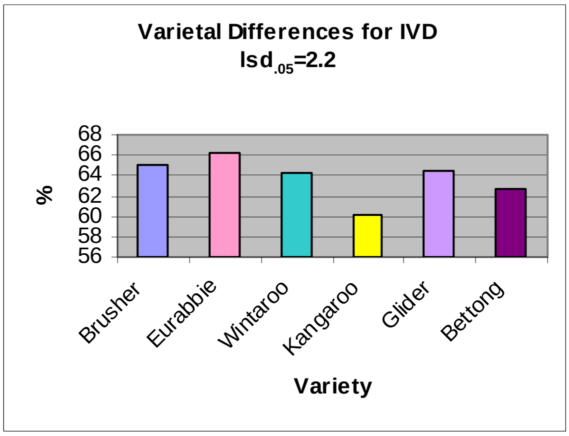
In addition to location/year differences, genotype differences in Brusher, Wintaroo, Kangaroo, Glider, Bettong, and Eurabbie were found for NDF, ADF, WSC, and IVD. There were no significant variety differences for CP. Eurabbie, Brusher, and Wintaroo had lower levels of NDF and ADF than Kangaroo and Bettong (Figure 6a and 6b). Kangaroo and Bettong had lower IVD and WSC compared to the other varieties (Figure 6c and 6d).



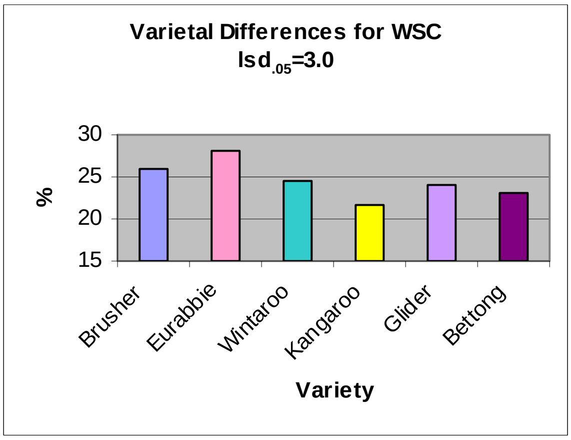
a. NDF



b. ADF



c. IVD



d. WSC

Figure 6. Variety differences for NDF (a), ADF (b), IVD (c), and WSC (d) in hay varieties Brusher, Eurabbie, Wintaroo, Kangaroo, Glider, and Bettong grown at Kingsford, SA in 2003.

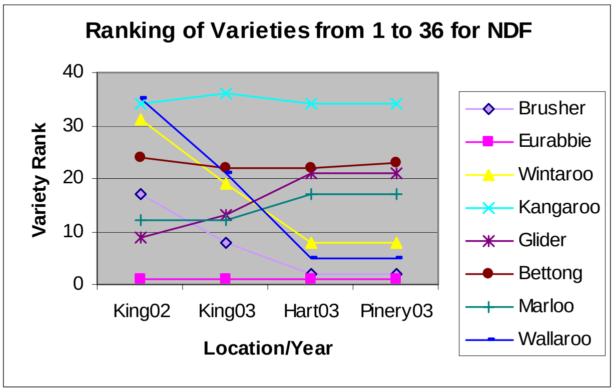
Eurabbie possesses the highest level of hay quality of all the varieties evaluated in this study and is used as the benchmark quality check in the Oat Breeding Program. Eurabbie is a dwarf stature oat variety and past hay quality performance shows that dwarf stature varieties consistently have better hay quality than tall stature varieties. Unfortunately a draw back using dwarf varieties for hay production is that the panicle may not emerge completely causing moisture problems in the bale. Brusher is a tall variety with excellent hay quality. Wintaroo and Glider have similar hay quality levels and have performed well in the export hay market. Bettong was the first hay variety identified with quality performance issues and feedback from the export market about palatability problems. This may be associated with low WSC and IVD. Kangaroo is the poorest quality variety in this study, but it has benefits from superior disease resistance compared to the other varieties.

Relative performance of the varieties to each other gives a measure of stability over years. Stage 4 trials sown at Kingsford in 2002 and 2003, Hart in 2003, and Pinery in 2003 had 36 genotypes. Eight hay varieties were ranked within the group of 36 with 1 having the best quality and 36 the poorest quality for NDF, ADF, WSC, and IVD (Figure 7).

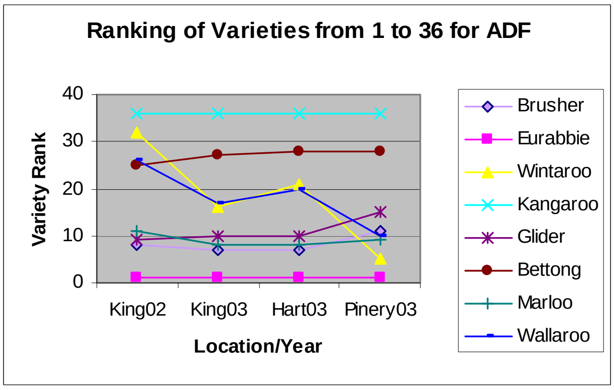
A few genotypes had consistently better quality than other varieties. Eurabbie was ranked in the top five varieties for low NDF and ADF (Figure 7a and 7b). Brusher ranked in the top 11 varieties for low NDF and ADF with the exception of King02. Kangaroo ranked 35 and 36 for the same two traits at all locations. Bettong was also consistently poorer compared to other varieties and lines for NDF and ADF. Wintaroo and Wallaroo varied the most in rankings for NDF and ADF compared to the other varieties shown in the graphs.

Kangaroo, Bettong and Marloo were ranked from about 25 to 36 for WSC indicating consistently low levels (Figure 7c). Wintaroo ranked from 11 to 16 in the group for WSC indicating more stability over locations/years compared to NDF and ADF. Brusher ranked in the top 10 for WSC and was also consistent for the four locations/years. The performance of Eurabbie and Wallaroo compared to the other varieties was affected by location/year. Wallaroo would have been ranked in the top 10 for WSC, except for King03 where it ranked 19. Eurabbie had a similar trend, but produced lower WSC compared to the other varieties at Hart03.

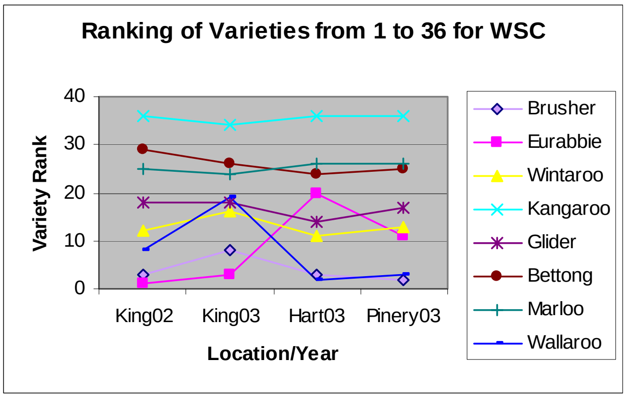
The rankings of the varieties were variable for IVD (Figure 7d). The exception was Eurabbie, which was ranked in the top 5 at all locations/years for IVD. Although Kangaroo was consistently ranked above 30 for NDF, ADF, and WSC, it performed better than Wallaroo at Hart03 and Pinery03.



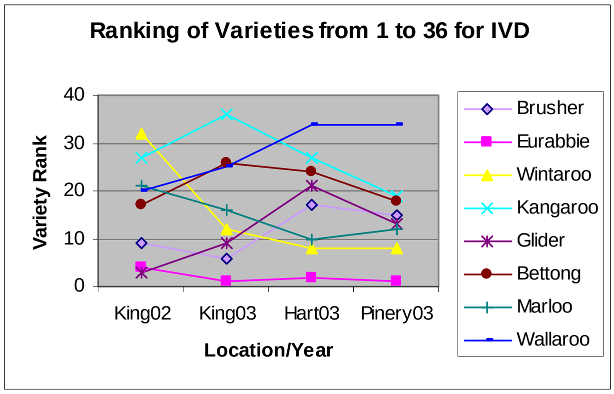
a. NDF



b. ADF



c. WSC



d. IVD

Figure 3. Eight varieties from four Stage 4 hay trials with 36 entries ranked according to relative order for NDF, ADF, WSC, and IVD.

Conclusion

The research has resulted in the development of protocols specific to the cereal hay industry needs. A multidisciplinary approach encompassing the needs of industry, producers, researchers and plant breeders has led to outcomes that have enhanced the genetic resource, production and marketing of oaten hay.
How to conduct research was a key question that was needed to be resolved by researchers so that milestones could be reached. The research into the complex interactions of cultivar, environment and management had to be unravelled to determine if there was genetic diversity to work with, what could be achieved on farm and what was influenced strongly by the environment.

Producing high quality hay has allowed the development of a strong export industry aligned to the needs of Asian dairy and beef production. As the market needs grew and supply needed to increase, a concerted effort was initiated to understand the contributions of genetics, environment and management to produce satisfactory yields of a high quality product to build a new industry.

Hay quality has been a focus of the hay industry. In order for the National Oat Breeding Program to deliver quality improvements, it was necessary to determine how the environment affects quality, the extent of genotypic differences, and the stability of genotypes for the quality traits, NDF, ADF, WSC, and IVD.

The results from the study indicate that there are significant environmental effects and genotypic differences for ADF, NDF, WSC, and IVD. Certain genotypes have greater stability in performance for ADF, NDF, WSC, and IVD. Therefore, developing hay varieties with more consistent high quality performance is feasible in the future.
Combining enhanced quality with high hay yield, for which there has been a negative relationship, is the greatest challenge for the export hay industry. Hay yields must increase for the industry to remain competitive but it must be with an enhancement of quality. This, and improved disease resistance, is also the challenge for the National Oat Breeding Program.

Farmers have been willing participants in this research and industry. These producers realised that objective measurement offered them a tool to assessing their own practices and production methods. The farmer objective has been to increase quality with little, if any, reduction in yield and to minimise adverse weather effects. The vision for the future is to increase yield while maintaining or increasing quality.