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Best practice super conditioning to produce quality export oaten hay

A report for the Rural Industries Research and Development Corporation

By Rural Directions Pty Ltd

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Foreword

Super conditioning is a relatively new processing technique which is considered to add value to the haymaking process when compared to cutting alone. It is practiced by 70-80% of export hay producers using a variety of machine types. This project examines the effects of the super conditioning process itself, in terms of what it does to hay end quality, and it also examines the different machine types to determine similarities and differences between the machines.

This report evaluates the super conditioning process as a whole, and also addresses each individual machine. There is detailed information regarding the degree of straw crushing, moisture loss, windrow structure and density, hay colour, and hay feed test values that each treatment produced under the conditions of the trial.

It highlights the differences between end product quality after different super conditioner treatments. The report also outlines how the correct use of super conditioning can improve export oaten hay, and reduce the risk associated with producing it.

The key finding of this project is the differences between super conditioned hay and mower conditioned hay in terms of quality and dry down time. Also of importance are the results from tests using each machine, and the different hay that each produces. These findings will help hay growers to make more informed choices in the future about super conditioning systems, and better understand why the process works.

This project was funded from industry revenue which is matched by funds provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 1500 research publications. It forms part of our fodder crops R&D sub-program which aims to facilitate the development of a sustainable and profitable Australian fodder industry.

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Peter O'Brien
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Abbreviations

ADF	acid detergent fibre
NDF	neutral detergent fibre
WSC	water soluble carbohydrates
DDM	digestible dry matter
DAC	days after cutting
Kph	kilometres per hour
Kpa	kilopascal
Psi	pounds per square inch
mm	millimetres
LSD	least significant difference

Contents

For colour representation of the tables and figures within this report, please see the RIRDC publications website which can be accessed at www.rirdc.gov.au/fullreports/fodder.html

Executive Summary

What the report is about

This report provides a comprehensive summary of the research findings from the project "Best Practice Super Conditioning to Produce Export Quality Oaten Hay." As such, it forms the basis for a management guide to super conditioning, including critical factors for success, and considerations when conducting super conditioning operations. The research is of vital importance as the export hay industry is built around a quality product. Further refining of the product will secure future markets and potentially open up new markets.

Who is the report targeted at?

The report is aimed at all levels of the export oaten hay industry. Growers will be able to make more informed decisions about whether to super condition the hay. There are also some practical guidelines to follow for the actual operation. Contractors will benefit from these guidelines, and will be assisted when looking at the different conditioning mechanisms for machinery purchase.

The report demonstrates sound research into best management practices. Therefore, hay buyers and exporters can use the information contained within this report to demonstrate what they require from their growers. Whilst super conditioning is not common in the domestic hay industry, the report is still of interest as it discusses techniques to reduce curing time of hay, and other factors which are relevant to all hay producers.

Background

This trial was instigated due to debate in the industry as to the merits of super conditioning. Anecdotally, there have been perceptions that super conditioned hay is a poorer quality product, and that it is more at risk from weather damage. There has also been conjecture as to the differences between machine types and setups, and the trial aimed to investigate these differences.

Aims and Objectives

When designing this trial some clear aims and objectives were outlined. These were to:

- assess the impacts of the super conditioning operation on the hay
- test if there are hay quality differences between the various machine types
- determine if there is an optimum time for super conditioning
- define some principles that need to be followed to make quality oaten hay.

The objective of the trial was not to provide a recommendation as to the best machine, but rather to observe the different ways that the machines work, and the effects they have on the hay.

Methods

The trial involved the use of six different super conditioners and one mower conditioner, and was conducted at paddock scale over 24 hectares. Two self propelled super conditioners were used, along with four tractor towed units. The mower conditioner was self propelled. Three timelines were assessed for conditioning: zero days after cutting (self propelled machines), two days after cutting, and four days after cutting.

Assessments conducted during the trial were:

- degree of crushing of stems, knots and florets
- windrow structure, including height, height off ground, windrow width, and windrow uniformity
- windrow temperature and humidity
- moisture decline of the hay
- fresh weight of the windrow
- hay quality including colour, acid detergent fibre (ADF), neutral detergent fibre (NDF), water soluble carbohydrates (WSC) and digestible dry matter (DDM)

- time from cutting to baling.

An automatic weather station was also set up at the site to record climatic conditions during the trial.

Key Findings

Some of the key findings to evolve from the trial are as follows:

Machine Setup Considerations

- Roller spacing which will influence straw, knot and floret crushing.
- Discbine fronts may cut cleaner and lower than sickle fronts, so may need to be adjusted to achieve sufficient clearance to reduce impact on high fibre contents.
- Differing roller speeds and a tearing action are more aggressive in treating florets. They may disintegrate rather than be crushed.

Windrow Structure

- Windrow structure (ie total height, width, height off ground) depends on how the machine and discharge chutes are set rather than the machine itself. These may need to be adjusted so that the windrow is positioned/shaped as you want it.
- Dense windrows with more weight per unit area may need to be cut a bit higher so they remain sitting above the ground.
- Lodged crops are more prone to leaving material sitting on the ground so you may need to adjust cutting height up to account for this.
- Crops that have been allowed to dry for a time after mower conditioning and before super conditioning sit higher, and maintain height better than those positioned straight after cutting.
- Narrow windrows can protect colour but may take longer to dry.
- Dense windrows take longer to dry than those that are more open.
- A faster operating speed results in a less uniform windrow. This effect is exacerbated as super conditioning is delayed.
- A tighter windrow structure aids in less bleaching and may improve hay colour.

Curing Time

- Ensure that knots are crushed as curing time is reduced. The mechanism rather than the timing is important here.
- Florets need to be crushed. It reduces dry down time, and prevents seed set.
- Moisture content will vary according to time of day. Hay may need to be checked at varying intervals and times of day to get a true indication as to if it is ready to bale.
- Dryness of knots is the critical factor in making the time to bale decision.
- Earlier super conditioning has the potential to dry hay quicker.
- Dense, compact windrows retain higher humidity and take longer to cure.
- In fine conditions, super conditioning shortens the time to baling when compared to mower conditioning alone.
- Delayed super conditioning (ie from day 2-4) has no impact on final time to baling.
- Reduced curing time can result in improved hay colour. Increased exposure to sunlight bleaches hay further.
- The more aggressive the treatment, the faster moisture is lost and the shorter the time to baling.

Hay Quality

- Super conditioning does not appear to result in a loss of yield compared to cutting alone, nor is yield influenced by time of super conditioning.
- Super conditioning itself has no major influence on hay quality under ideal conditions. It has the potential to improve hay quality by reducing curing time, which can improve colour and reduce risk of weather damage. Hay quality can be improved over hay that is mower conditioned only if the machine is set up correctly and conditions allow.
- Cutting height will influence ADF%. A lower cut will increase fibre content as it increases the proportion of lower plant parts in the sample (as fibre increases lower in the plant). This will also decrease DDM.
- The fewer operations that occur the more colour is retained.

Implications

The implications of these findings for the industry are that there is a place for super conditioning in hay enterprises. There are improvements in curing time that can be made with the use of super conditioners, and this may result in less hay being weather damaged as it cures and is baled quicker. The trial showed that super conditioning can improve hay quality over mower conditioning, when used correctly in the right circumstances. Whilst it is still unclear as to the effect of rain on super conditioned hay, when rain does not occur there are quality improvements that can be made.

There are also implications for machinery manufacturers arising from the trial. Numerous adjustments can be made to most of the machines, however the greatest impact can be had from altering roller gap and also the rear discharge mechanism. The roller gap will influence the crushing of the straw, whilst the rear discharge will influence windrow formation. If manufacturers can continue to develop new systems and concepts that allow flexibility for these two factors, the super conditioning process will continue to grow in value.

Recommendations

Based on one years' trial data, it is difficult to make solid recommendations. However there are some general principles that can be recommended to growers and contractors relating to super conditioning. It is vital to know the climate of the district in which you are operating - in particular the average rainfall frequency during the hay making season. The risk of rainfall will determine much of the set up of super conditioning machinery, and indeed the timing of the operation.

If rainfall is common during hay making season then there are two choices:

1. setup the windrow to dry as quickly as possible, use a super conditioner and try and avoid the rainfall by curing the hay as quickly as possible.
2. alternatively, the machine may be set up to make a windrow that will protect the hay from rain, and delay super conditioning until after the rainfall event.

This decision will then influence the remainder of the hay making operation. If the hay is to be cured as quickly as possible, then an aggressive machine that crushes a lot of knots and florets will achieve this, along with an open windrow.

However, if trying to protect the hay from weather damage, it is desirable to alter the rear discharge so that windrow is tight and allows water to runoff, stopping it penetrating the windrow. Super conditioning would also be advisable after the rainfall event, although the aggressiveness of the operation may need to be reduced.

Introduction

The export oaten hay industry is a sizeable contributor to Australia's economy, and is worth at least $150 million annually. The export hay market is driven by quality, and maintaining or improving the quality of hay is seen as a must for further industry growth and development. Super conditioning is one tool which may be able to drive this quality improvement, and also manage weather risk. Super conditioning is the process of mechanically crushing cut hay to increase drying rates and improve final product quality.

This project looks at the super conditioning operation, by assessing different machine systems and timings in the field, when compared to a mower conditioner. By doing this, the aim is to:

- clarify the role of super conditioning in the production of export quality oaten hay (versus no super conditioning)
- evaluate the effects of different super conditioners on crushing, moisture content, windrow positioning and windrow structure
- quantify the effect of the super conditioners on the quality of export oaten hay.

By meeting these aims it is hoped the following outcomes will be achieved:

- increased understanding as to why super conditioning actually works
- ability to improve the effectiveness of the super conditioning operation resulting in better quality hay produced more often
- ability for contractors and machinery manufacturers to improve setup, modify existing machines, or improve machinery design
- better quality hay can increase farm and industry income levels – improving individual farm business profits, contributing to regional wealth and more prosperous regional communities.
- promotion of a product quality culture.

Background

Super conditioning is a relatively recently adopted practice that is perceived to add value to the haymaking process when compared to cutting alone. It is being practiced by 70-80% of export hay producers with a variety of machine types. There is much debate amongst the farming and contracting community as to the effectiveness of differing mechanisms within machines. Currently there is only anecdotal evidence as to the performance of each, its influence on drying time and moisture content and the quality of the end product. Each machine differs as to how plant material is treated, how the final windrow is structured and where it is positioned. Time to baling is also important. All these factors will influence final product quality, a factor which is a key focus of this project, as it is critical to farm business returns and to achieving market share.

Improving the quality of export oaten hay has the potential to increase farm and industry income levels. It is estimated that improving hay quality with correctly practiced super conditioning could increase grower income by 10-20%. This will improve individual farm business profits and contribute to regional wealth, resulting in more prosperous rural communities. A broader industry benefit is also in promoting a "product quality" culture. Although the focus is on export hay, project results will also be relevant to domestic hay producers, many of whom are yet to adopt super conditioning as a part of hay production.

Methodology

Trial Design

A site was chosen in the high rainfall district to the east of Clare, South Australia in November 2005. A 10-11 tonne per hectare crop of Riel oats was selected, producing over 400 bales from a 24 hectare trial area. A randomised complete block design was used with four replicates and ten treatments at farmer scale; plot size was ten metres by six hundred metres (see Appendix). Each plot had four designated sub sections for windrow structure assessments and moisture sampling.

Treatment Setup & Initiation

All plots were initially cut using a self propelled mower conditioner (as used for treatment 1), apart from treatments 2 and 3 where self propelled machines cut and super conditioned in the one pass.

The trial was cut on the 16th November 2005, starting with replicate one at 9.00am and finishing with replicate four at 7.00pm.

The following tables (Tables 1-10) and photographs (Figures 1-7) outline the setup and details of each treatment used in the trial.

Table 1: Setup Details for Treatment 1

Treatment 1	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle bar
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm

Figure 1(L-R): Side view of SP mower conditioner; rear view of mower conditioner; roller design of mower conditioner.

Table 2: Setup Details for Treatment 2

Treatment 2	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere / Gilmac
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 895
Speed of Travel	5 kph
Roller System	Small Ribbed Steel (Cutter) / Smooth Steel on Smooth Steel (Super Conditioner)
Number of Rollers	2 / 2
Roller Gap	2 mm
Pressure Setting & Adjustment	40 psi
Comments: Hydraulic oil flow and engine horsepower are at the maximum and do not allow for the machine to have an increased capacity or speed. Conveyor belt delivers the material from the cutting front to the Gilmac super conditioner mounted under the machine in red in the photographs below.	

Figure 2 (L-R): Rear view of John Deere/Gilmac Unit; side view of John Deere/Gilmac Unit; belt fed roller system in John Deere/Gilmac Unit

Table 3: Setup Details for Treatment 3

Treatment 3	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	New Holland
Model	HW340
Cutting System Type	Disc (5 metre width)
Cutting System Make & Model	Discbine with Super Conditioner Roller Cartridge
Speed of Travel	8 kph
Roller System	Steel on Rubber interlocking
Number of Rollers	2
Roller Gap	3 mm
Speed of Rollers	2400 rpm
Pressure Setting & Adjustment	¾ up the gauge arm
Comments: Disc cutters and the rollers have the same speed and are adjusted as one.	

Figure 3 (L-R): Rear view of New Holland SW340; side view of New Holland SW340; interlocking roller system for New Holland SW340

Table 4: Setup Details for Treatment 4

Treatment 4	
Day of Use	16^{th} November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	18^{th} November 2005 = Day 2
Propulsion	Tractor Towed
Manufacturer	Ashmore Engineering
Model	Haymax
Speed of Travel	9 kph
Roller System	Broad ribbed steel on smooth steel
Number of Rollers	2
Roller Gap	2 mm
Pressure Setting & Adjustments	75 mm spacer on tension arm
PTO Speed	540 rpm
Windrow Pickup system	Finger tyne
Rear discharge flap	Fixed at 90 degree
Side Discharge flaps	Fixed at 90 degree
Comments: Rear discharge flap was a standard box type design with no adjustment.	

Table 5: Setup Details for Treatment 5

Treatment 5	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	20th November 2005 = Day 4
Propulsion	Tractor Towed
Manufacturer	Ashmore Engineering
Model	Haymax
Speed of Travel	9 kph
Roller System	Broad ribbed steel on smooth steel
Number of Rollers	2
Roller Gap	2 mm
Pressure Setting & Adjustments	75 mm spacer on tension arm
PTO Speed	540 rpm
Windrow Pickup system	Finger tyne
Rear discharge flap	Fixed at 90 degree
Side Discharge flaps	Fixed at 90 degree
Comments: Machine settings were not altered for second treatment timing.	

Figure 4 (L-R): Front view of Haymax showing finger tyned pickup; Haymax in operation showing deposition of windrow; roller system in Haymax

Table 6: Setup Details for Treatment 6

Treatment 6	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	18th November 2005 = Day 2
Propulsion	Tractor Towed
Manufacturer	Buschutz Engineering Pty Ltd
Model	hydra-squeeze
Speed of Travel	9 kph
Roller System	Large Steel on large Steel both with 5-10mm rubber coating
Number of Rollers	2
Roller Gap	2 mm
Pressure Setting & Adjustments	324 Kpa (47 psi)
PTO Speed	540 rpm
Windrow Pickup system	Roller pickup
Rear discharge flap	Nil
Side Discharge flaps	Closed evenly each side to a 1 metre gap
Comments: Machine is very heavy and can only be towed at speeds up to 50kilometres per hour. Roller pickup works very effectively and has no conditioning effect on the hay material.	

Table 7: Setup Details for Treatment 7

Treatment 7	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	20th November 2005 = Day 2
Propulsion	Tractor Towed
Manufacturer	Buschutz Engineering Pty Ltd
Model	hydra-squeeze
Speed of Travel	9 kph
Roller System	Large Steel on large Steel both with 5-10mm rubber coating
Number of Rollers	2
Roller Gap	2 mm
Pressure Setting & Adjustments	324 Kpa (47 psi)
PTO Speed	540 rpm
Windrow Pickup system	Roller pickup
Rear discharge flap	Nil
Side Discharge flaps	Closed evenly each side to a 1 metre gap
Comments: Machine settings did not alter for second treatment timing.	

Figure 5 (L-R): Roller pickup system visible on Hydrasqueeze; Hydrasqueeze in operation showing deposition of windrow; rear view of Hydrasqueeze showing adjustable rear wings

Table 8: Setup Details for Treatment 8

Treatment 8	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	18th November 2005 – Day 2
Propulsion	Tractor Towed
Manufacturer	Agland Industries
Model	Macerator 6610
Speed of Travel	9 kph
Roller System	Rubber on Rubber interlocking first followed by a fine ribbed small steel on small steel
Number of Rollers	4
Roller Gap	2 mm
Speed of Rollers	Rubber = 600 rpm, Top Steel 1300 rpm, bottom steel 1500 rpm.
Pressure Setting & Adjustments	Rubber Rollers 255 kpa (37 psi), Steel Rollers 410 kpa (60psi) and the reserve air tank at 690 kpa (100 psi) this must be greater than the previous two pressures added.
PTO Speed	1000 rpm
Windrow Pickup system	Finger tyne
Rear discharge flap	Set at 45 degree
Side Discharge flaps	Fixed at 90 degree
Comments: Machine is quick and easy to tow and setup. Has a 540 PTO option available. Can only set roller gap to a 1mm minimum for safety reasons. You do need to have an air compressor near by to allow for pressure adjustments. No ability to close side discharge flaps in as they are fixed.	

Table 9: Setup Details for Treatment 9

Treatment 9	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 millimetre
Day of use	20th November 2005 – Day 2
Propulsion	Tractor Towed
Manufacturer	Agland Industries
Model	Macerator 6610
Speed of Travel	9 kph
Roller System	Rubber on Rubber interlocking first followed by a fine ribbed small steel on small steel
Number of Rollers	4
Roller Gap	2 mm
Speed of Rollers	Rubber = 600 rpm, Top Steel 1300 rpm, bottom steel 1500 rpm.
Pressure Setting & Adjustments	Rubber Rollers 255 kpa (37 psi), Steel Rollers 410 kpa (60psi) and the reserve air tank at 690 kpa (100 psi) this must be greater than the previous two pressures added.
PTO Speed	1000 rpm
Windrow Pickup system	Finger tyne
Rear discharge flap	Set at 45 degree
Side Discharge flaps	Fixed at 90 degree
Comments: Machine is quick and easy to tow and setup. Has a 540 PTO option available. Can only set roller gap to a 1mm minimum for safety reasons. You need to have an air compressor near by to allow for pressure adjustments. No ability to close side discharge flaps in as they are fixed.	

Figure 6 (L-R): Finger tyned pickup of Macerator 6610; Macerator 6610 in operation showing deposition of windrow; Rear fine tooth rollers

Table 10: Setup Details for Treatment 10

Treatment 10	
Day of Use	16th November 2005 = Day 0
Propulsion	Self Propelled
Manufacturer	John Deere
Model	4995
Cutting System Type	Sickle Bar (5 metre width)
Cutting System Make & Model	John Deere 896
Speed of Travel	6.5 kph
Roller System	Small Ribbed Steel
Number of Rollers	2
Roller Gap	2 mm
Day of use	18th November 2005 = Day 2
Propulsion	Tractor Towed
Manufacturer	Ag Shield Mfg.
Model	Recon 300
Speed of Travel	9 kph
Roller System	Small Steel on Small steel loosely interlocking on an angle
Number of Rollers	2
Roller Gap	2 mm
Pressure Setting & Adjustments	Hydraulic ram adjusted locking collar set at approximately 40mm
PTO Speed	540 rpm
Windrow Pickup system	Roller pickup
Rear discharge flap	One hole down from being full open
Side Discharge flaps	Closed evenly each side to create a 1 metre gap
Comments: Machine is very light and quickly set up, and it can be towed easily behind a standard utility.	

Figure 7 (L-R): Side view of Recon300; Recon 300 in operation; rear view of Recon300, showing rollers and adjustable rear flaps

In Field Assessments

Degree of Crushing

Stem Effect

Straw was assessed according to its shape after super conditioning. This was done by measuring the width and depth of 10 stems from each section in each plot using digital callipers. Each stem was measured between two nodes, to ensure that it was uniform across all treatments. The difference between the measurements of the width and depth of each stem was calculated. If a stem was round, this difference was close to zero, however if a stem was crushed flat, there was a larger difference between width and depth. Prior to cutting, random stems of the standing crop were assessed for width and depth as a reference point.

The straw was also assessed visually for crushing and recorded via digital photography. After the knots, florets and stems had been assessed; straw samples that were representative of the majority in that treatment were taken and photographed. Parameters that were noted included shredding of the straw, crimping of the straw, and whether the straw was intact or had disintegrated.

Knot Effect

The degree of crushing of knots was assessed at one location in each of the four sections within each plot. This occurred immediately after the machines had passed through. A minimum of 25 knots were assessed at each section. Random stems were selected and the knots squeezed between the thumb and forefinger. The squeezing action determined whether in fact the knot had been crushed, according to whether there was any ‘give’ or sponginess in the knot. The numbers of knots crushed and not crushed was recorded and converted to percentage (%) of knots crushed.

Floret Effect

The degree of crushing of florets was assessed at one location in each of the four sections within each plot. This occurred immediately after the machines had passed through. Random stems were selected and florets squeezed between the thumb and forefinger. The top four florets on each stem were tested, as these were generally the only florets that were maturing at the time of cutting (the oat panicle matures from the top down). A minimum of 25 florets were tested in each section. The squeezing action determined if the floret had been crushed, according to whether there was any ‘give’ or sponginess in the floret. The numbers of florets crushed and not crushed was recorded and converted to a percentage (%) of florets crushed.

Moisture Decline

The moisture decline assessment was carried out twice daily (am and pm) on all four sections of each plot. Sampling one began at 8.00 am and finished at approximately 10.00 am. Sampling two began at 4.00 pm and concluded at approximately 6.00 pm. The purpose of the two sampling times was to observe the fluctuation in moisture status in the hay, comparing moisture content following a cool night to that after a day of drying.

Ten random stems were taken from the upper region of the windrow, the windrow was then lifted up, and ten random stems were removed from the lower region of the windrow and put into the same paper bag. Sampling both areas aimed to give a representative sample, as the top of windrow was generally drier than the bottom. Having both samples provided an average for the windrow.

Samples were weighed immediately, and fresh weights recorded. Once completed, samples were allowed to continue to air dry in a shed, until room was available in a drying oven. The samples were put into a 60^{o}C oven for at least 24 hours until completely dried. Drying time reduced over the length of the project as increased drying occurred in the windrows. Once the samples were dry, they were reweighed to obtain a dry weight. This was recorded, and moisture percentage (%) calculated.

Windrow Structure

The windrow structure assessments were carried out daily from super conditioning until baling. The four sections in each plot were assessed during this period.

Height of the windrow off the ground

The height of the windrow off the ground was measured using a metre ruler. The ruler was positioned perpendicular to the windrow at ground level in the centre of the windrow. The measurement taken was the distance from the bottom of the windrow to the ground.

Overall windrow height

Windrow height was measured using a metre ruler in the centre of the windrow. The ruler was positioned perpendicular to the windrow at ground level. The total height of the windrow from the ground was measured.

Windrow Width

Windrow width was measured using a metre ruler, recording across the broadest point of the windrow. Whilst the windrows did not generally have neat edges, the width was measured using the bulk of the windrow rather than the outlying stems.

Cross Sectional area of the windrow

The windrow area was calculated from the width and height of the windrow and the height off the ground of the windrow. It is the area represented by a cross section of the windrow.
The windrow area was calculated using the formula:

Windrow Area = (Height of windrow – Height off the ground) x Width of windrow

The area of the windrow has implications on the aeration of the windrow and drying time, as well as water shedding ability.

Fresh weight of the windrow

The biomass yield was assessed once daily from the time of super conditioning until baling. A quadrant 0.5m in width was placed across the windrow, with a hedge trimmer being used to cut a 0.5m cross section out of the windrow. This section was removed and weighed on a set of digital scales, before being returned to its original location in the windrow. The weight of this section was then converted to tonne/hectare using the formula:

Biomass (t/ha) = measured weight x 4

Windrow Uniformity

A visual score was used to assess the uniformity of the windrow. Visual assessment occurred once daily from conditioning until baling. A score on a 1 to 5 scale was given to each assessed section of the windrow, with 1 being the least and 5 being the most uniform. Uniformity was assessed as:

- the windrow is the same height and width along its length
- the straw within the windrow is lying in the same direction
- the windrow will feed into the baler evenly and consistently along its length.

Windrow Climate

Relative Humidity

The relative humidity was measured once daily at each sampling section within each plot. The relative humidity was measured by placing a thermohygrometer into the centre of the windrow, and recording the reading once the machine had settled. This occurred each day from conditioning to baling.

Temperature

The temperature was measured once daily at each sampling section in each plot. Temperature was measured by placing a thermohygrometer into the centre of the windrow, and recording the reading once the machine had settled. This occurred each day from conditioning to baling.

Baling

Windrow pickup

After baling each plot was assessed for hay that had not been picked up by the baler. An insignificant amount of residual material was found, and there were no visual differences between treatments. It was therefore deemed not necessary to collect and weigh to determine actual losses of hay. Digital photos were taken of the residues that remained from each treatment.

Time from cutting to baling

The time to baling was measured in days from cutting. Baling time was governed by the grower, who regularly checked readiness to bale. Plots were deemed ready to bale when greater than 90% of the knots snapped open easily. It was initially expected that the moisture assessments would determine when baling would occur. However this measurement recorded total moisture only and did not differentiate between moisture contained in stems and that contained in knots. Moisture assessments were used as a guide only.

Climate Monitoring

A Davis Vantage Pro weather station was set up on the site prior to the trial commencing. This recorded temperature, humidity, rainfall, wind speed and direction, dew point, and barometric pressure at hourly intervals for the duration of the trial. This data was then downloaded and interpreted.

Quality Testing

Hay quality measurements were conducted via Balco Australia's quality testing systems. The feed tests were conducted by a laboratory in accordance with AFIA (Australian Fodder Industry Association) standards, and the laboratory participates in the AFIA ring testing system, which is a quality assurance program. All plots were cored according to industry standards, with the cored samples being analysed for the following parameters:

Water Soluble Carbohydrates (WSC)

Water soluble carbohydrate was analysed using Balco Australia's quality testing protocols. WSC is a measure of the total soluble sugars which are present in forage. These sugars include glucose, fructose, sucrose and fructans, and are almost completely digestible.

Acid Detergent Fibre (ADF)

Acid detergent fibre was analysed using Balco Australia's quality testing protocols. ADF estimates the cellulose and lignin content of a feed. The lower the ADF, the higher the digestible dry matter and metabolisable energy.

Neutral Detergent Fibre (NDF)

Neutral detergent fibre was analysed using Balco Australia's quality testing protocols. NDF estimates the total cell wall content in a feed, and is the most useful measure of fibre content currently available.

Digestible Dry Matter (DDM)

Digestible dry matter was analysed using Balco Australia's quality testing protocols. DDM is the percentage of the feed dry matter actually digested by animals, estimated using a laboratory method which is standardised against DDM values from feeding trials. High quality feeds have a DDM of over 65%, whilst feeds below 55% DDM are of poor quality and will not maintain liveweight even if stock have free access to it.

Hay Colour

Hay colour was objectively assessed using a scanning system as per Balco Australia's quality testing protocols. Each sample was scanned three times with the final measurement being the average of the three.

Data Analysis

Averaging & Calculations

All results measured for the windrow structure, windrow climate and moisture decline are presented as numerical averages of all the sub samples assessed. These are then used to calculate a treatment average.

Statistical Analysis

Data for quality test results and degree of crushing assessment was analysed as a randomised complete block design using Statistix 8 with analysis of variance (LSD method at 5%). Statistics have been presented as an F probability (0.05) to show significance, with LSD (0.05) values being presented for significant effects.

Economic Analysis

The overall hay delivery score and grade was determined for each plot. This was calculated by entering colour, ADF, NDF, WSC, and DDM into Balco Australia's sliding scale system for hay quality and deriving a final quality score.

Discussion of Results

Degree of Crushing

The results have highlighted significant differences between the treatments for the various parameters measured. It is important to note how each treatment was set up for each machine as per the tables in the methodology section of this report, particularly with regards to roller gap. Table 11 summaries the degree of crushing found in the study for all treatments.

Table 11: Summary of Degree of Crushing Statistical Analysis

Treatment	Stem Width	Stem Depth	Stem Difference	Knots	Florets
	(millimetres)	(millimetres)	(millimetres)	% Crushed	% Crushed
1	5.25	3.59	1.66	14.8	34.8
2	5.53	2.89	2.63	67.1	62.2
3	5.55	3.20	2.35	23.5	47.0
4	5.58	2.80	2.78	74.4	66.0
5	5.36	3.46	1.89	57.3	41.0
6	5.44	3.18	2.26	34.8	41.7
7	5.33	3.49	1.84	44.7	47.5
8	5.56	2.81	2.74	82.7	71.6
9	5.30	3.14	2.16	63.7	49.4
10	5.34	2.99	2.34	50.6	44.4
LSD (5%)	**n.s. (0.4971)**	**0.4209**	**0.6199**	**12.997**	**15.248**

There were significant differences between the treatments for stem depth, stem difference, and the percentages of knots and florets crushed. Trends are evident, as treatments 2, 4 and 8 were the most aggressive across not one but all parameters. Similarly, treatment 1 was the least aggressive across all parameters tested. Of the treatments that involved the same machine on different days, some patterns emerged. The earlier conditioning was significantly more aggressive in treatment 4 than treatment 5, and treatment 8 than treatment 9. This was not the case with treatments 6 and 7, where there was not a significant difference between the two treatment timings.

Stem Width

There were no significant differences found in stem width after conditioning (Figure 8). It was noted whilst conducting the assessment that stems tended to split when flattened, rather than remaining intact and stretching wider. This meant that the stem width did not change greatly, hence the similarity between treatments.

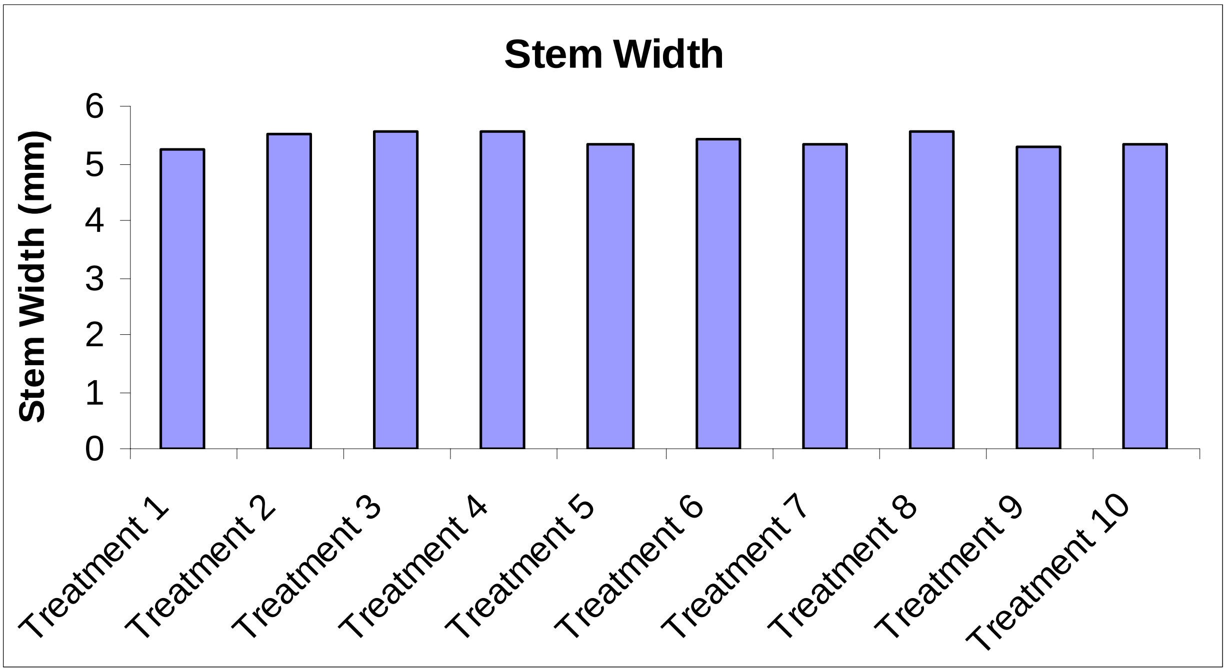

Figure 8: Stem width measurements over the treatments

Stem Depth

There were significant differences recorded between the treatments for stem depth (Figure 9). Those treatments with lower stem depth values had more aggressive treatments and hence had more flattened stems. Treatments 2, 4, and 8 left the stems the flattest. It was noted when conducting the assessment that the flatter stems tended to be split and broken. This opening up of the stem has implications for moisture loss and curing time; splitting the stem open allows more airflow and will reduce curing time.

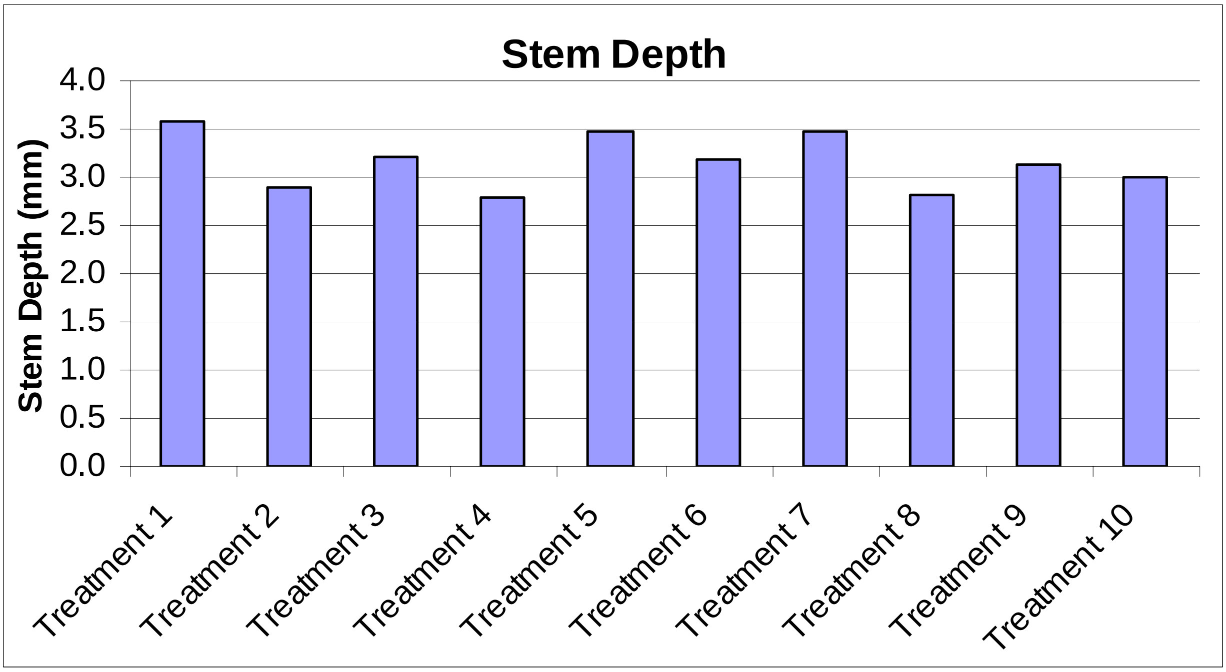

Figure 9: Stem depth measurements over treatments

Treatments 8 and 9 involved a machine that had rollers operating at different speeds. This led to a tearing action, as the hay was pulled through the rollers, which further accentuated the splitting of the stem, and contributed to reducing curing time.

Stem Difference

There were significant differences between the treatments for stem difference (Figure 10). This followed the same pattern as stem depth, with treatments 2, 4 and 8 having the highest stem difference. This was an indication that the corresponding treatments were crushing the stems severely, resulting in a large difference between the width and depth of the stem. Samples of stems were assessed prior to cutting and conditioning, and these were found to have stem differences close to zero (they were quite round). This indicates that the closer to zero the stem difference, the less aggressive the conditioning treatment.

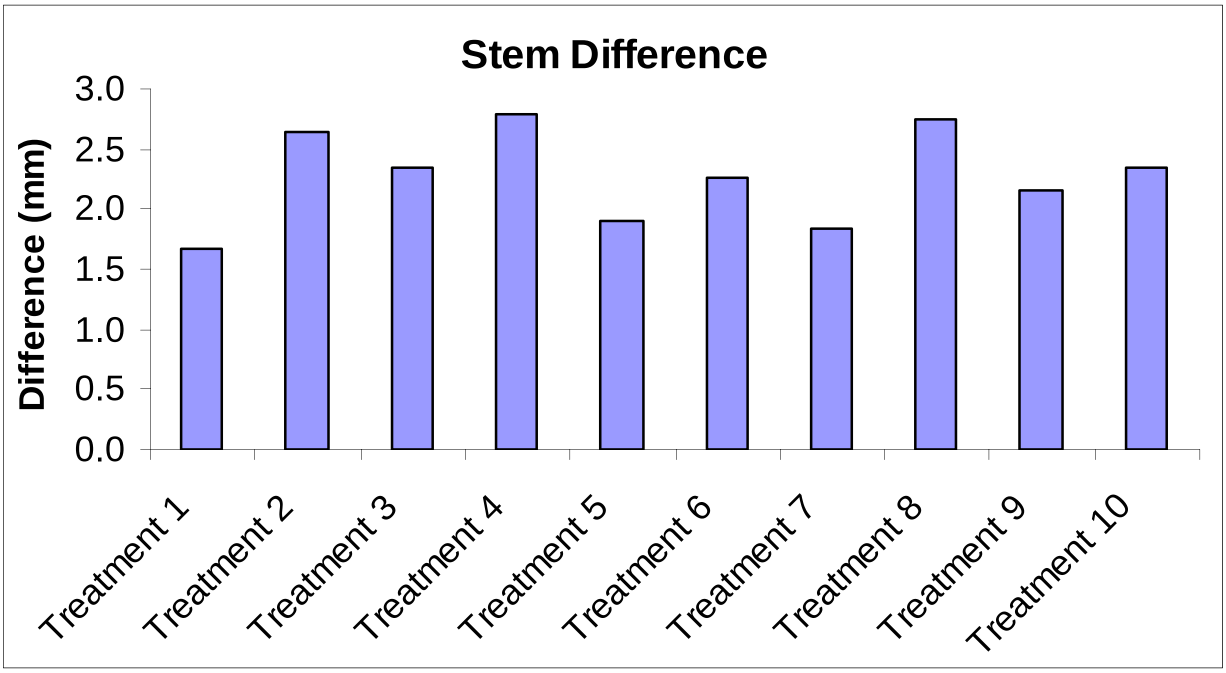

Figure 10: Stem difference measurements across treatments

A pattern was observed of the treatments involving the same machine on different days. Those treatments used earlier after cutting had higher stem differences, indicating the earlier conditioning was crushing the stems more than the later timing. This was apparent when comparing treatment 4 with treatment 5, treatment 6 with treatment 7, and treatment 8 with treatment 9. This may be a result of stems being moister earlier on in the drying process, and more malleable and easily flattened. As the stems dried out they were less malleable and more likely to spring back into place after conditioning.

Straw Effect

The straw effect graph (Figure 11) illustrates the relationship between stem depth, width and difference. It shows that despite there being no differences between stem widths, stem depth was still variable and this led to the stem differences (roundness) discussed previously.

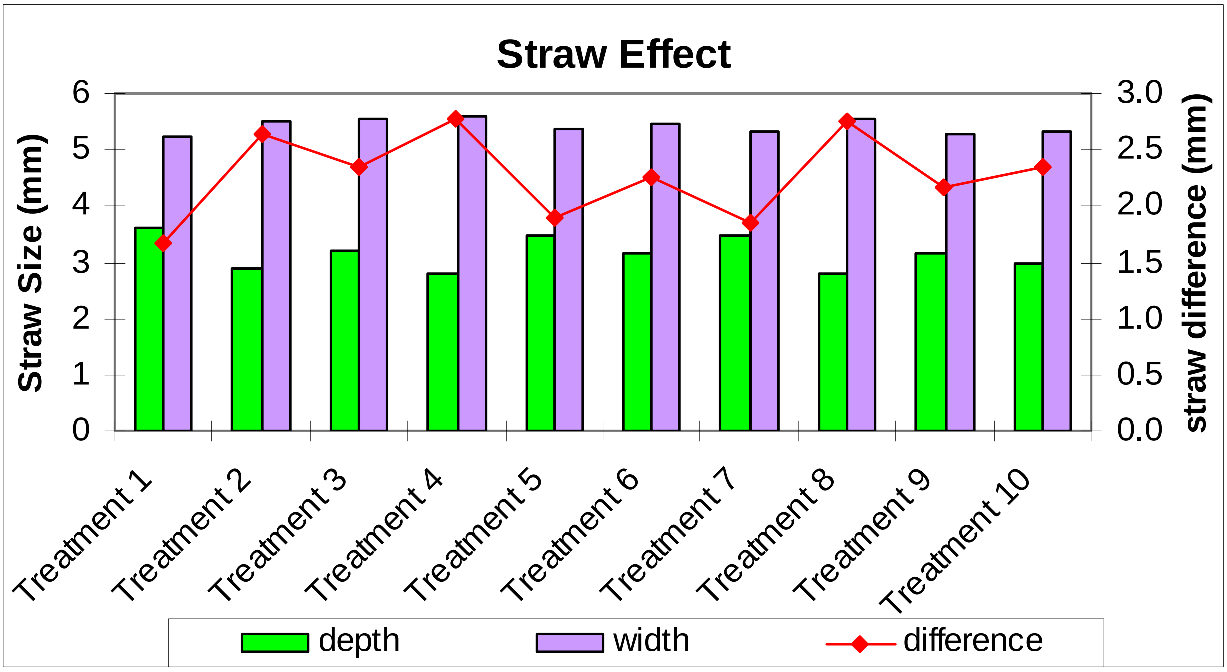

Figure 11: Relationships between straw characteristics across treatments

Knot Effects

There were significant differences between the treatments in the number of knots crushed (Figure 12). Crushing of knots is important for curing, as the knots tend to be the last part of the plant to lose moisture and hence determine baling time. By crushing the knots and opening them up for air and heat to get in, curing time can be reduced.

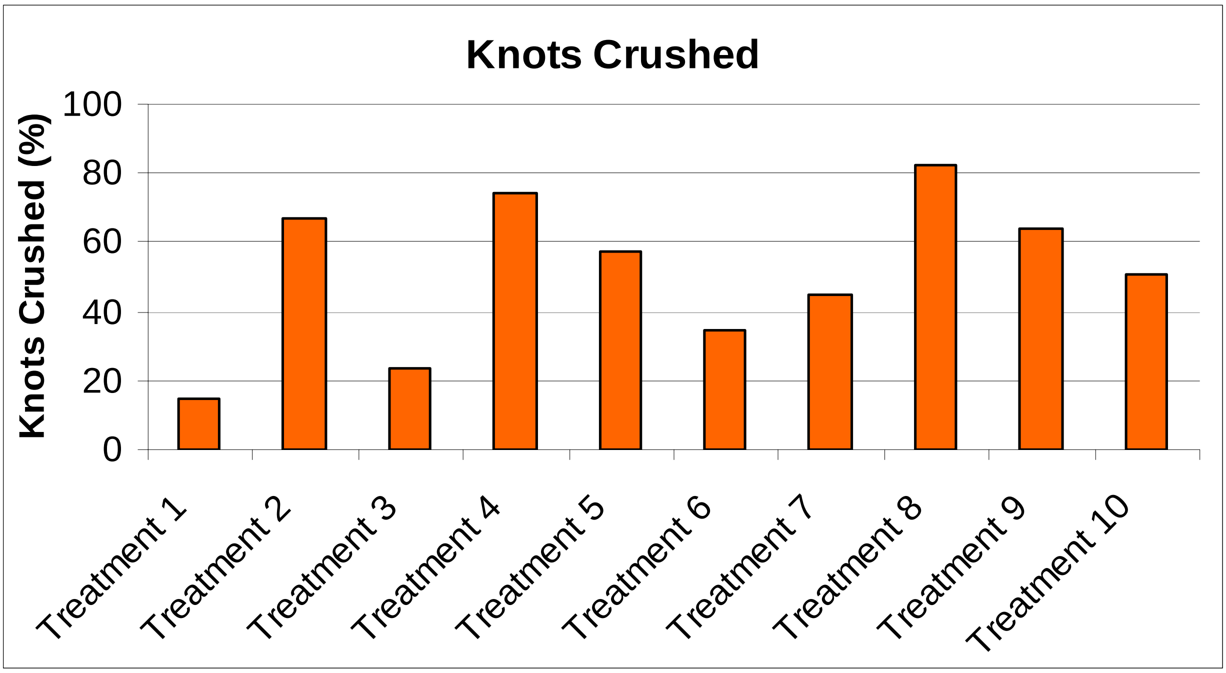

Figure 12: Percentage of knots crushed across treatments

As shown by figure 12, treatment 8 was the most aggressive on knots, followed by treatments 2, 4, and 9. Treatment 1 was the least aggressive in crushing knots. There was no distinctive pattern about whether conditioning earlier or later crushed more knots; the differences were more obvious between the actual mechanism that was used.

Stem Photography

The photograph of stems representative of treatment 1 shows that very little structural damage has occurred to the hay (Figure 13). The stems are intact, quite round, and knots are generally not damaged.

Figure 13: Representative stems from treatment 1

The photograph of stems representative of treatment 2 shows some flattening of stems (Figure 14). The stems are no longer round, and knots have been flattened and crushed to some degree.

Figure 14: Representative stems from treatment 2

The photograph of stems representative of treatment 3 shows that the stems remain intact (Figure 15). There is a little flattening of the stem, and some crimping has occurred, however the knots are generally intact and have not been crushed.

Figure 15: Representative stems from treatment 3

The photograph of stems representative of treatment 4 shows a degree of flattening (Figure 16). The stems have split in places, there is some definite crimping, and the stems are no longer round.

Figure 16: Representative stems from treatment 4

The photograph of stems representative of treatment 5 shows some flattening and crimping of the stems (Figure 17). There has also been damage to the straw, and breakage of the straw which may be a result of the hay being drier when it is conditioned.

Figure 17: Representative stems from treatment 5

The photograph of stems representative of treatment 6 shows that some splitting of the stem has occurred (Figure 18). There is also crimping of the stem, and a degree of flattening. Some knot damage has been inflicted, although this is only evident on some of the knots.

Figure 18: Representative stems from treatment 6

The photograph of stems representative of treatment 7 shows a degree of splitting in the straw (Figure 19). There is also crimping of the straw, and some breakage. The stems are not round, although not as flat as some other treatments. The knots appear relatively intact.

Figure 19: Representative stems from treatment 7

The photograph of stems representative of treatment 8 shows significant flattening of the stems (Figure 20). There has also been a lot of splitting, crushing of the knots, and twisting of the straws. This appears the most aggressive treatment.

Figure 20: Representative stems from treatment 8

The photograph of stems representative of treatment 9 shows that the straw is quite twisted and damaged (Figure 21). There has been splitting of the stems, and they have been flattened and broken in places.

Figure 21: Representative stems from treatment 9

The photograph showing stems representative of treatment 10 shows a degree of flattening (Figure 22). The stems are no longer rounded, and have begun to split in places. The knots appear relatively intact.

Figure 22: Representative stems from treatment 10

Floret Effects

There were significant differences between the treatments for the number of florets crushed (Figure 23). Treatments 8, 4 and 2 were the most aggressive, crushing the most florets. There was no distinct pattern as to the timing of conditioning and its effect on crushing florets. The more aggressive treatments were observed to have disintegrated the floret on occasions, rather than simply crushing it. This was particularly evident where machines had different roller speeds and a tearing action.

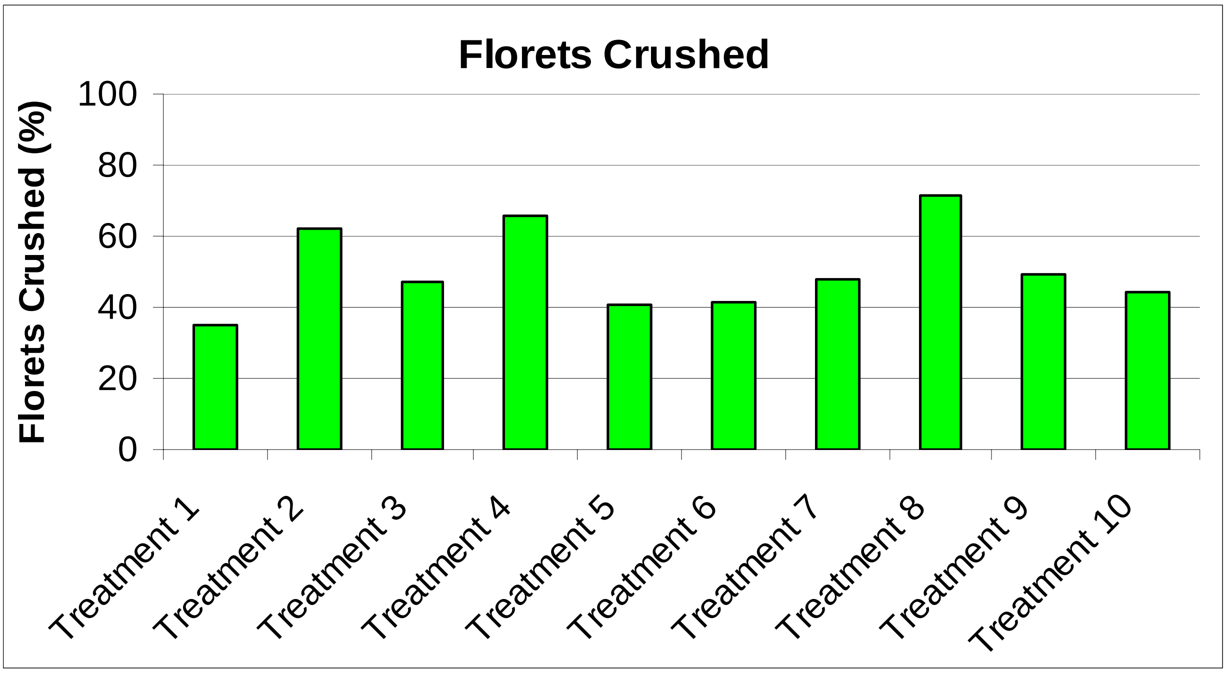

Figure 23: Percentage of florets crushed across treatments

Florets have the potential to form grain in the windrow or bale if cutting is slightly late. This can lead to problems with vermin, as well as transferring seeds from one property to the next, which may be a quarantine issue. It is for these reasons that crushing of the floret and stopping grain formation is important. The floret will also lose moisture more rapidly once it has been conditioned, because if it has been crushed there is more air penetration to dry it out.

Moisture Decline

There was variation between the treatments in terms of moisture content over the course of the trial. This was unable to be analysed statistically due to the nature of the data, so conclusions are drawn from the trends evident in Table 12 and Figures 24-29.

Table 12: Moisture % of the various treatments for am and pm sampling

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
Pre Cutting	85	85	85	85	85	85	85	85	85	85
0 - pm	71	68	70	69	69	70	61	69	69	68
1 - am	61	58	61	60	40	61	53	63	58	62
1 - pm	38	38	37	44	39	42	38	43	39	43
2 - am	38	31	40	35	36	32	29	38	32	35
2 - pm	30	28	33	20	25	26	23	22	27	26
3 - am	30	27	30	25	28	29	29	27	29	29
3 - pm	21	20	17	8	17	16	17	10	20	16
4 - am	30	30	30	27	29	27	29	26	29	29
4 - pm	11	6	12	5	9	9	9	10	8	8
5 - am	21	19	21	19	18	18	25	17	18	20
5 - pm	9	8	9	5	6	7	9	6	6	6
6 - am	21	21	21	23	21	22	20	20	21	22
6 - pm	9	9	9	7	7	8	8			6
7 - am	17	16	17	17	16	16	16			16
7 - pm	7	6	7	5	6	6				5
8 - am	11		12							11
8 - pm	6		9							6
9 - am	21									
9 - pm	8									
10 - am	12									

There was a distinct diurnal fluctuation for moisture content across all treatments. This was due to the influence of sampling time. Each day the plots were sampled in the morning and evening, and the morning samplings tended to return higher moisture readings due to the dampness that the hay had experienced overnight. This moisture was then lost during the day as hay was exposed to breeze and warmer temperatures, which led to the evening samplings having lower moisture content.

There was a sharp decline in moisture initially. However, by day 5 all treatments had been performed and the moisture began to plateau (Figure 24). It is evident that the evening sampling moisture readings were remaining very similar, yet the morning readings continued to get lower and lower after

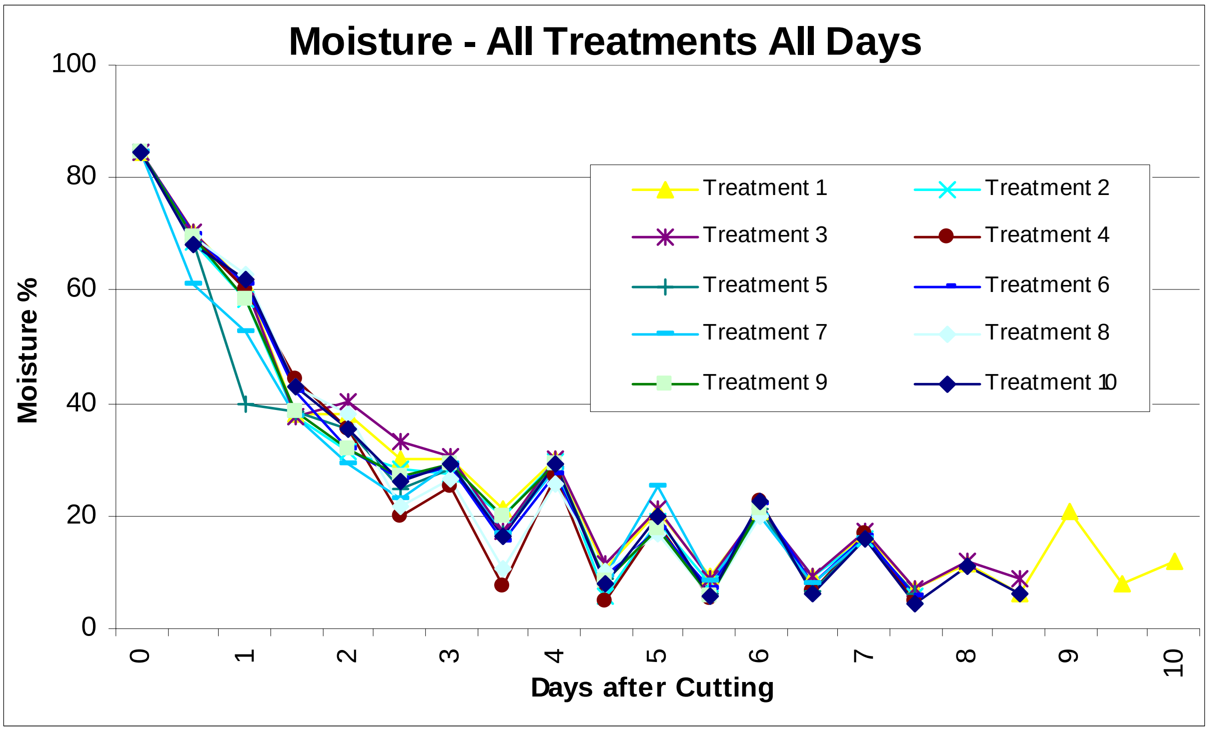

Figure 24: Moisture decline profile of all treatments

day 5 (Figure 25). This would imply that checking the hay in the evening may not give a true representation of how dry the hay is, because there was no difference between the evening samplings after day 4 (Figure 26).

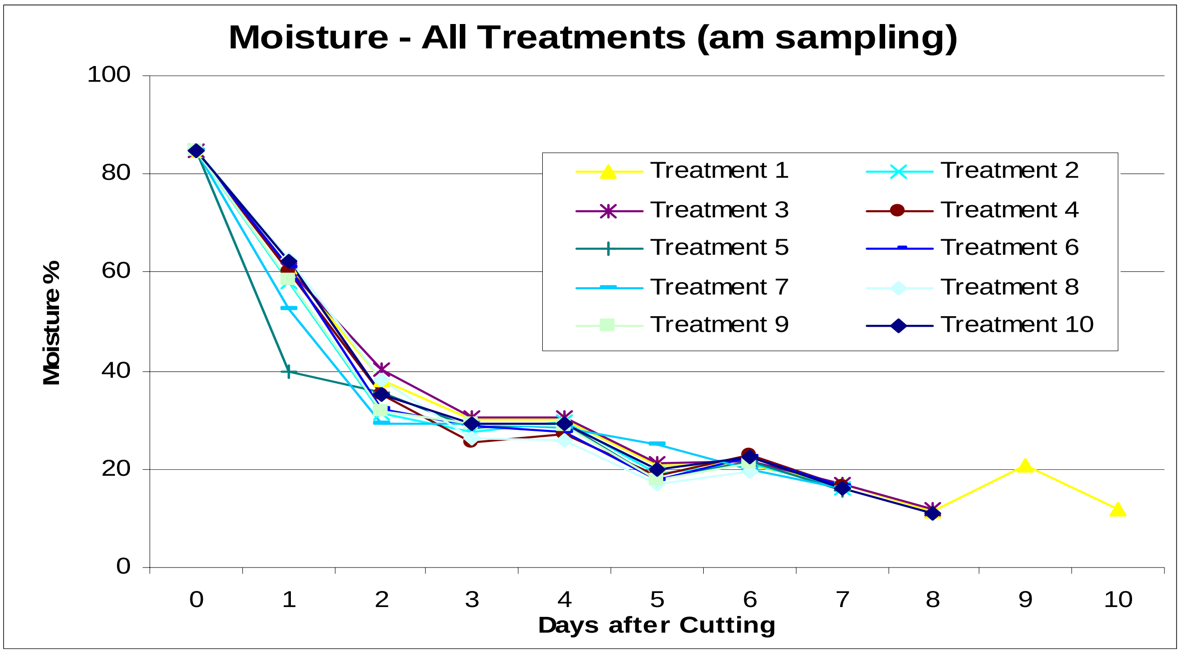

Figure 25: Moisture decline in AM samplings across all treatments

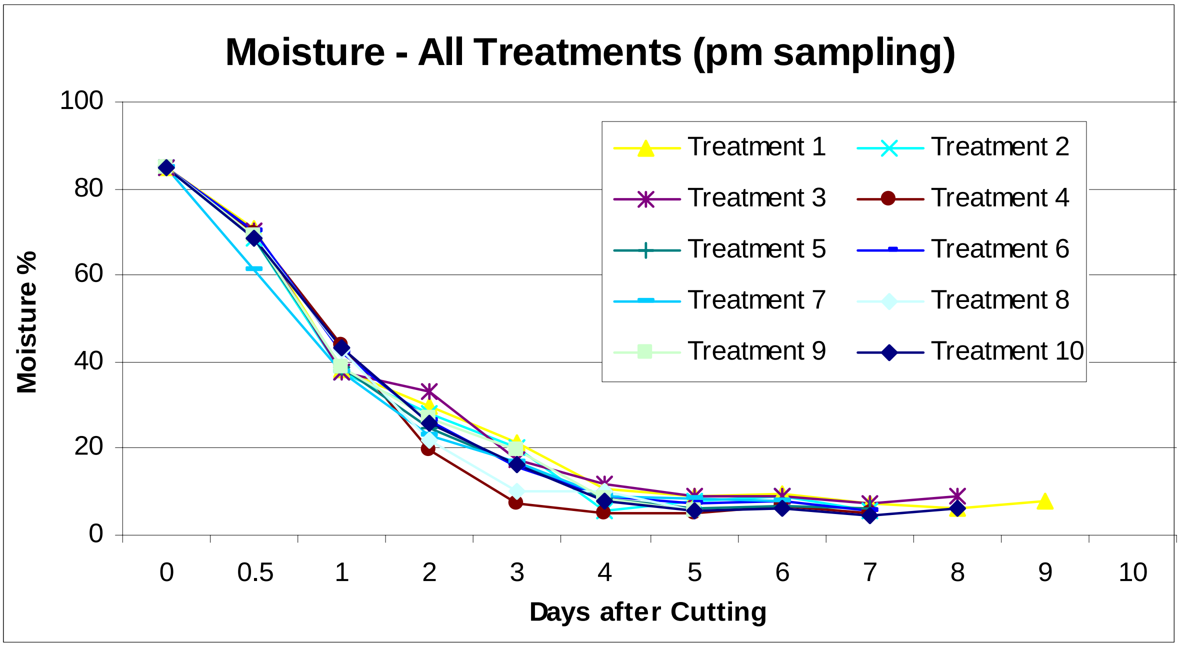

Figure 26: Moisture decline in PM samplings from all treatments

It is possible that after day five the evening reading was at a level where moisture, perhaps other than in knots themselves, was not going to change. In other words it had reached a "dryness plateau" that it was unable to dry beyond. The only moisture left to lose was in the knots.

When looking at all treatments together, it is clear that treatments 4 and 8 arrived at their lowest moisture content the quickest of all treatments. They were already at 10% or less after 3 days, which was before treatments 5, 7 and 9 had been super-conditioned. This indicates that earlier super conditioning has the potential to dry hay quicker than later operations.

Of the all in one cut and condition treatments, treatment 2 dried down the quickest (Figure 27). It was also the first of these three treatments to be dry enough to bale. Treatment 2 also had the highest degree of crushing of these treatments, which may have influenced moisture loss. Treatment 1 was the mower conditioner, whose dry down rate was not that dissimilar to treatment 3.

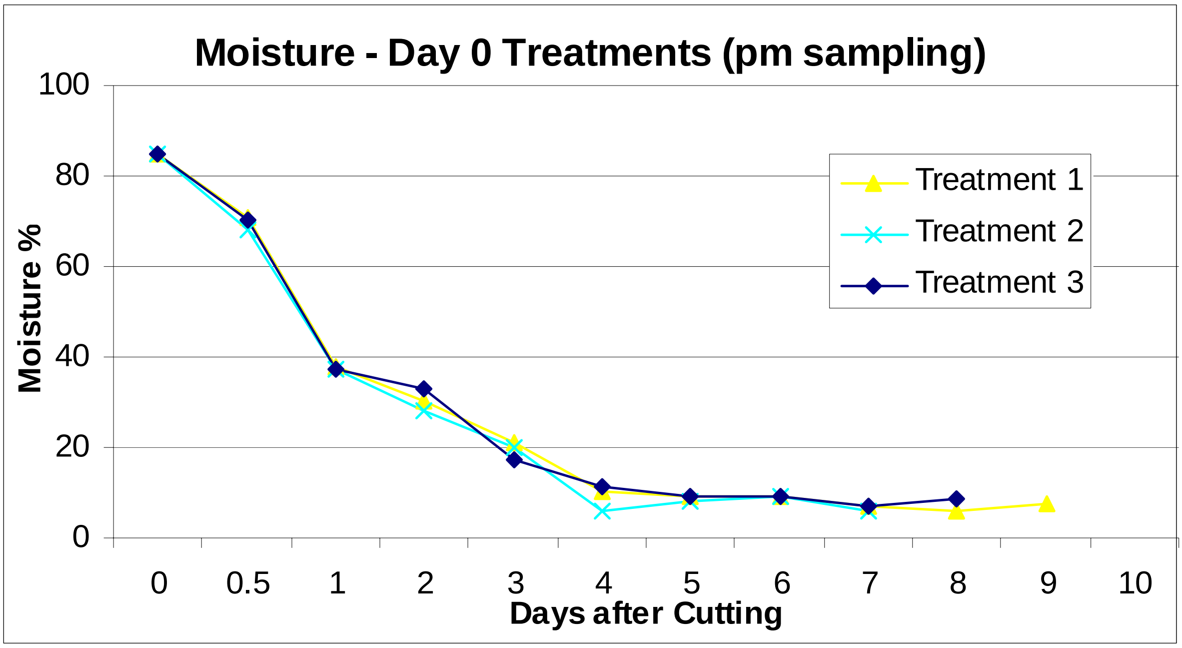

Figure 27: Moisture decline in PM samplings from self propelled treatments

Treatments 4 and 8 lost moisture the fastest out of the day 2 treatments (Figure 28). They were also the most aggressive of these treatments in terms of crushing the straw and crushing knots and florets. This would indicate that the more aggressive the treatment is on the straw, the faster it will lose moisture.

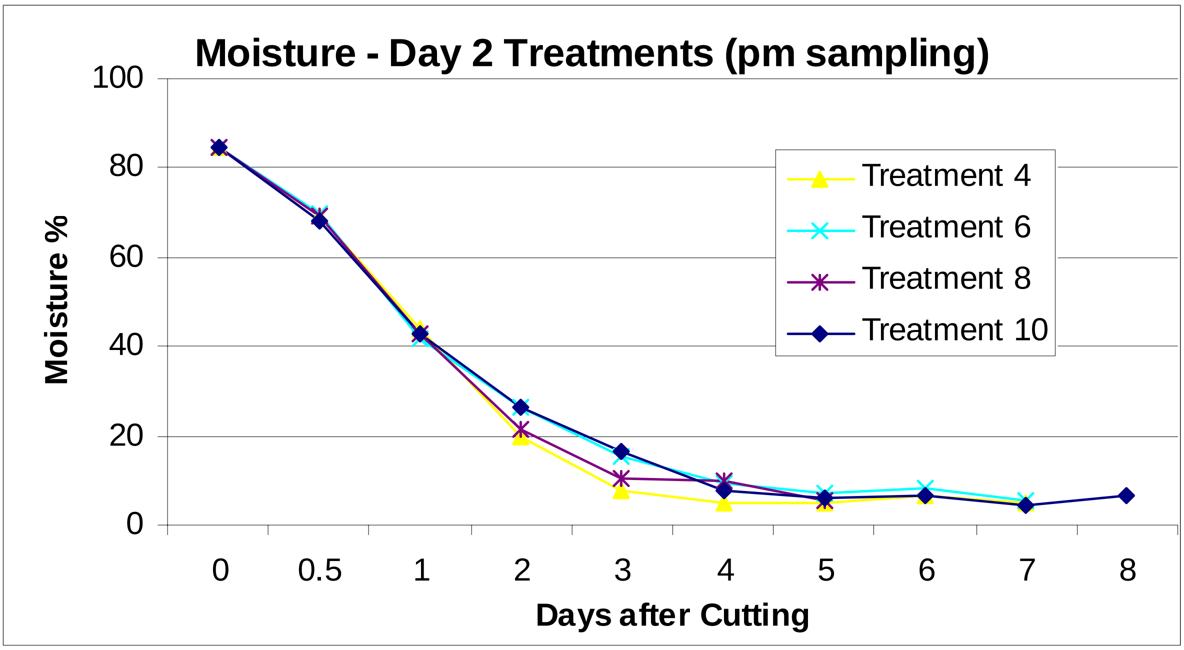

Figure 28: Moisture decline in PM samplings across day 2 treatments

There is little difference in the moisture loss patterns of the treatments which were carried out on day 4 (Figure 29). The only difference became obvious on day 5 when treatment 9 had slightly lower moisture than the remainder of the group. This treatment was baled first.

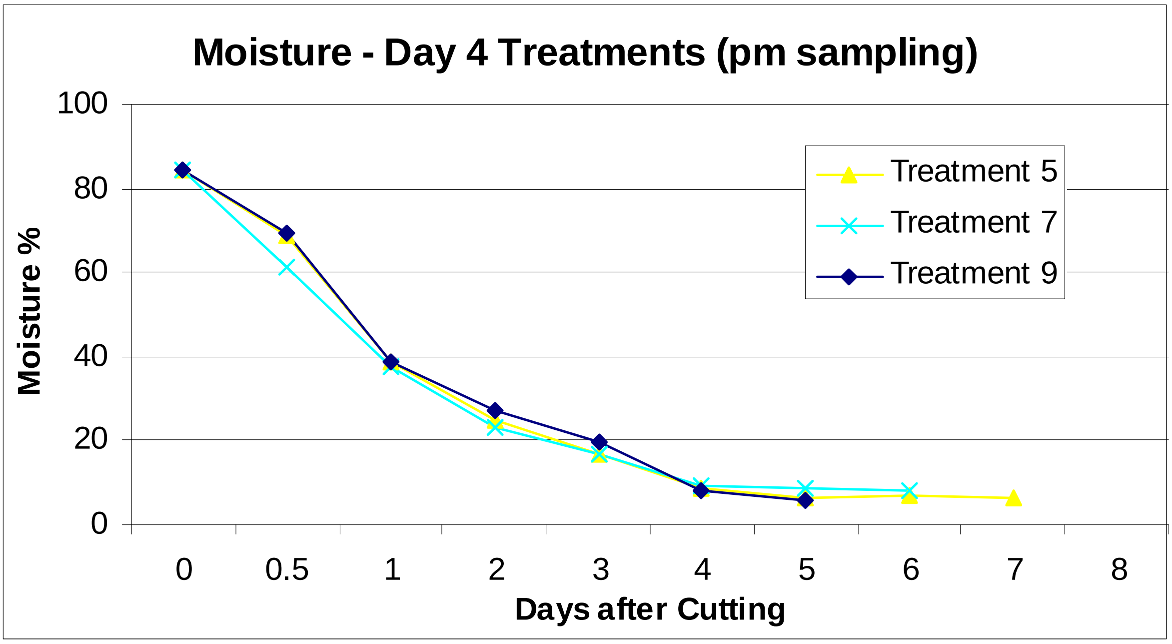

Figure 29: Moisture decline in PM samplings across day 4 treatments

Windrow Structure

The results highlighted slight differences between the treatments for the various parameters measured. However it should be noted that windrow structure can vary considerably depending on the way that rear discharge chutes on the various machines are set up. Most machines can be adjusted so that this can be influenced. In interpreting these results it is important to note how each machine was set up for the individual treatments. Refer to the tables in the methodology section of this report (pages 10-19).

Height of the windrow off the ground

The windrow height off the ground was affected by the structure of the material left below the row (Table 13; Figure 30). Where the crop had lodged the windrow was positioned on the surface of the soil allowing movement of moisture into the drying material, and reducing airflow. Where lodging was not an issue the remaining structure left the windrow positioned above the ground.

The super conditioning operation for treatments 4 to 10 inclusive involved picking up the windrow, treating it and then placing it back onto its original location, utilising the same structural material that it had previously been resting on. Table 13 gives no heights for days 0 to 3 for treatments 4 to 10. Until the super conditioning operation occurred height from the ground was as per treatment 1 (given that these rows were also mower conditioned with the same machine before other treatments were then applied).

Table 13.Average data results for the height of the windrow off the ground.

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	11.00	10.50	6.94							
1	12.13	12.13	10.63							
2	10.13	10.19	9.69	10.50		10.25		11.13		9.13
3	8.81	8.63	6.94	9.00		10.88		10.44		9.63
4	9.96	9.94	9.75	9.88	9.75	11.69	10.56	11.44	10.94	11.19
5	9.44	10.06	8.56	8.00	11.06	10.75	12.38	10.00	10.38	8.31
6	10.06	10.94	9.44	9.44	11.38	11.13	10.75			9.56
7	8.50	9.00	7.63							7.75
8	10.75									

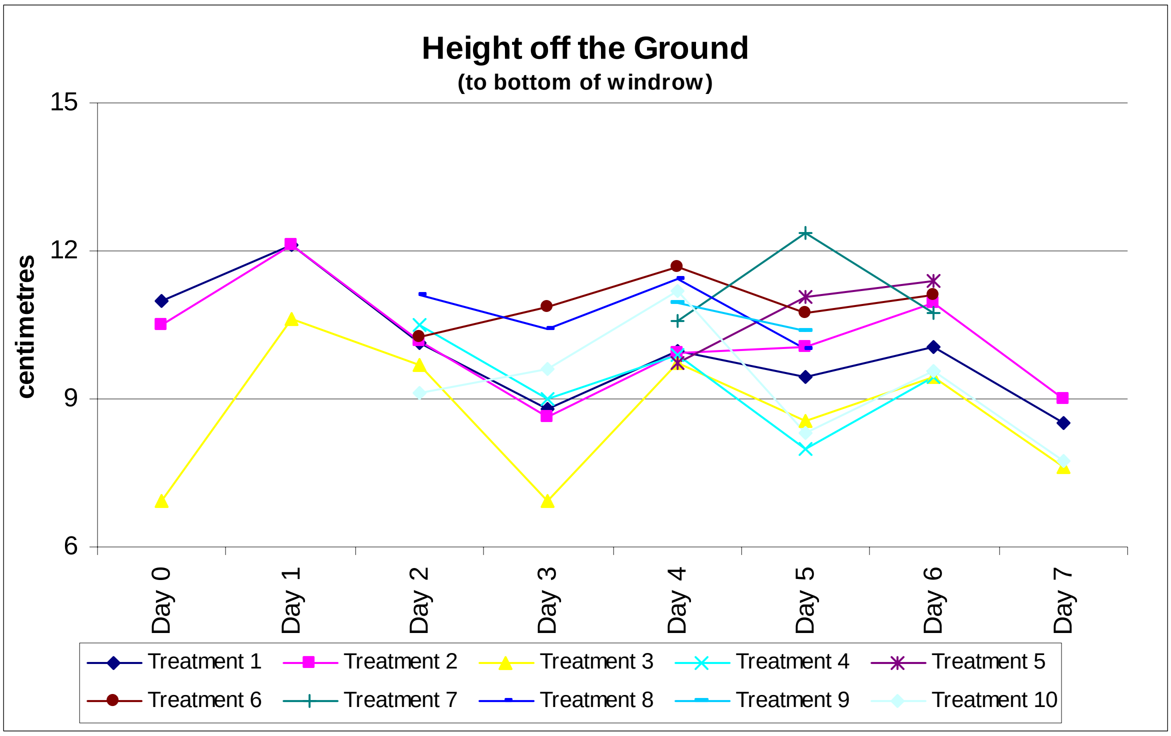

Figure 30: Height Off the Ground for all treatments

The dense windrow structure of treatment 3 resulted in a larger weight per area and as a result the windrow was positioned closer to the ground. Height of cutting may also have been a factor, because treatment 3 was cut with a machine with a discbine front, which appeared to cut cleaner and lower than the other machines (for more discussion refer to later in the report). Treatments conditioned at day 2 and day 4 allowed windrows to be placed higher, with the height then being maintained (Figure 32 and 33). It is assumed that the lighter weight of material contributed to this. In comparison day 0 treatments exhibited a steady decline in height. These heights are mainly determined by the height of cutting and the way the windrow is placed back onto the remaining structure.

The day 0 treatments trend in a very similar manner with a gradual decline over time (Figure 31). Treatment 3 is consistently a smaller distance from the ground compared to treatments 1 and 2. Treatment 2 over time showed an increase in the height off the ground. It is thought that as the material dried its weight decreased. There was no physical change that occurred to lift this height.

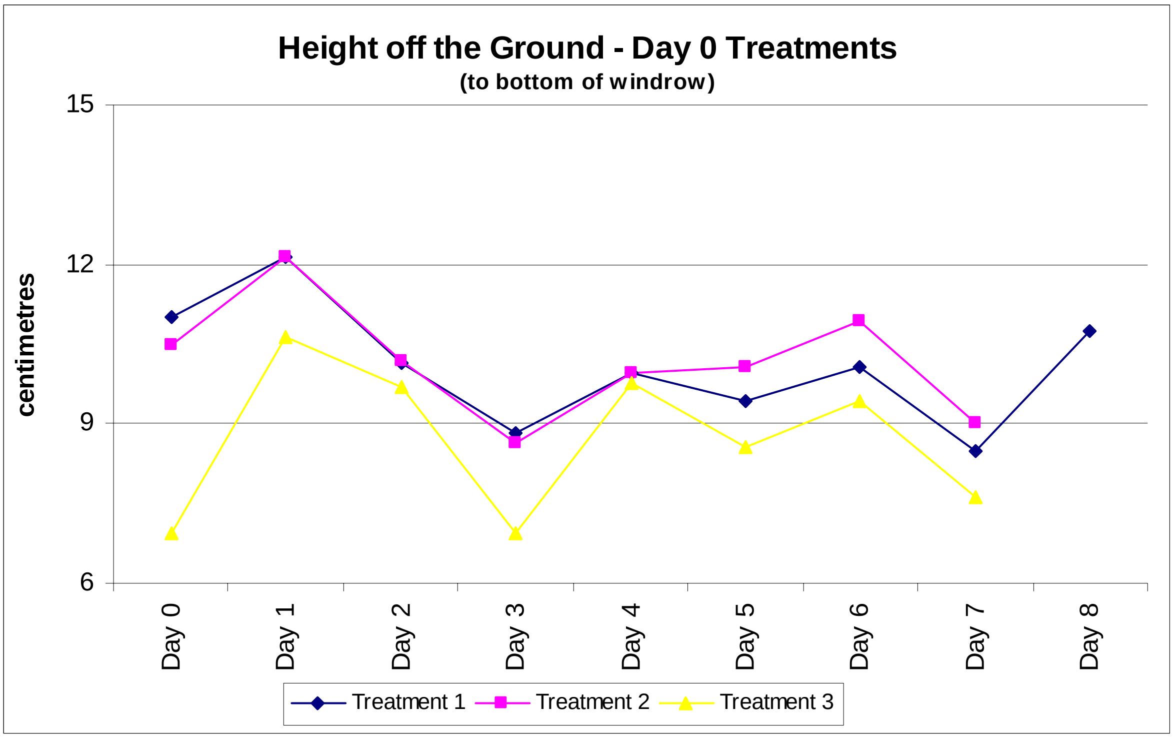

Figure 31: Height Off the Ground for all day 0 (self propelled) treatments

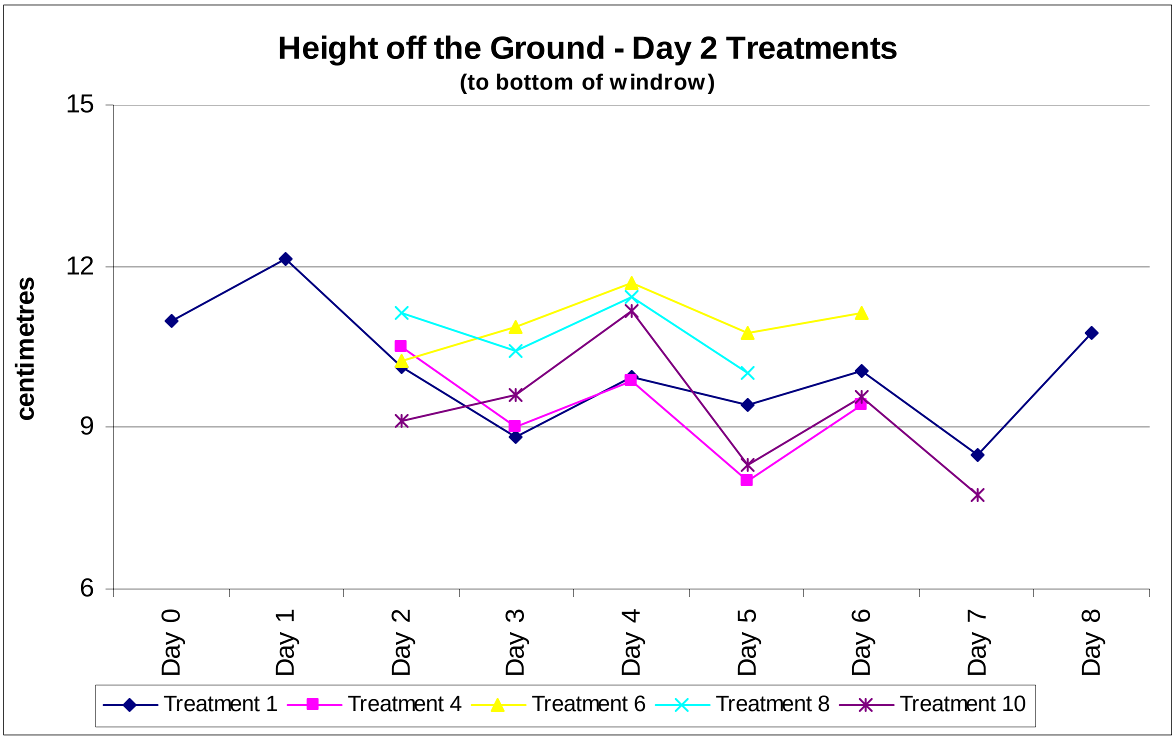

Figure 32: Height Off the Ground for all day 2 treatments compared to treatment 1

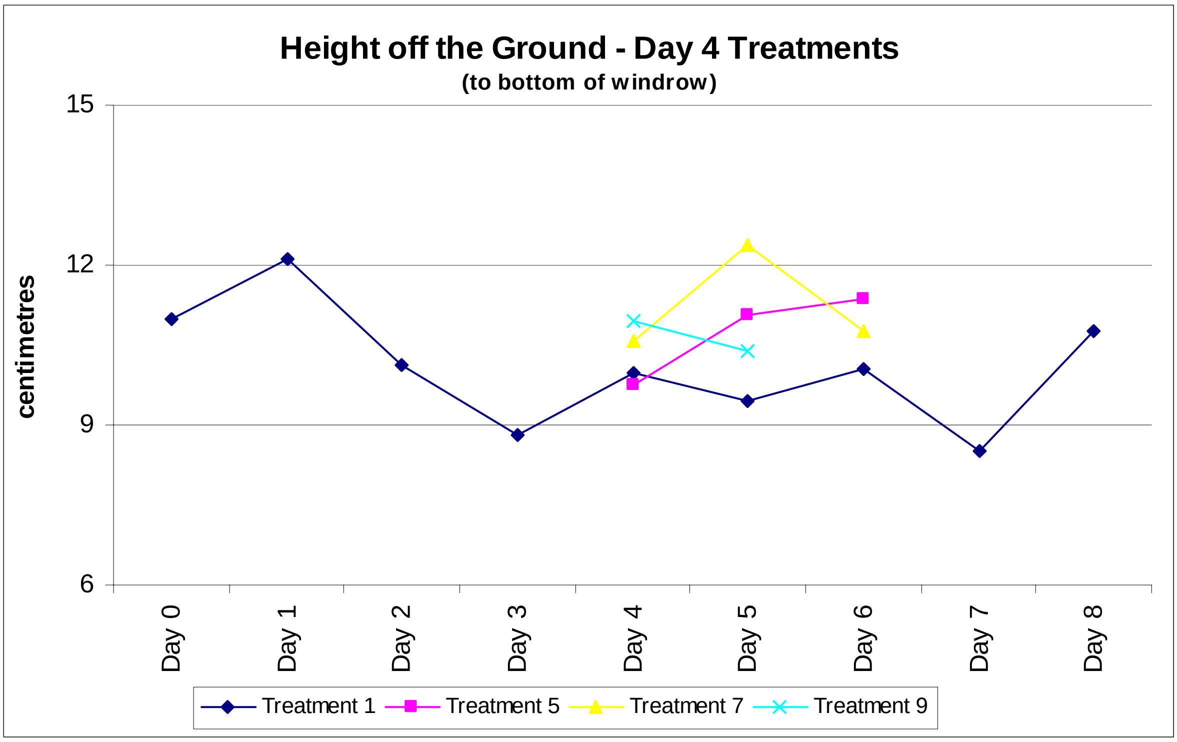

Figure 33:Height Off the Ground for all day 4 treatments compared to Treatment 1

After super conditioning all treatments left the windrows higher off the ground than the standard cutting treatment. Treatments 4 and 10 moved closer to the ground over time as the windrow settled, taking a 2-3 day timeframe for this to occur. If rain had occurred this may have been a significant factor. Treatments 6 and 8 maintained a fairly uniform height from the time the treatment occurred until baling.

All day 4 treatments lifted the windrow height further off the ground than for treatment 1 and were all baled within 2 days of the treatments. The short time period to baling does not allow a lot to be determined from these treatments.

Overall windrow height

The windrow height was contingent mainly on the pattern in which material was positioned after treating the hay, as determined by the configuration of the rear discharge flaps and the dryness of the material (Table 14; Figure 34). Treatments 4 and 5 hit the rear flap and fell to the ground. Treatments 8 and 9 layered the material in an upright biscuit like manner within the finished windrow, whilst all other treatments were projected out and onto the ground without a mechanism to slow the material as it was discharged from the machine. Table 14 gives no heights for days 0 to 3 for treatments 4 to 10. Until the super conditioning operation occurred height from the ground was as per treatment 1 (given that these rows were also mower conditioned with the same machine before other treatments were then applied).

Table 14. Averaged Data Results for the Overall Windrow Height.

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	41.50	37.75	36.19							
1	34.19	34.88	33.69							
2	34.56	34.00	33.00	32.25		40.63		37.75		34.00
3	31.81	33.75	29.69	34.06		38.81		38.38		33.81
4	31.38	32.00	29.88	31.69	36.88	36.75	46.06	37.06	37.13	32.00
5	32.44	30.63	28.81	34.31	38.44	38.06	40.69	35.50	37.38	30.81
6	32.50	31.25	30.13	31.00	35.13	36.75	38.00			29.81
7	32.81	32.44	31.50							28.69
8	33.00									

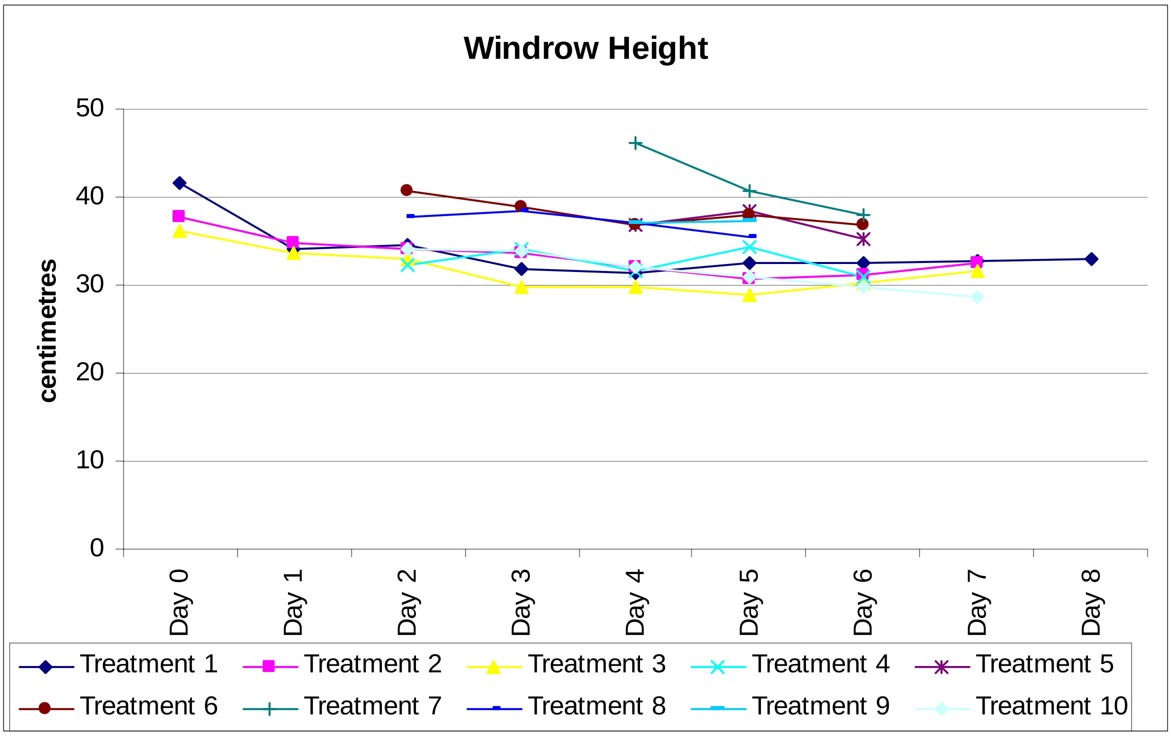

Figure 34: Windrow height overall for all treatments.

All treatments maintained a uniform windrow height once the treatment had occurred. The day 0 treatments showed a slight reduction over the first one to two days and then plateau out as material dries. Treatment 4 and treatment 10 had no influence on windrow height, remaining comparable to the day 0 treatments. All other treatments conducted on day 2 and day 4 increased the overall windrow height and maintained this increase through to baling, with the magnitude of the increase being 5-10cm.

Windrow Width

Until the super conditioning operation occurred, width was as per treatment 1 (given that these rows were also mower conditioned with the same machine before other treatments were then applied). Table 15 gives no widths for days 0 to 3 for treatments 4 to 10. The results indicate a large variation between treatments as a result of the width of the side discharge flaps on each machine rather than due to the actual super conditioning process itself (Table 15; Figure 35). In most instances considerable adjustment is available, enabling the row to be narrowed or expanded depending on operator setup. This adjustment is critical to influencing the final result. A wider row can aid in reducing drying time but can expose more material to direct sunlight which may cause a decline in hay colour. Alternatively, if the row is altered so it is narrower then air flow may be restricted and drying time can be increased. This effect was evident with the comparison between treatments 2 and 3, with treatment 3 having a tightly bound, narrow windrow that took longer to be ready to bale.

Table 15. Averaged Data Results for Windrow Width.

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	164.69	154.06	129.06							
1	160.13	144.31	126.25							
2	159.69	139.38	124.69	146.25		117.19		127.81		158.44
3	156.00	145.81	123.19	144.00		122.13		128.38		165.88
4	159.69	140.94	129.69	150.00	152.19	121.56	120.94	126.25	134.19	159.38
5	163.13	138.75	130.00	150.94	156.56	127.19	126.88	130.63	135.00	155.63
6	163.13	147.19	130.50	149.75	150.75	125.94	121.38			160.56
7	152.81	138.75	121.38							156.56
8	160.63									

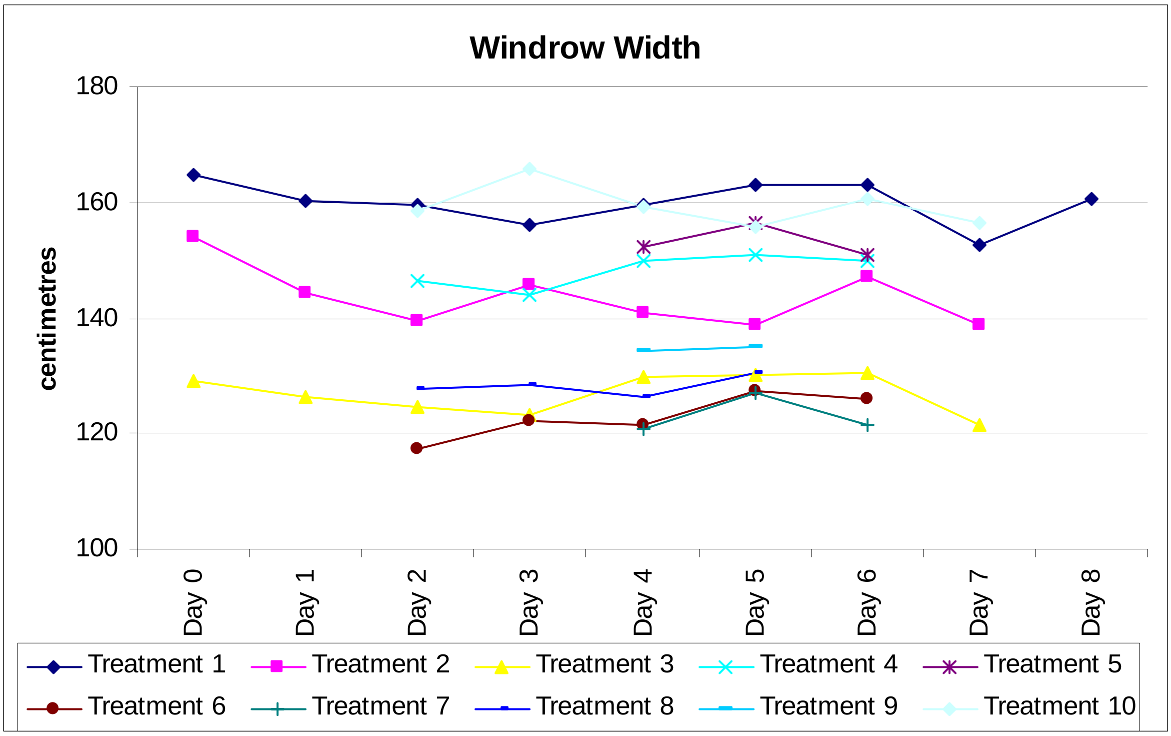

Figure 35: Windrow width for all treatments

Cross Section area of the windrow

Until the super conditioning operation occurred, the cross section was as per treatment 1 (given that these rows were also mower conditioned with the same machine before other treatments were then applied). Table 16 gives no results for days 0 to 3 for treatments 4 to 10. The results in Table 16, are a calculation using the previous three assessments (height off ground, height and width) to determine a two dimensional area if the windrow was cut at right angles to the ground. The cross section area is an indication of the density of each treatment. A smaller area like treatment 3 is more compact than treatment 5, which is more open. This effect is due to the width and height of the row and how the super conditioner projects the material out of the rear of the machine to create the structure that holds the windrow together. The overall outcome is that the super conditioning process has reduced the windrow dimensions with an ideal being about 3500cm² for this hay crop and yield. Areas below 3500cm² that were super conditioned took longer to dry as did the non-super conditioned material with a slightly larger cross sectional area.

Table 16. Averaged Data Results for the Cross Section Area of the Windrow in centimetres².

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	5024	4185	3777							
1	3531	3287	2914							
2	3918	3319	2907	3177		3554		3406		3947
3	3587	3666	2804	3621		3413		3583		4026
4	3412	3113	2608	3272	4136	3041	4292	3235	3512	3322
5	3757	2888	2624	3963	4285	3477	3595	3328	3644	3498
6	3663	2992	2700	3231	3588	3218	3309			3251
7	3715	3245	2895							3274
8	3569									

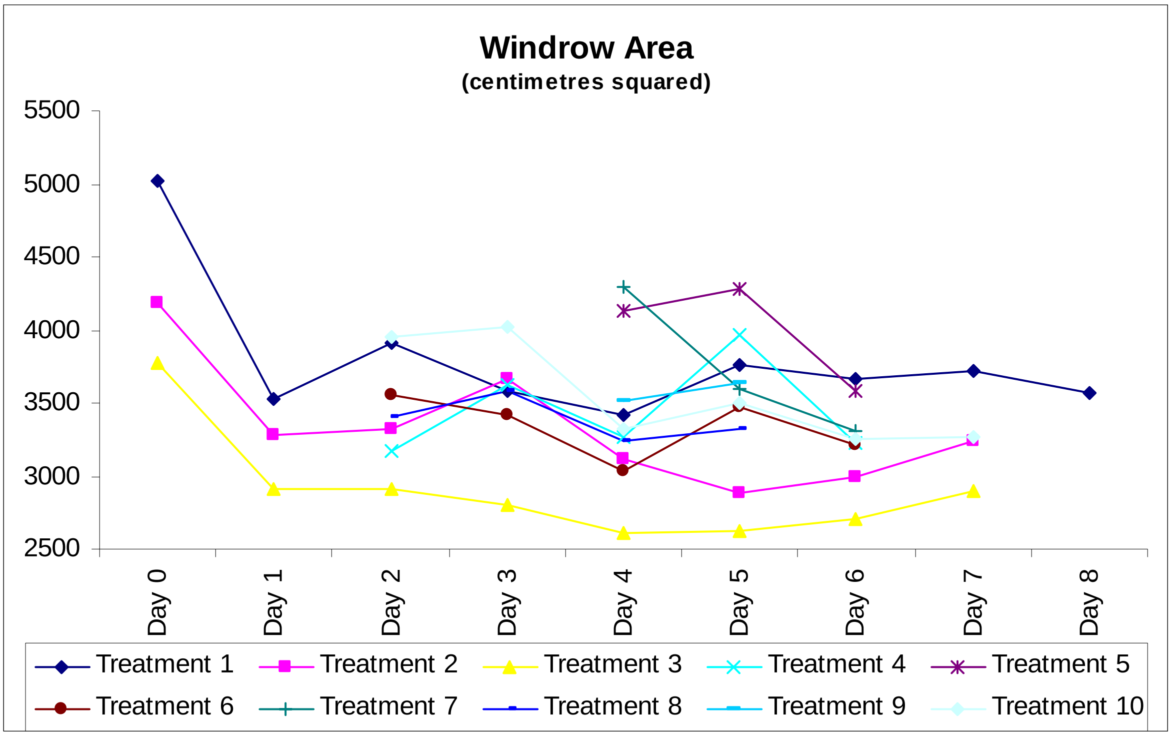

Figure 36: Windrow area for all treatments

Figure 36 shows all super conditioning treatments provided a cross sectional area smaller than treatment 1 (considered as the standard for this trial as it is not super conditioned). The only treatments with a greater area were treatments 5 and 7, and they were also the only treatments to indicate a considerable decline in area by the time of baling. The majority of treatments have provided a final area of approximately 3500cm² and have maintained this from the time of the treatment occurring through to baling.

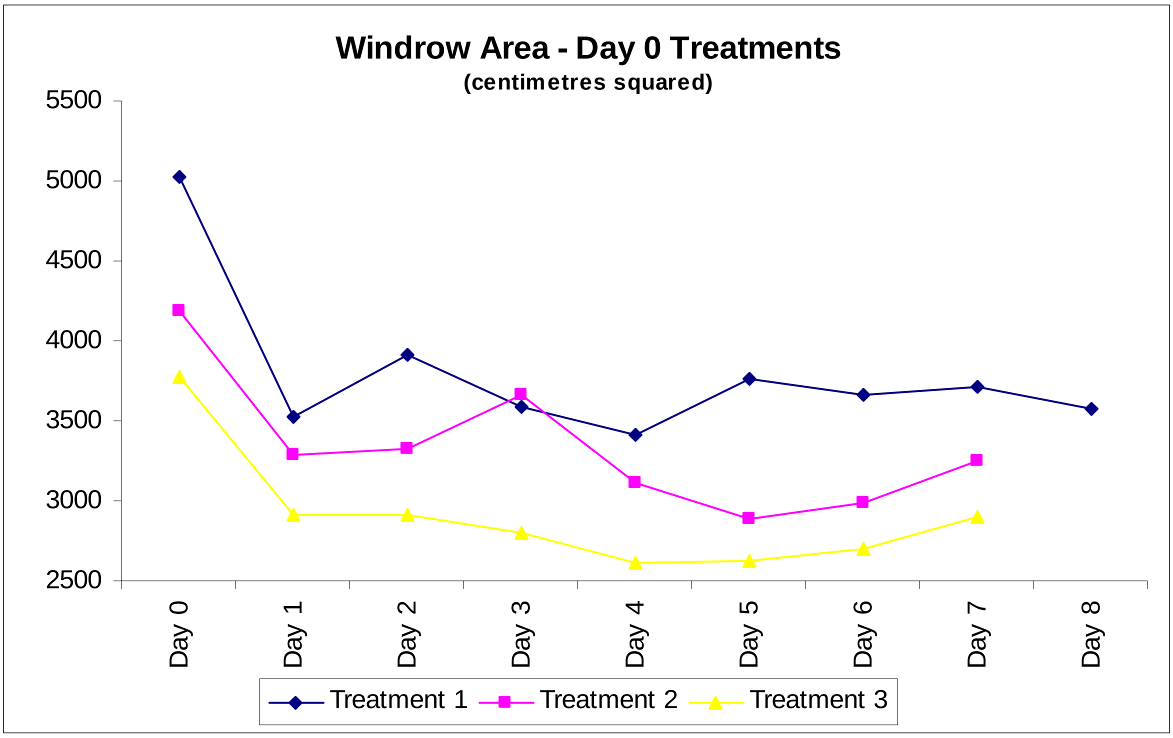

Figure 37: Windrow area day 0 (self propelled) treatments

The all in one operations of cutting and super conditioning provided a more compact windrow (Figure 37). The machine set up for treatment 3 produced a very compact windrow, due to the positioning of rear and side discharge flaps.

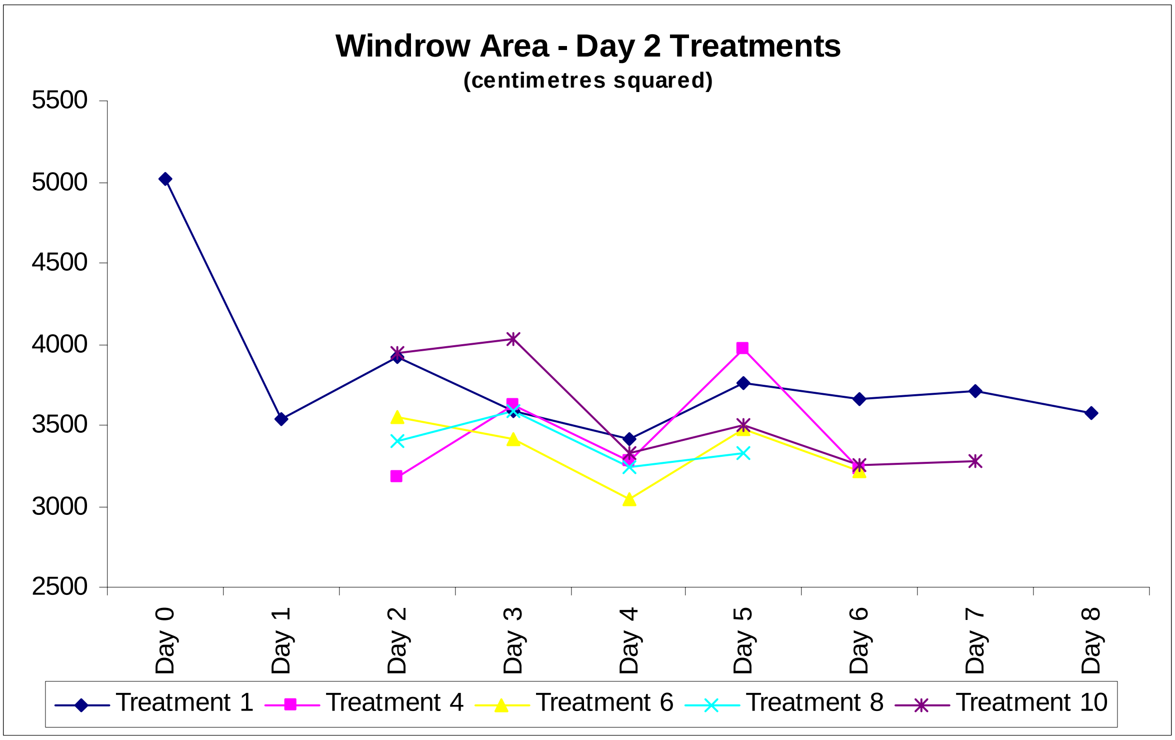

Figure 38: Windrow area for day 2 treatments compared to treatment 1

All day two treatments resulted in final windrow areas of similar size (3500cm²) and only one treatment has shown a decline in area over time being treatment 10 (Figure 38). The other treatments have all provided a very firm structure within the windrow to maintain this area for the duration of the drying period to baling.

The day four treatments have all provided an initial area greater than the structure produced by the cutting treatment (treatment 1), as material being super conditioned was drier and lighter (Figure 39). Treatments 5 and 7 resulted in this initial super conditioned area being reduced over time, compared to treatment 9 that provided a uniform structure which held its shape over time.

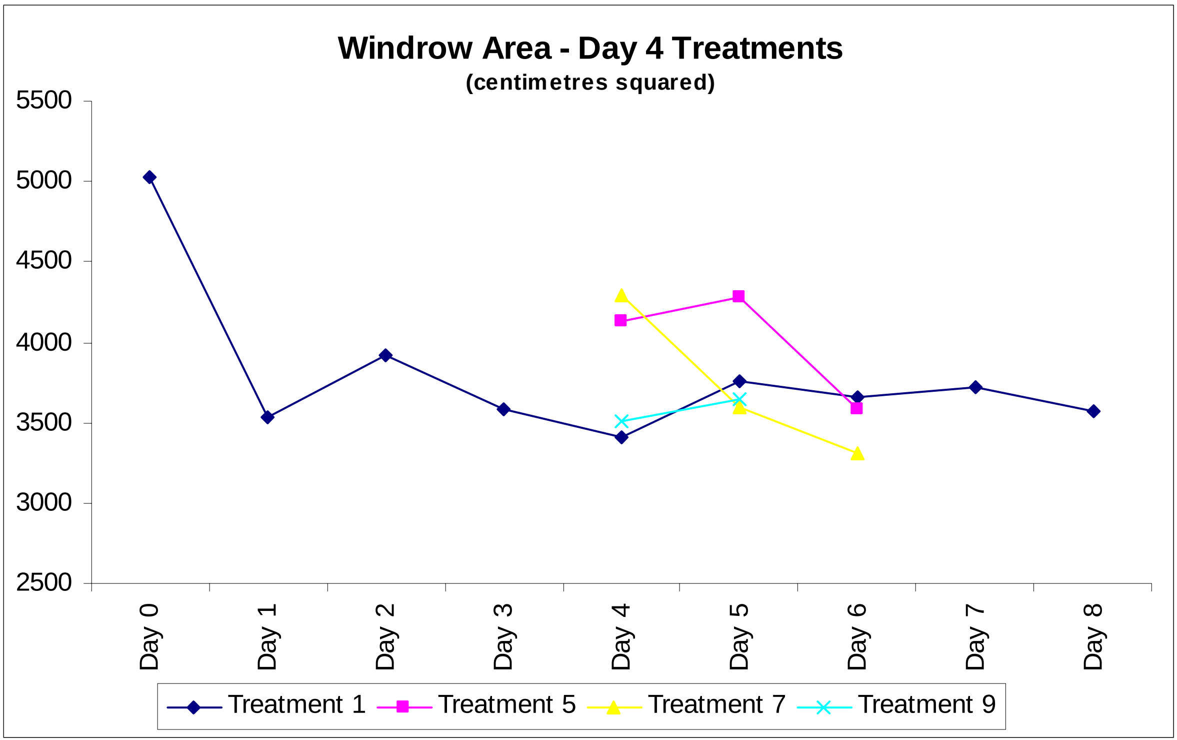

Figure 39: Windrow area for day 4 treatments compared to treatment 1

Fresh weight of the windrow

The fresh weight information could not be statistically analysed due to the nature of the data (Table 17). Interpretation is done by drawing conclusions from the graphs. What is apparent in Figure 40 is that there is no set order of fresh weight between treatments, with quite a variation over the duration of the trial. This probably reflects differences in the moisture loss as the windrows are drying down. All treatments follow the same basic curve as the moisture decline graphs.

What Figure 40 does demonstrate is that there were no clear cut differences between the treatments in terms of weight of windrow. It has been speculated that super conditioning can cause loss of yield due to leaf loss and powdering of hay, yet this is not borne out by the fresh weight results. There also does not appear to be any difference in fresh weight between the different timings of super conditioning in the trial.

Table 17. Averaged Data Results for the Fresh Weight of the Windrow.

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	34.525	33.945	32.425							
1	19.420	17.805	21.520							
2	13.945	16.665	15.160	11.808		13.325		12.825		14.360
3	13.450	11.890	14.345	10.970		11.990		12.880		13.815
4	11.390	11.845	11.665	9.425	11.565	10.425	10.780	10.385	11.155	10.495
5	10.600	11.030	10.530	9.250	9.790	10.415	10.185	10.175	10.175	9.738
6	11.210	10.250	10.230	9.650	9.765	9.560	10.140			10.771
7	10.795	12.245	10.950							11.025
8	10.040									

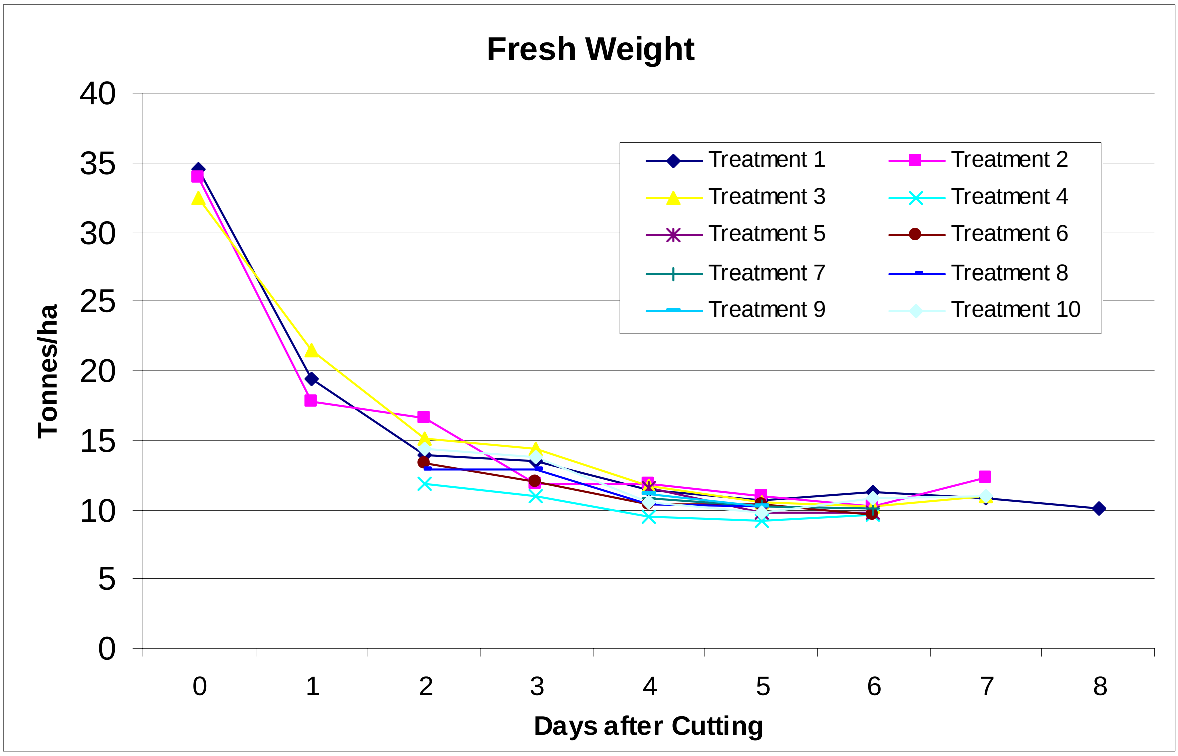

Figure 40: Fresh weight of windrow across all treatments

Windrow Uniformity

The windrow uniformity did not alter after the final treatment occurred with all treatments providing a consistent result over the duration of the trial, as presented in Table 18.

Table 18. Averaged Data Results for the Windrow Uniformity.

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	2.28	2.56	2.25							
1	2.25	2.56	2.22							
2	2.41	2.53	2.28	1.91		1.66		1.75		2.13
3	2.19	2.28	2.00	1.84		1.63		1.69		2.06
4	2.56	2.47	2.49	2.13	2.00	1.53	1.25	1.69	1.66	2.66
5	2.31	2.38	2.22	1.91	1.84	1.78	1.63	1.66	1.81	2.19
6	2.19	2.25	2.09	1.94	1.84	1.69	1.63			2.19
7	1.97	2.19	2.19							2.09
8	2.06									

Figure 41 shows how the cutting treatments 1, 2 and 3 have provided a more uniform windrow formation compared to the treatments conducted two and four days after cutting. The treatments conducted after cutting had windrows with slightly uneven heights and widths along the row. Again, these effects resulted from the way the rear flaps of the machines were configured rather than as result of the super conditioner rollers and the action. Adjustment to provide a different outcome is possible. These after cutting treatments were also conducted at a faster operating speed (9 kph) which would have contributed to the varied windrow uniformity.

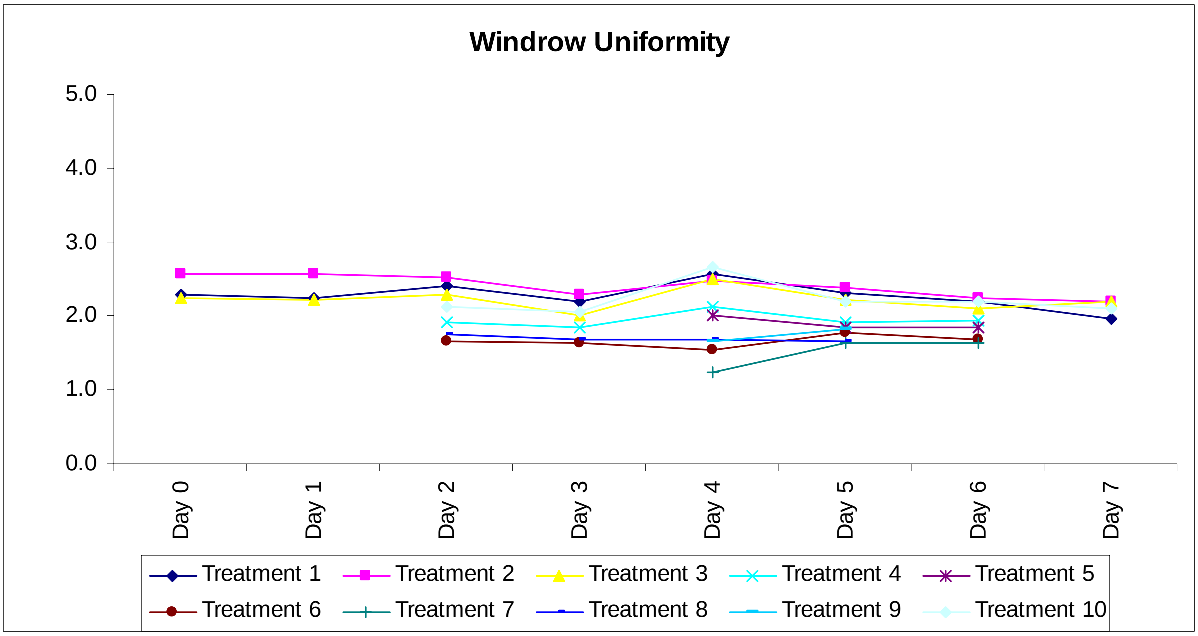

Figure 41. Windrow uniformity for all treatments.

The windrow uniformity did not change over the course of the trial for treatments which involved the self propelled machines. The slight changes evident in figure 42 are due to assessor and sampling variation on a day to day basis.

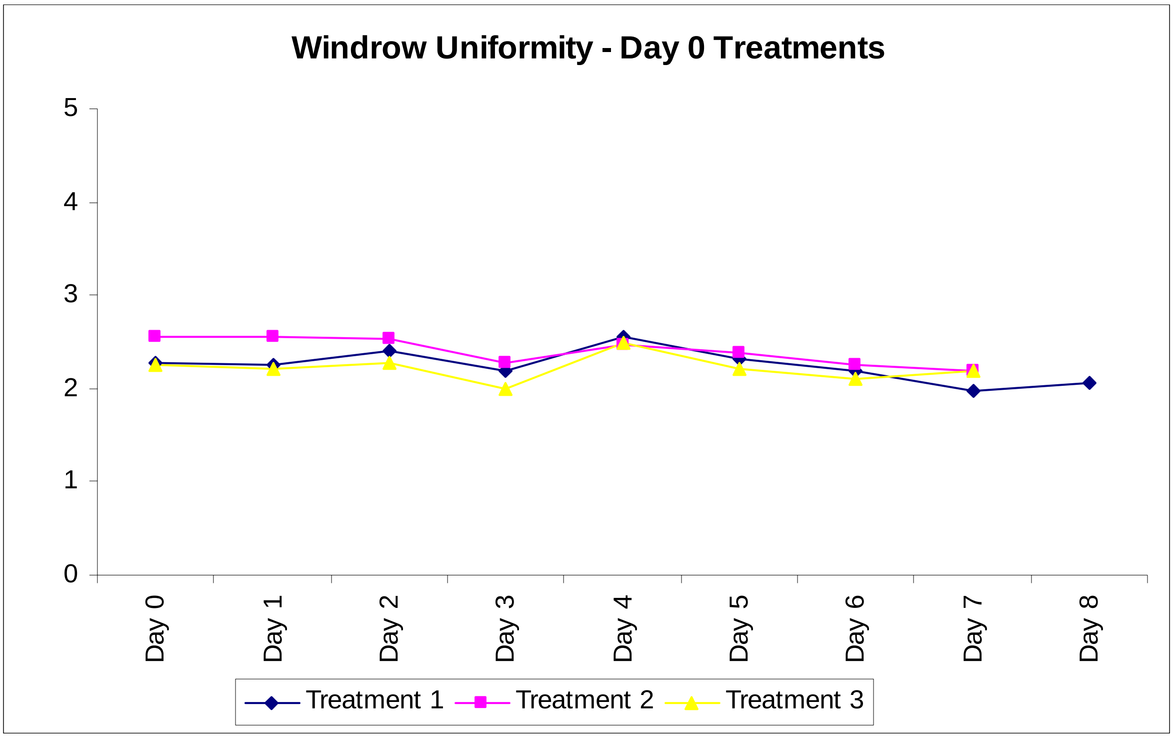

Figure 42: Windrow uniformity for day 0 (self propelled) treatments

The results from the day 2 treatments compared to treatment 1 show the various machines have distorted the original windrow that was created by the mower conditioning machine (Figure 43). Treatments 6 and 8 resulted in a windrow with an uneven structure along the row. This may have been beneficial in reducing the drying time especially with treatment 8, with air flow along the row being disrupted and entering the row rather than continuing past.

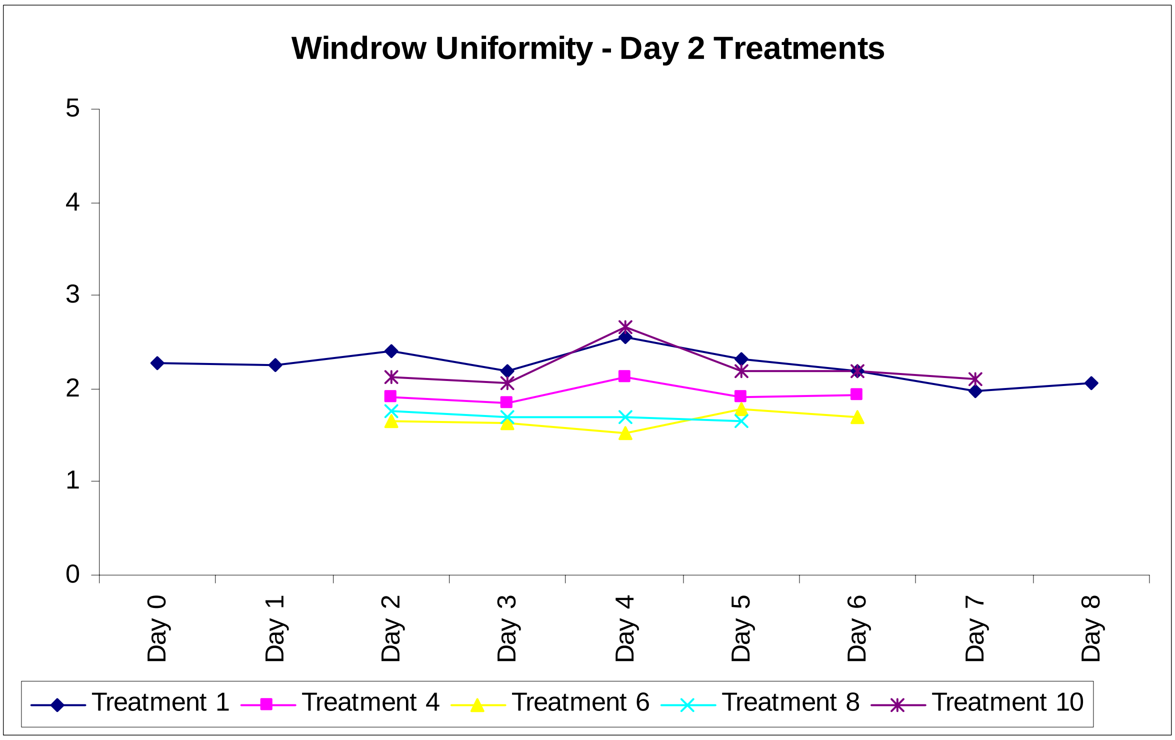

Figure 43: Windrow uniformity for day 2 treatments compared to treatment 1

The results for all these treatments could be adjusted by altering the side and rear discharge flaps on the various machines when set up. Treatment 10 had a minimal affect on the windrow formed by the original cutting treatment 2 days earlier. Treatment 4 had a fixed rear and side discharge system with no adjustment and had only a slight effect on the windrow uniformity.

All treatments at day 4 created a more uneven windrow, possibly due to the lighter weight of material (Figure 44). This may have been beneficial as these treatments were all baled earlier than treatment 1. A less than uniform structure to a windrow was a good outcome for a faster drying time. Perhaps airflow within the windrow increased (although as air flow was not measured this assumption cannot be confirmed).

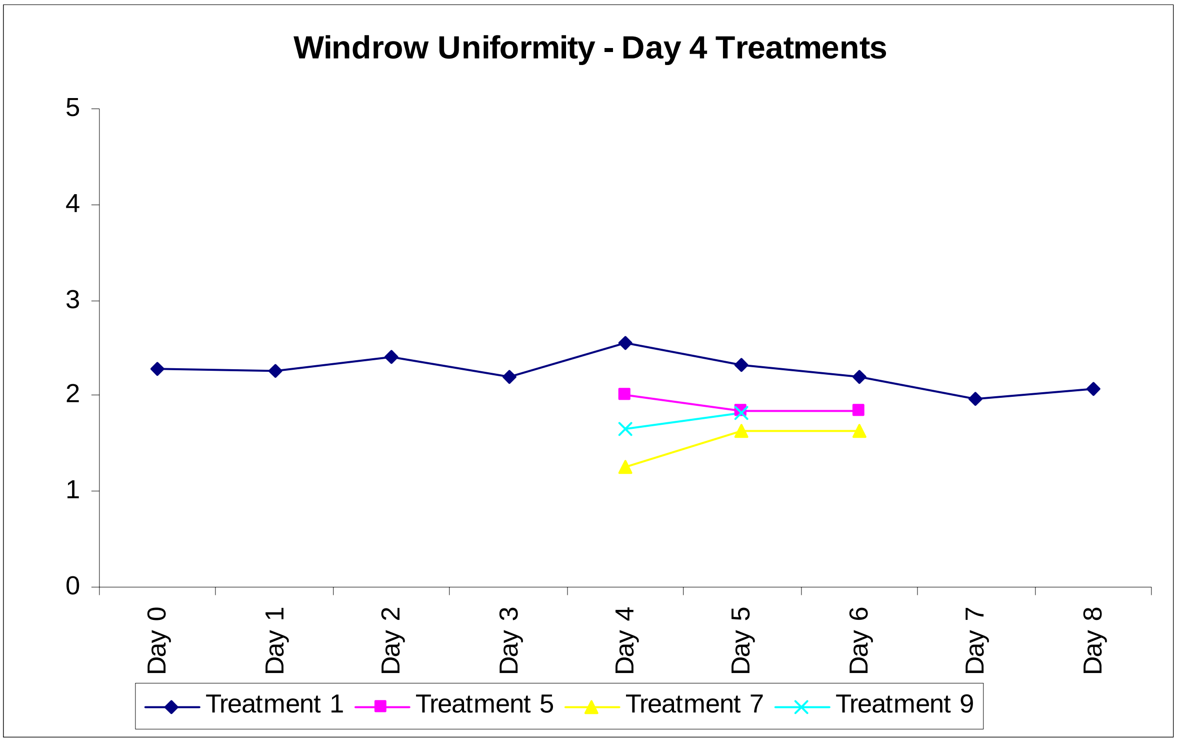

Figure 44: Windrow uniformity for day 4 treatments compared with treatment 1

Windrow Climate

Relative Humidity

The relative humidity was unable to be analysed statistically due to the nature of the data (Table 19), so interpretation can only come from trends evident in, Figure 45.

Table 19: Relative humidity averages for each treatment and each day

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	49.9	46.2	48.5							
1	43.1	32.3	43.6							
2	65.5	64.1	72.1	64.4		56.5		61.2		65.3
3	43.9	42.4	50.6	42.6		42.7		46.4		44.6
4	27.2	27.3	33.3	29.2	31.6	27.1	23.4	20.9	27.6	26.0
5	26.9	26.9	29.6	30.6	25.2	25.8	27.3	28.2	25.6	27.4
6	29.2	26.7	28.6	31.4	29.9	25.4	31.6			29.3
7	24.6	26.3	25.4							26.2
8	43.9									

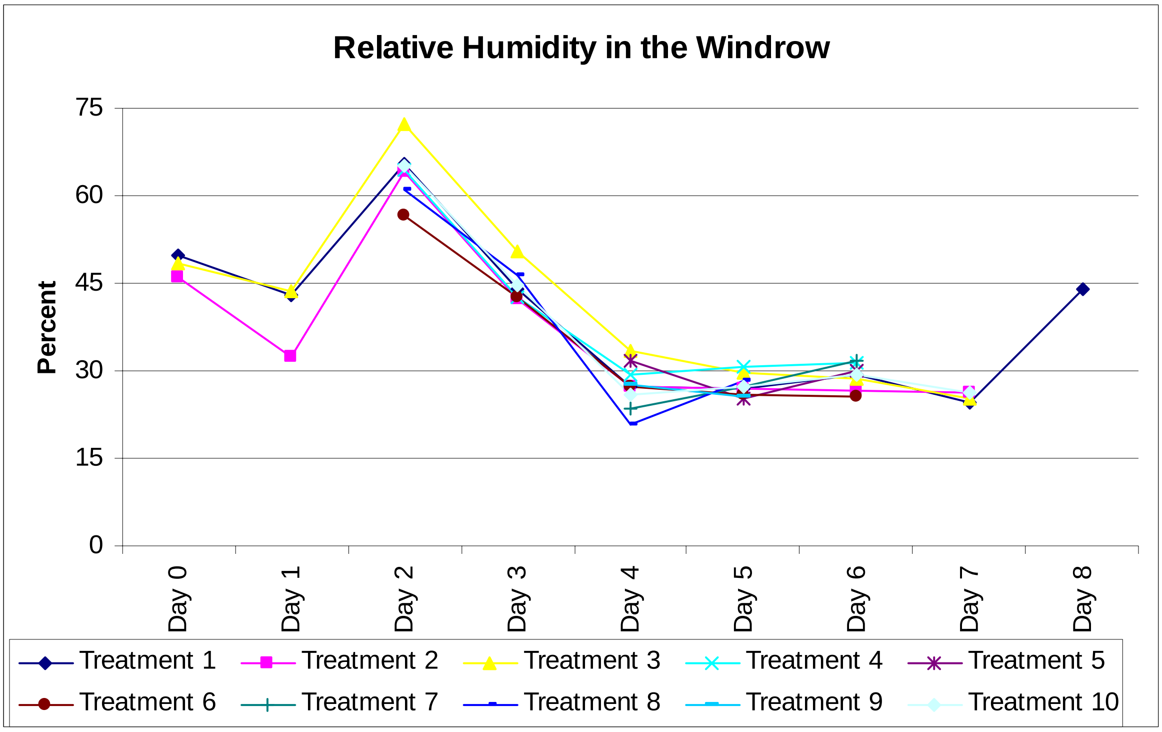

Figure 45: Relative humidity in the windrow across all treatments

Windrow structure has played a major role in manipulating the relative humidity in the windrow. The treatment with the lowest cross section area, treatment 3, also had the highest relative humidity of any windrow for much of the trial. This was also one of the final treatments to be baled, and indicates that the denseness of the windrow led to higher humidity, and therefore slower curing.

Temperature

There are no obvious patterns that emerge between the treatments for windrow temperature (Table 20). All treatments followed a very similar pattern throughout the trial (Figure 46). Windrow temperature reflects ambient temperature at the same time. The influence of windrow structure due to machines is minimal. Future projects may find more value in using permanent data logging probes in the windrow. Ongoing monitoring, rather than a measurement at a point in time may be more accurate.

Table 20: Temperature averages for each treatment and each day

Day	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9	Treatment 10
0	25.8	27.4	26.0							
1	33.3	32.4	33.8							
2	24.5	24.2	24.4	24.3		25.0		24.4		24.7
3	24.9	25.2	24.2	25.3		24.3		25.8		25.6
4	28.7	28.5	27.8	28.7	28.4	28.6	30.2	30.2	29.0	30.5
5	32.8	32.7	33.0	32.3	33.0	32.2	32.0	32.7	32.9	33.0
6	29.2	30.6	29.4	28.7	28.2	29.9	28.5			28.5
7	31.9	31.1	31.9							32.5
8	27.9									

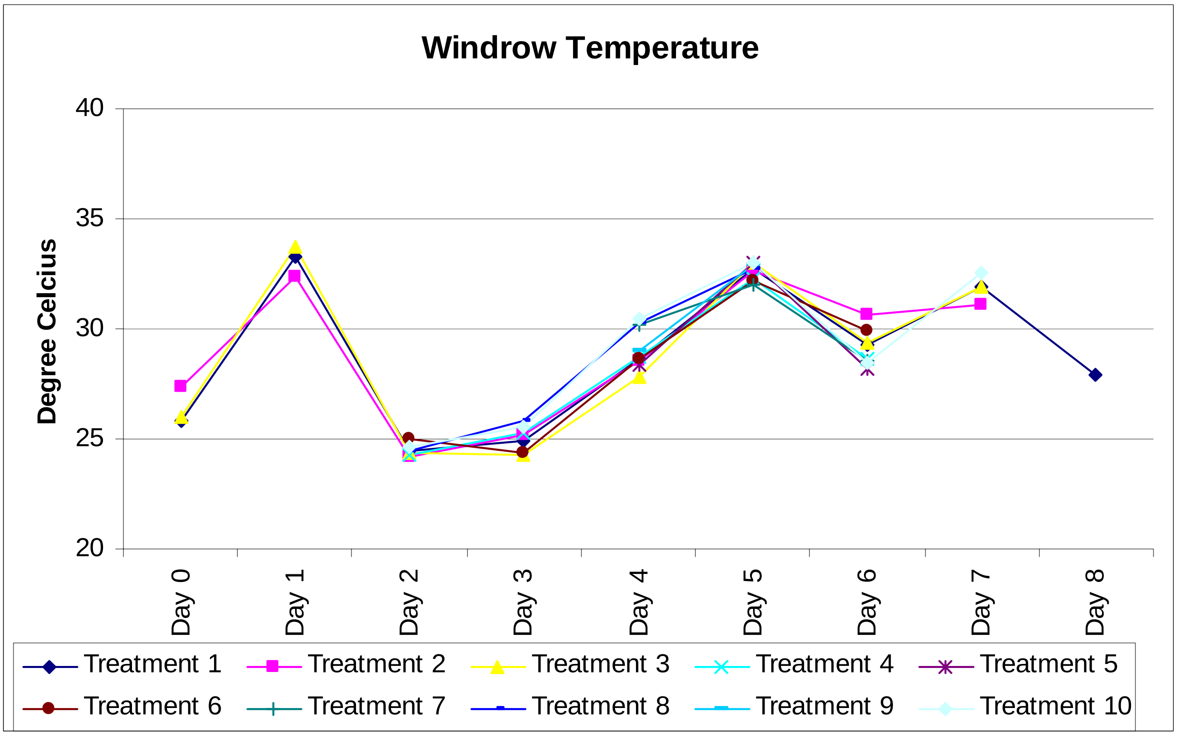

Figure 46: Windrow temperature across all treatments

Baling

There were significant differences in the time to baling between the treatments (Figure 47). Treatments 8 and 9 were the first to be baled after 6 days, with treatment 1 the last to be baled after 9 days. This reflects a 3 day difference in baling across the trial, with the mower conditioner (treatment 1) the last to be baled. This verifies the claim that super conditioning can reduce curing time.

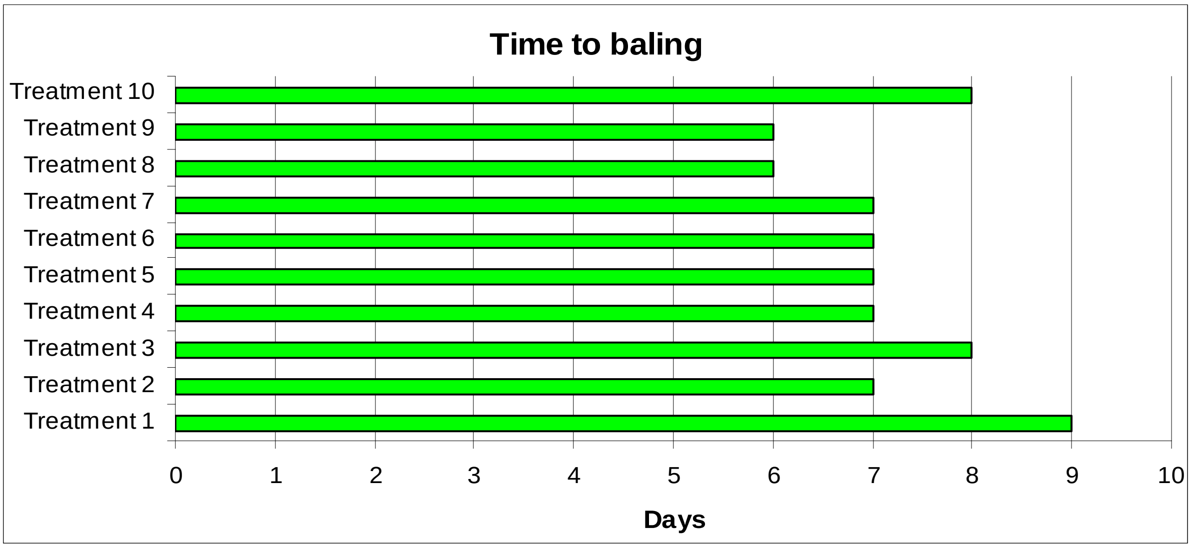

Figure 47: Time from cutting to baling for the trial

Knots Crushed and Baling

There was a correlation between knots and florets crushed and baling time (Figure 48). Treatments which were able to crush more knots and florets were the first to be baled. As the hardest parts of the plant are crushed, moisture is more readily evaporated away and hay cures more quickly. There was no difference between the treatments involving the same machines used on different days in terms of baling time. In principle, the more aggressive the conditioning process, the faster the curing of hay and the less time to baling.

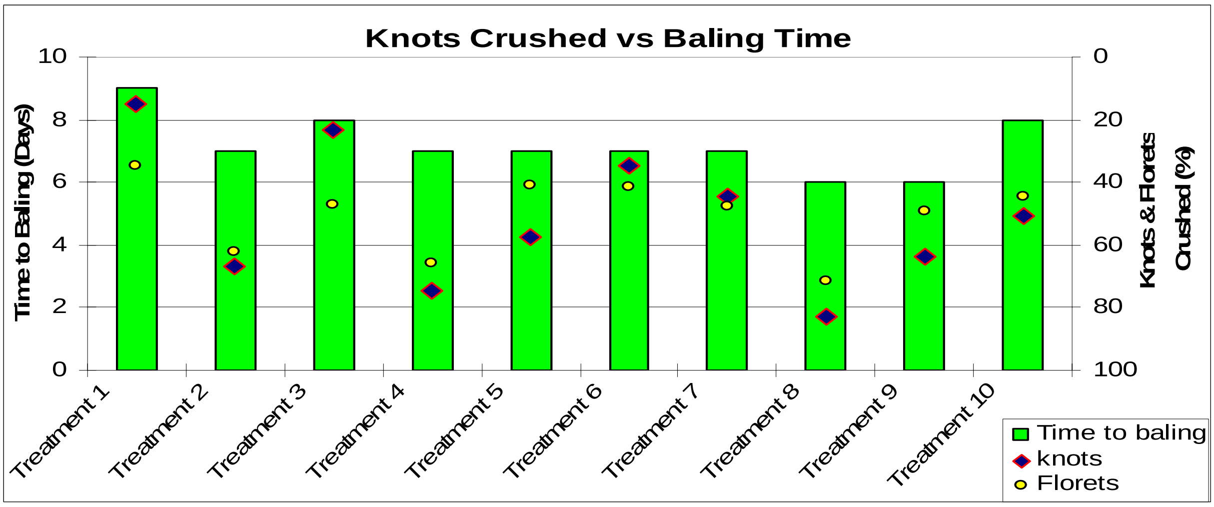

Figure 48: The correlation between knots crushed and baling time

A possible downside could be having these plant structures opened can pose a threat of rain damage. Water may be able to penetrate more parts of the plant and have a greater impact on the hay. Baling time in itself can have an impact on weather risk, as the shorter the time between cutting and baling, the less exposed the hay is to weather damage. It is important to know the average rainfall frequency of the district when considering super conditioning, as the average rainfall frequency will determine the risk window for hay cutting.

Quality

The feed test results showed some statistical differences between the treatments. ADF% was statistically significant (Table 21). There were differences between the other feed test parameters; however none were significant at the 5% confidence level. However, there was statistically significant differences in the colour scan results.

Table 21: Summary of statistical analysis of feed test and colour scan results

Treatment	Colour Scan	ADF (%)	NDF (%)	Digestibility (%)	WSC (%)
1	63.3	37.2	59.2	59.3	13.7
2	70.4	35.8	58.3	61.3	14.1
3	61.2	38.6	60.9	57.1	12.9
4	64.9	36.7	58.3	59.8	15.9
5	64.8	36.8	59.5	59.2	14.7
6	68.9	37.8	60.2	57.4	14.8
7	64.3	37.0	59.2	59.1	14.8
8	65.2	36.5	58.9	59.3	13.9
9	66.9	37.0	59.0	62.3	14.4
10	60.9	38.4	59.6	58.6	14.3
LSD 5%	**4.973**	**1.428**	**ns (1.748)**	**ns (2.175)**	**ns (1.856)**

Water Soluble Carbohydrates (WSC)

There were no significant differences between treatments for WSC% (Figure 49). There were some slight differences between the machines, with treatment 4 having a relatively high reading.

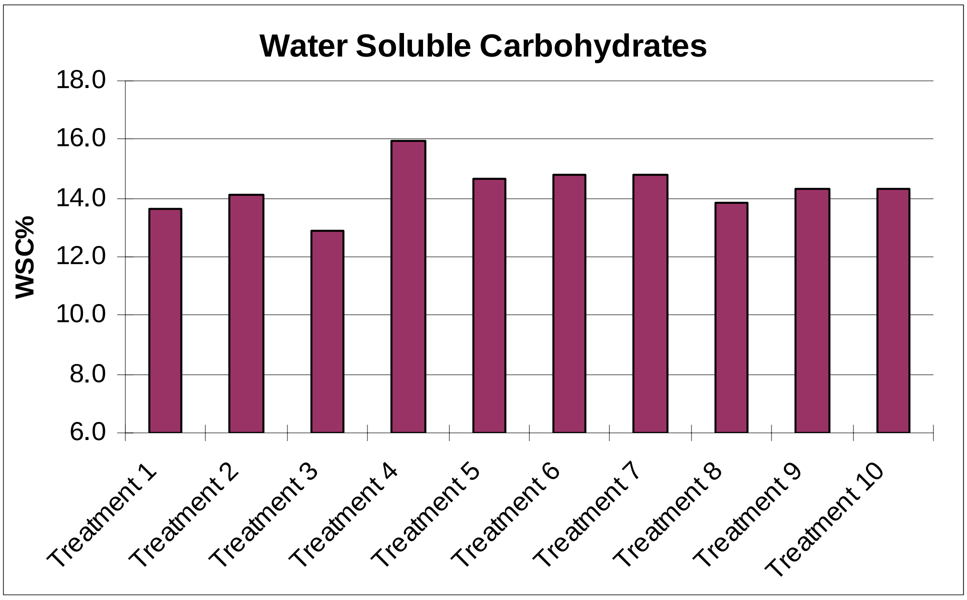

Figure 49: WSC across all treatments

Anecdotally, super conditioning has been thought to lead to quality losses after rainfall. Plants are opened up, allowing rainfall to penetrate and leach the water soluble carbohydrates out of the plant. This has the two fold effect of reducing hay yield and decreasing the quality of the hay. Water soluble carbohydrates are an important component of hay quality as they influence palatability, and are an energy source that is absorbed directly into the blood stream. Further trial work would be required to provide solid evidence as to the effect of super conditioning on water soluble carbohydrate losses after rainfall.

Acid detergent fibre (ADF)

There were significant differences between the treatments for ADF% (Figure 50). Treatments 3 and 10 had the highest content of ADF of the treatments. There does not appear to be a visible pattern between ADF and time of conditioning, as there is a random spread of values across these times. The amount of fibre in hay can be related to the height of the cut, as fibre concentration increases in the lower regions of the oat plant. Therefore cutting the crop lower will increase the concentration of fibre in the hay.

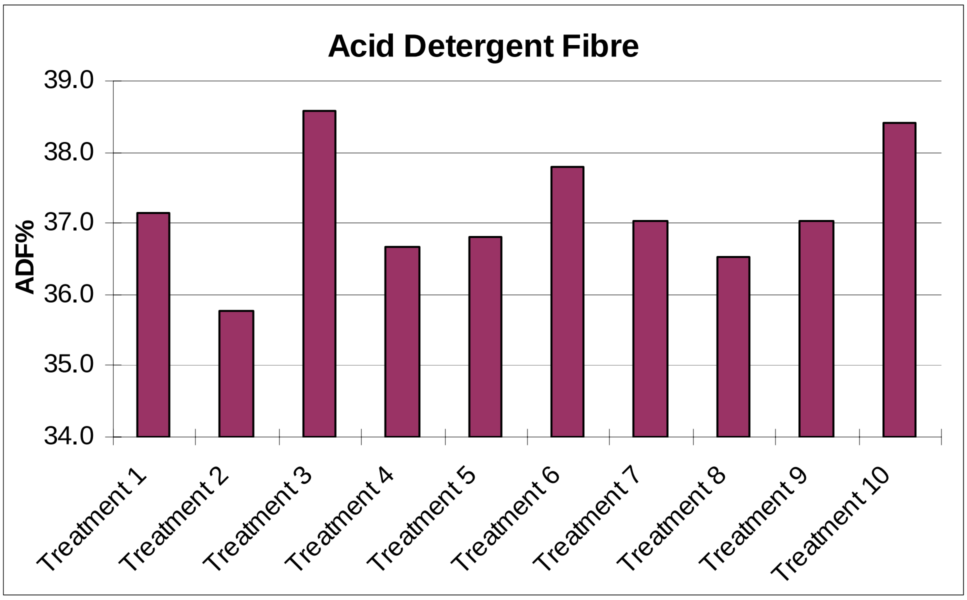

Figure 50: ADF across all treatments

Treatment 3 involved a self propelled machine with a discbine front cutting mechanism; all other machines had sickle bar fronts. This machine was observed to cut the crop cleanly in patches where it had lodged, compared to the sickle bar cut adjacent to it. It follows then, that the discbine front was cutting the hay cleaner, and slightly lower than the remainder of the machines. This explains the higher ADF levels in treatment 3, and also the lower height off the ground of the windrow as discussed previously.

Treatment 10 also had high ADF content. This can not be explained by height of cutting, as this treatment was cut with the same machine as the majority of the trial. Leaf loss during conditioning may have been a factor. If leaf was lost then this would result in a greater proportion of the hay being stem, which is where the fibre component is found. The leaf loss difference was not observed at the time of the trial and is speculation only at this stage.

Neutral Detergent fibre (NDF)

There were no significant differences between the treatments for NDF% (Figure 51). Treatment 3 remained relatively high compared to the other treatments. This was a factor of cutting height and cleanness as discussed previously.

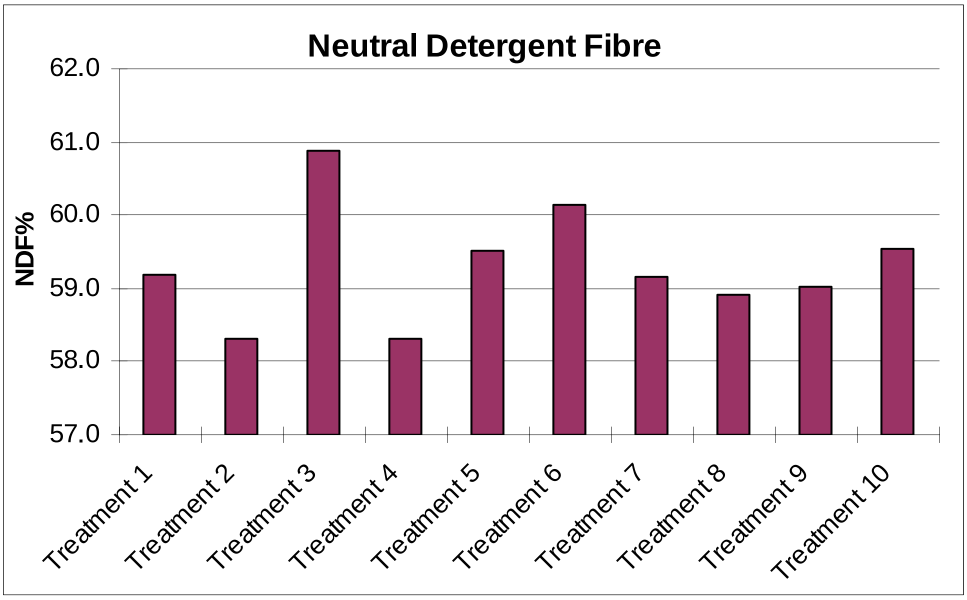

Figure 51: NDF across all treatments

Digestible Dry Matter (DDM)

There were no significant differences between the treatments for DDM (Figure 52). There was however, a correlation to other feed test parameters. Treatments 3, 6, and 10 had the lowest DDM. They also had the highest ADF concentrations. The high fibre component of the hay meant that digestibility was reduced, and this is why these treatments were downgraded in terms of quality. Digestibility is inversely proportional to ADF.

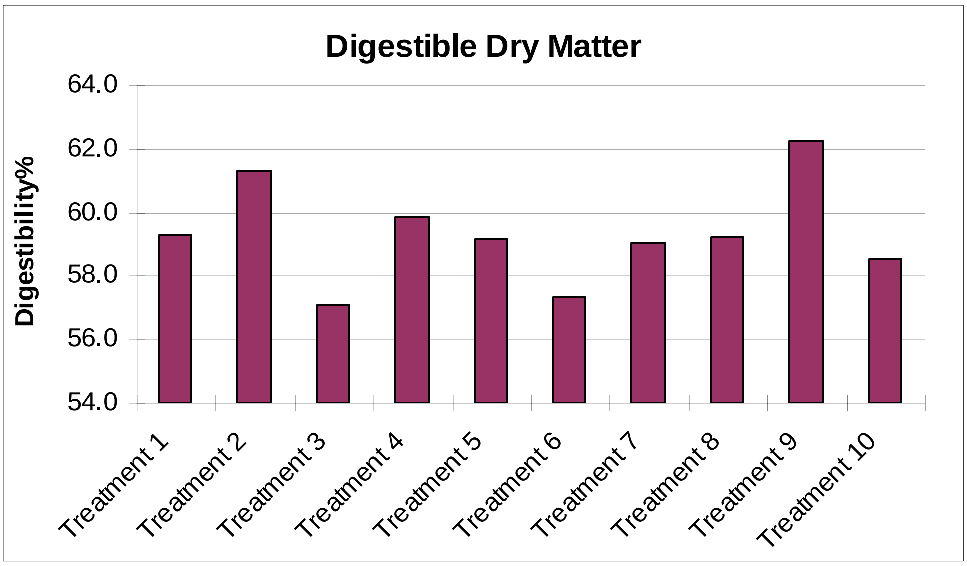

Figure 52: DDM across all treatments

Hay Colour

There were significant differences between the treatments for hay colour scan (Figure 53). It is important to note that all treatments received the maximum grade for hay colour according to Balco Australia's scoring system. Yet there were differences in the actual scan results of the hay above the threshold for maximum grade. Treatments 2, 6, and 9 had the highest colour scan score, with treatment 2 exceeding a score of 70.

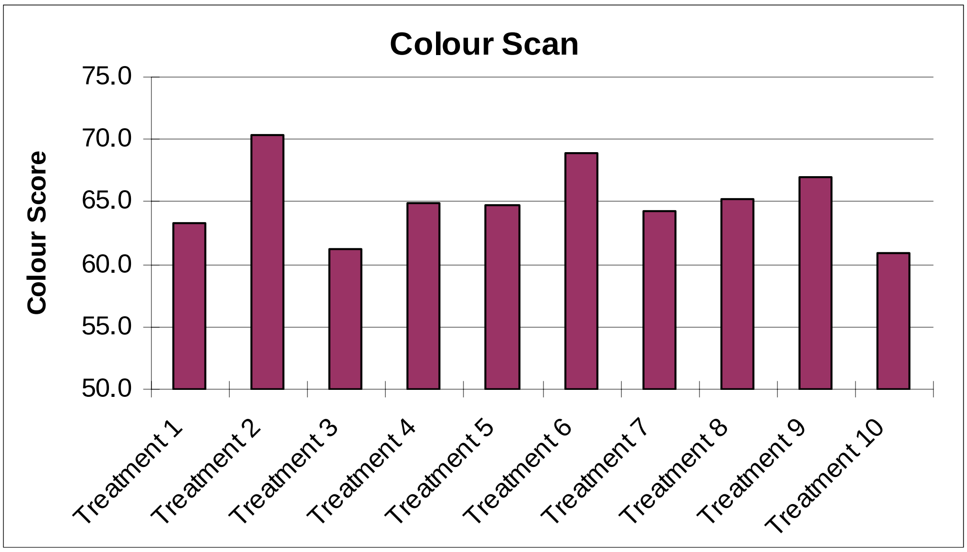

Figure 53: Colour scan results across all treatments

The colour score is a reflection of how much bleaching of the hay had occurred. Bleaching occurs when ultra-violet sunlight hits the hay and bleaches the green colour. Higher bleaching will lead to a lower colour scan score. The amount of sunlight which is able to bleach the hay is a function of climate, time to curing, and the amount of hay exposed to the light.

The loss of colour is a factor for quality as the visual characteristics of the hay are thought to influence preference and intake. Under present marketing arrangements hay colour accounts for 60% of the final grade of export hay, and as such the price received per tonne. Therefore it is very important to maximise colour to maintain price and have a profitable hay enterprise.

Climate influences bleaching by determining the sunlight that is available to bleach the hay. Dull, cloudy weather will not bleach hay to the degree that bright, sunny weather will. During the course of the trial the weather was generally quite sunny.

The longer that hay remains in the paddock, the more bleached it becomes. This is a reason why reducing curing time is important for producing quality hay, as bleached hay is of poorer visual quality. In this trial the three treatments that were the last to be baled, treatments 1, 3 and 10 also had the lowest colour scan results. This is a reflection of the longer curing time of these treatments.

Exposure of the hay to light also relates to windrow structure and how many times the windrow has been turned or repositioned. Every time hay is raked, tedded, or super conditioned, parts of the windrow which had previously been shaded are exposed to sunlight. Treatment 2 had the highest colour score of the trial, and this was cut by an all in one machine with no further interference with the windrow until baling. This meant that the interior of the windrow was protected from sunlight throughout curing, which has led to less bleaching and a higher colour score.

If a windrow has a tight outer surface, then the sunlight finds it difficult to penetrate and bleach the interior of the windrow. This is a trade off however, as it will reduce air flow and dry down time. This may mean that the hay is in the paddock for longer, and gives the hay a greater chance of being bleached.

Economic Evaluation

When all of the quality parameters were put together a final quality grade was established, known as the Hay Delivery Score, in accordance with Balco Australia's grading system. There were significant differences between the treatments for Hay Delivery Score (Figure 54). The Hay Delivery Score is directly correlated to the price received, as price in $/t is allocated according to this score. For this reason price was also found to be significantly different between the treatments.

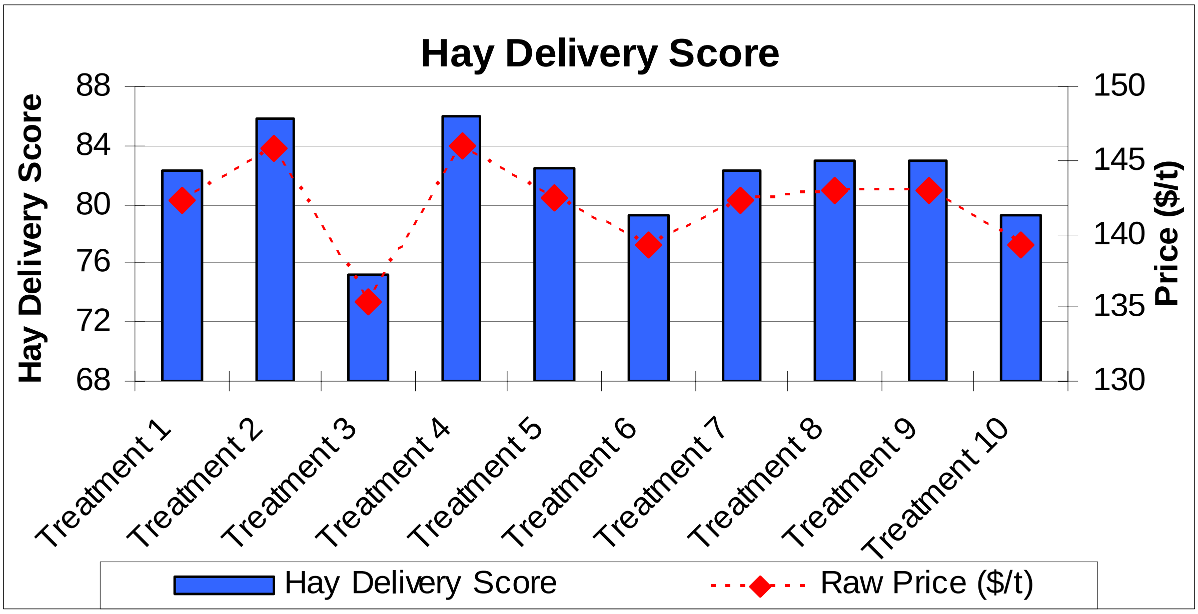

Figure 54: Hay delivery score and price for all treatments

Treatments 2 and 4 had the highest hay delivery score and price received. This was due to the relatively low fibre component of both of these hays, which resulted in a higher quality score. Treatment 3 returned the lowest quality hay of the trial, again, largely a function of the fibre content. All treatments were above the standard required for maximum hay colour grade, so this did not impact on the final differences in hay delivery score.

Conclusions

Producing export oaten hay is all about producing a quality product, super conditioning is part of the process to achieving this outcome, if this operation is carried out thoroughly considering all the factors in this report, then super conditioning will assist in providing better quality export oaten hay.

Windrow Structure

Windrow structure has a huge impact on the end quality of hay and the curing time. There are mechanical adjustments that can be made to many super conditioners and hay cutting machines which will influence windrow structure. Experimenting with these adjustments can move the windrow to the side, stack the windrow higher and narrower, or flatten the windrow out wider. The less dense the windrow, the faster it will dry down due to air circulation and reduced relative humidity.

Having a well aerated windrow must be balanced against the need to protect the hay from weather damage. A windrow that is evenly domed and quite dense will tend to runoff surface water and protect the interior of the windrow from weather damage if rainfall occurs, .however it will take longer to cure and be baled. Knowing the rainfall frequency of the district is crucial in determining the desired windrow structure. If rain only occurs very rarely on average whilst hay is on the ground, then an open windrow is desirable, as the need for protection from rainfall is minimised. Yet if rainfall is a regular occurrence during hay season, the windrow may need to be denser to prevent rain from penetrating the row and reducing the quality of the product.

Degree of Crushing

There is a clear correlation between the aggressiveness of the super conditioner and a reduction in the curing time of the hay. There were no quality penalties from aggressive conditioning evident in the trial. If the hay program is large, and reduction of curing time is important, then the use of a super conditioner to crush knots and florets and open up the stem is advised.

Although treatments which were performed using the same machine on different days showed differences in the degree of crushing, there was no difference in baling time. This was surprising given that there was a strong tendency for baling time to be reduced when knots and florets were crushed. It would be interesting to test if the curing time could be further reduced by using combinations of super conditioners, and whether this would have an impact on hay quality.

Baling Time

Ideally time between cutting and baling should be as short as possible. But if labour or machinery is an issue then it may not be possible to be cutting and baling hay within a week. When this is the case, the use of super conditioners would need to be questioned. All super conditioners in the trial were baled before the mower conditioner treatment, which means that super conditioned hay will cure quicker. Yet if no rain is forecast, is there a quality advantage to having the hay baled quicker or is it just an additional cost? The mower conditioner treatment in the trial was the last treatment to be baled, but it was not the poorest quality hay. In fact it received a higher hay delivery score than 3 of the super conditioner treatments. In terms of hay quality under the ideal curing conditions experienced during this trial, the mower conditioner treatment performed as well and better than some of the super conditioner treatments. Yet the longer the hay is in the paddock, the greater the likelihood of downgrading from loss of colour, and the greater the chance of weather damage. For this reason, super conditioning plays an important role in the hay process by reducing baling time.

Machinery Factors

Labour available

There are other factors that need to be considered when looking at super conditioning. There is a labour requirement with the operation. Does the business have the extra labour unit and tractor required to perform an extra operation on the hay. If not, then perhaps an all in one machine should be considered, as this will require only one labour unit.

Speed of travel

The speed of travel of the self propelled machines may render them unviable if there is a large hay program that needs to be cut within a small window of time. The horsepower required powering the super conditioner unit as well as propelling the machine makes the all in one unit slower to operate than a standard mower conditioner or windrower, and this means that fewer hectares can be cut per day. Speed of travel can also be a factor for the tractor towed machines, particularly in relation to transport between paddocks. It was noted during the trial that differences exist between the machines in their ease of transport between properties. If contracting is part of the business strategy, or the property is spread out geographically, ease of travel should be considered to minimise down time in the operation.

Reliability

As with any item of machinery, a significant investment will be made if a super conditioner is purchased, and reliability of the machine is a key feature. The hay making season is restricted by climate and having machinery breakdowns when the climate is right for making hay can be very costly. As with any piece of machinery, seek testimonials from others who have used it, and ensure that there is good service and back up support available with the machine prior to purchase.

Setup

Machine adjustment and setup are a critical part in achieving quality export oaten hay, an operator needs to understand the impact of all aspects of setup and operation of the super conditioner. All machine types/mechanisms work in slightly different manners but are all capable of achieving the desired result for a hay producer. The key factors to consider are roller speed, roller gap, rear discharge chute adjustment and speed of travel, whilst operating the machine, roller pressures and height of cut and cutting system need to be understood to meet the quality required as everyone is tempted to take that bit more to achieve a higher yield but it is most times at the expense of quality.

Limitations

Care needs to be taken when drawing conclusions from one year of trial data. Each season, crop, and situation will vary, and no two paddocks will behave the same way when evaluating the production of oaten hay. Despite this, data is still relevant and some preliminary conclusions may be drawn. It is important to note that further work is required to fully validate the results; in particular testing super conditioning when inclement weather is involved. This will provide a greater understanding of the true value of super conditioning process and the potential impacts of the types of mechanisms that were evaluated in this trial.

Appendix

Trial Plan

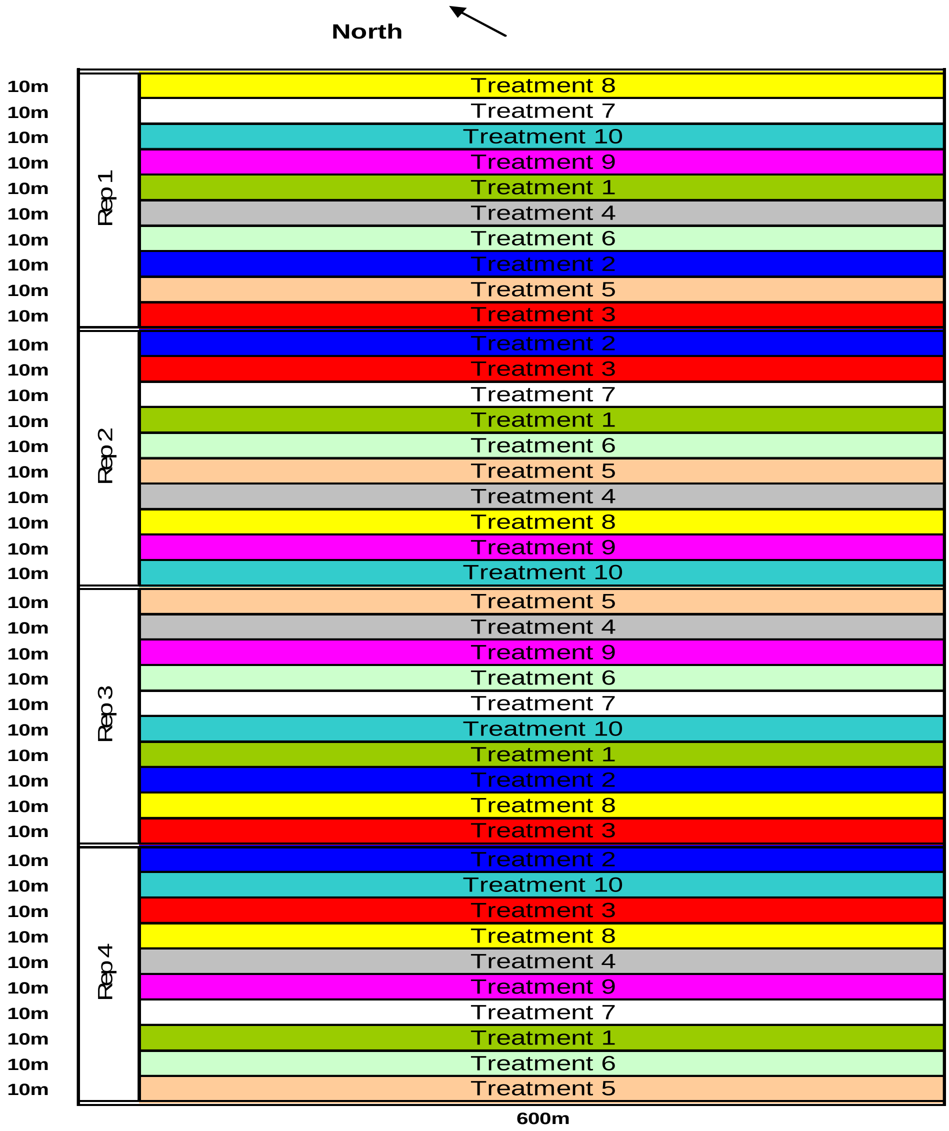

Table 22: Treatment list

Treatment	Machine	Timing
1	Mower Conditioner	Day of Cutting
2	John Deere/Gilmac	Day of Cutting
3	New Holland	Day of Cutting
4	Haymax	Day 2
5	Haymax	Day 4
6	Hydra-Squeeze	Day 2
7	Hydra-Squeeze	Day 4
8	Macerator 6610	Day 2
9	Macerator 6610	Day 4
10	Recon300	Day 2