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Fungicides for control of leaf rust in forage oat in Australia

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Abstract

Forage oat is an important annual forage crop in Australia, but leaf rust can cause significant yield losses. Fungicides can be used for control, but little is known about the economic benefits. Field trials were conducted over two years under irrigated and dryland conditions in southern Queensland, using a range of fungicides and cultivars. The application of fungicide to susceptible cultivars with low levels of leaf rust did not produce a significant increase in forage yield. However, application of fungicide significantly increased forage yield when leaf rust was moderate. The fungicides Tilt and Folicur were both satisfactory in reducing the level of leaf rust infection. Economic modelling showed that the application of fungicide to control leaf rust is most likely to produce a net economic benefit when (a) the crop is grown under irrigated conditions or under good dryland conditions, and (b) when the level of leaf rust infection is at least moderate. It is unlikely to produce a net benefit under marginal dryland conditions. Selection of high yielding, late maturity cultivars will help to overcome the yield loss associated with leaf rust, even in the absence of management strategies such as fungicide application.

Executive summary

Forage oat (*Avena sativa* L.*)* is the preferred winter forage crop for beef cattle in sub-tropical Australia and is widely grown in coastal and inland areas of central and southern Queensland and northern New South Wales. Leaf rust (*Puccinia coronata* f. sp. *avenae*) is the most serious disease of forage oats, reducing forage yield, quality and palatability. Breeding for resistance is the preferred option for control of leaf rust; however, the longevity of resistant cultivars has always been a problem. Losses from leaf rust can be slightly reduced through appropriate management of the crop but growers often do not notice leaf rust infection until the problem is serious.

Fungicides have become a viable means of controlling leaf rust infection in forage oat crops, because the cost of application has decreased dramatically. However, no information is currently available on the economic thresholds for fungicide application. The purpose of this project was to determine the loss in forage yield from leaf rust infection in forage oats, the response in forage yield to fungicide application, and to develop a set of recommendations on the circumstances where fungicide application is likely or unlikely to be economically beneficial.

Forage oat cutting trials were planted in 2012 and 2013 at Gatton and Wellcamp under irrigated and dryland conditions respectively. A range of foliar and seed fungicides used for rust control in cereals were applied to plots of three forage oat varieties, along with an untreated control. Plots were assessed for leaf rust infection and cut multiple times to measure forage yield during the season. A simple model was developed to convert loss of forage yield into loss of liveweight gain in cattle and calculate the economic benefit of fungicide application under different growing conditions and levels of leaf rust infection.

The application of fungicide to susceptible forage cultivars in the presence of low levels of leaf rust (0 – 10% leaf area infected) did not produce a significant increase in forage yield. However, the application of fungicide in the presence of moderate levels of leaf rust (20 – 30% leaf area infected) did produce a significant increase in forage yield, although the size of the response varied according to other factors such as the time of year, seasonal conditions and the length of time between cuts.

Cultivar selection is important in determining the forage yield of a commercial crop, irrespective of the presence of a leaf rust infection or the use of fungicide treatments to control rust. Selection of high yielding, late maturity cultivars will help to overcome the yield loss associated with leaf rust, even in the absence of management strategies such as fungicide application.

The fungicides, Tilt and Folicur, were both satisfactory in reducing the level of leaf rust infection in susceptible varieties to a level where there was no significant reduction in forage yield. The effects of Tilt and Folicur on leaf rust infection or forage yield were not significantly different to each other, suggesting there is no relative advantage to either chemical.

The application of fungicide to control leaf rust is most likely to produce a net economic benefit when the crop is grown under irrigated conditions or under good dryland conditions, and unlikely to produce a net benefit under marginal dryland conditions. The application of fungicide to control leaf rust is most likely to produce a net economic benefit when the level of leaf rust infection is at least moderate, except under marginal dryland conditions.

These results will be communicated to forage oat growers through the publication of a technical note, inclusion in the annual Forage Oat Variety Guide and through a press release to rural media outlets. The use of fungicides should be regarded as one option in a range of strategies that forage oat growers can use to minimise the effects of leaf rust.

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1. Background

Forage oat (*Avena sativa L.)* is the preferred winter forage crop in sub-tropical Australia and is widely grown in coastal and inland areas of central and southern Queensland and northern New South Wales. Over 500,000 ha of forage oats are planted annually. The value of the liveweight gain produced from this feed source by the beef cattle industry each year is estimated at $250M. Forage oat is also an important feed source for the dairy cattle and sheep industries.

Leaf rust (*Puccinia coronata f. sp. avenae*) is the most serious disease of forage oats, reducing forage yield, quality and palatability. Leaf rust is a highly virulent fungal disease which spreads via spores through the air, and will readily infect susceptible crops when environmental conditions are suitable. Leaf rust is more common in areas with warmer temperatures and higher rainfall, but will also occur in lower rainfall areas when seasonal conditions are favourable. A recent survey of forage oat growers (Winter 2008, unpublished) found that 61% of growers had experienced leaf rust in their crops in the previous 5 years. Nine percent of growers had leaf rust on a frequent basis (three years in five), 24% had leaf rust infrequently (one year in five) and 27% had leaf rust occasionally (one year in ten). When susceptible varieties are grown in conditions favourable to leaf rust, yield loss can range from 10–50% and can cause plant death in severe cases. The survey found that, when leaf rust occurred in their forage oat crops, 19% of growers rated the damage as slight (less than 10% yield loss), 20% rated the damage as serious (10–30% yield loss) and 17% rated the damage as severe (greater than 30% yield loss).

Breeding for resistance is the preferred option for control of leaf rust. The Department of Agriculture, Fisheries and Forestry (DAFF) in Queensland operates a forage oat breeding program based at Leslie Research Centre in Toowoomba, Queensland. The objective of the project is the commercial release of improved forage oat cultivars with high forage yield, durable resistance to leaf rust, late maturity and high re-growth potential. However, the longevity of resistant cultivars has always been a problem. Leaf rust has a high level of genetic variability and mutation change in the pathogen is common. New races of leaf rust often develop which overcome the combination of resistance genes present in specific varieties. In addition, leaf rust-resistant varieties are sold at a premium price by commercial companies, and this discourages many growers from using resistant varieties. Seed of older susceptible varieties is usually much cheaper and readily available. As a result, at least 70% of the forage oat area each year is sown to varieties that are susceptible to leaf rust.

Losses from leaf rust can be slightly reduced through appropriate management of the crop, for example by grazing or cutting rust-infested crops before the disease becomes severe, and then grazing lightly and often during the remainder of the season. However, growers often do not notice leaf rust infection until the problem is serious, and then grazing management is too difficult. Losses from leaf rust can also be reduced by avoiding planting too early in the season. However, a major trend over the last ten years is planting of forage oats in January and February to provide high quality feed in early autumn. Therefore, a greater proportion of the crop is being planted in the period of higher risk for rust infection.

From a technical perspective, fungicides are a viable means of controlling leaf rust infection in forage oat crops. The widespread use of fungicides for control of leaf and stripe rust in wheat and barley crops has dramatically lowered the cost of application of these fungicides and increased the availability and ease of application (Appendix

8.2). Tebuconazole (e.g. Folicur) and propiconazole (e.g. Tilt) are both registered in all states for control of leaf rust on forage oats. These systemic fungicides provide a good level of control of rust in forage oats, reducing or eliminating the existing symptoms of infection and preventing new infection for 20–30 days after application. Tilt and Folicur have a withholding period for grazing of 7 and 14 days respectively.

Fungicides are used to control leaf rust in oats in other parts of the world, and most research has focussed on the efficacy of different fungicides, application rates and timing of application of improving the grain yield of oats. For example, Hagan and Pegues (2010) examined timing of application of different fungicides for leaf rust control on disease severity and grain yield in grain oats in southern USA. Soovali and Koppel (2011) also examined timing of fungicide application on grain oats in eastern Europe, with particular emphasis on determining economic thresholds for application. Large areas of oats are grown for both grain and forage production in Brazil and a number of studies have focused on the effectiveness of different fungicides, timing of application, application rates and volumes for leaf rust control in oats (Oliveira, Boller et al. (2007); Martinelli, Reichert et al. (1984); Martinelli (1996)). However, no references can be found to the effect of fungicide application on the forage yield of oats, despite the widespread registration of fungicides for control of leaf rust in oats. The positive effect of fungicide application on grain yield can be easily measured in grain crops, along with the associated gross margins. However, the accurate measurement of forage yield is more difficult, and it is more difficult to translate changes in forage yield into changes in economic value of liveweight gain in cattle.

The use of fungicides in commercial forage oat crops in Australia is an emerging trend, and became more common during the wetter winter seasons between 2008 and 2010. However, no information is currently available on the economic thresholds for fungicide application. Anecdotally, fungicide control is more likely to be viable in higher value crops, for example, high quality hay crops and forage oat seed crops. Application of fungicide may also be useful in emergency situations, where a grower is relying on a large area of forage oats for fattening of young cattle, the forage oat crop has a serious rust infection, and no alternative feed is available. However, no precise information is available on the yield loss caused by leaf rust and the yield gain from fungicide control in broad-acre grazing crops that are typical of the region. An economic assessment of fungicide use in forage oats would ensure that forage oat growers use fungicides when it is profitable to do so, and avoid their use when it is unprofitable.

The purpose of this project is to determine the level of forage yield loss expected from a given level of leaf rust infection in forage oats, and the forage yield increase expected from the use of fungicides to control leaf rust infection. This information will be used to develop a set of recommendations on the circumstances where fungicide application to control leaf rust on forage oat is likely or unlikely to be economically beneficial, and to deliver these recommendations to forage oat growers.

2. Project objectives

2.1 To measure the level of yield loss that occurs in a susceptible variety for a given level of infection by leaf rust, and calculate the economic value of this yield loss;

2.2 To measure the level of yield increase that occurs in a susceptible variety when fungicide is applied to protect against leaf rust infection, and calculate the economic value of this yield increase;

2.3 To develop a set of recommendations from this data on the circumstances where fungicide application to control rust on forage oat is likely or unlikely to be economically beneficial;

2.4 To deliver this set of recommendations to forage oat growers.

3. Methodology

Forage oat cutting trials were planted at two sites in each of two years, 2012 and 2013. The trial locations were the Gatton Research Station (Gatton) and Wellcamp Research Station near Toowoomba (Wellcamp), belonging to DAFF. These trials were conducted alongside the main breeding trials for the DAFF forage oat breeding program, and received the same management inputs (fertiliser, irrigation, cutting dates) as the breeding trials. Both sites had a black cracking clay soil and a weed-free cultivated seed-bed.

In 2012, the trials were planted at Gatton and Wellcamp on 2 April and 3 April respectively, and on 11 April and 8 April in 2013 respectively. In both years, the Gatton trial received a pre-plant application of a blended fertiliser, providing the equivalent of 100 kg/ha nitrogen, and the Wellcamp trial received a pre-plant application of urea, providing the equivalent of 50 kg/ha nitrogen. Both sites were planted using a small cone seeder and a standard plot size of 4 rows x 15 cm spacing x 10 m length. The Gatton trial was fully irrigated in both years, and was top-dressed with urea (50 kg N/ha) after each cut. The Wellcamp site had a full profile of sub-soil moisture at planting in both years and did not receive any additional irrigation or fertiliser. Both trials established well in both years and grew vigorously during the season (Appendix 8.1).

Varieties and fungicide treatments were randomised in a split-plot design with three replications at both sites in both years. Three varieties of forage oat were chosen in each year to represent the range of commercial varieties available to industry. In 2012, the varieties were Genie (late maturity, very high forage yield, leaf-rust susceptible), Taipan (late maturity, moderate forage yield, leaf-rust susceptible), and Coolabah (medium maturity, low forage yield, leaf-rust susceptible). In 2013, Drover (medium-late maturity, moderate forage yield, leaf-rust resistant) was substituted for Taipan at both sites.

Fungicide treatments were chosen to represent the most commonly available fungicides for leaf rust control. In 2012, the four treatments were: (1) Untreated control; (2) Propiconazole (Tilt 250SC®) at 500 mL/ha; (3) Tebuconazole (Folicur 430SC®) at 290 mL/ha); and (4) Azoxystrobin + Cyproconazole (Amistar Xtra®) at 800 mL/ha (see Appendix 8.2 for list of commercially available fungicides). In 2013, these four treatments were repeated, and an additional seed treatment was added, Fluquinconazole (Jockey Stayer®) at 4.5 L/tonne (see Appendix 8.3 for list of commercially available seed treatments). Fungicides were manually applied using a LPG pressurized backpack spray unit and a modified mini-boom spray with two nozzles and an application width of 1 m. In both trials in both years, Tilt and Folicur were first applied to forage oat plots at about six weeks after planting, and re-applied 7–10 days after each cut giving a protection period of 3-4 weeks prior to the subsequent cut. In 2012, Amistar Xtra was only applied late in the growing season prior to Cuts 5 and 6 when risk of leaf rust infection was highest. In 2013, Amistar Xtra was applied throughout the season at the same time as Tilt and Folicur.

To provide an adequate level of leaf rust disease in the treatment plots, a mix of leaf-rust susceptible varieties were planted in long rows adjacent to trial plots and inoculated with a mixed bulk of leaf rust races early in the season. Plots were visually assessed for the level of leaf rust infection prior to each forage cut, using a scale from 0 to 100, where 0 = no infection and 100 = total leaf area covered by leaf rust. Using a small plot forage harvester, each plot was cut at a minimum height of 12–15 cm and weighed. Forage samples were taken from a subsample of plots and dried to convert the plot weights to a dry weight basis. In 2012, six cuts were taken at Gatton and four cuts at Wellcamp, and in 2013, eight cuts were taken at Gatton and three cuts at Wellcamp. Forage yield results for each cut and for total yield were analysed independently for each site and year with Genstat v15, using analysis of variance for a split plot design.

4. Results

a. Gatton 2012

2.1.1 Leaf rust incidence

The level of leaf rust infection was low to moderate throughout the season at the Gatton site in 2013 (Table 1). Infection level was moderate in the control treatment in late autumn (Cut 1), low during the winter months (Cut 2-4) and moderate during early spring (Cuts 5-6). In most cases, the fungicide treatments reduced the level of leaf rust infection, but did not completely eliminate infection.

Table 1: Mean leaf rust infection of forage oat plots (as percentage leaf area infected) prior to cutting at Gatton in 2012 (where 0 = no infection, 20-30 = moderate infection).

Treatment	Genotype	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6
Control	Genie	18	18	18	15	30	22
Control	Taipan	23	17	17	8	27	23
Control	Coolabah	23	18	18	17	30	23
Tilt	Genie	5	7	5	0	7	10
Tilt	Taipan	8	10	5	0	7	5
Tilt	Coolabah	10	8	5	0	7	7
Folicur	Genie	8	10	3	2	10	8
Folicur	Taipan	18	10	3	0	10	7
Folicur	Coolabah	13	10	7	2	10	8
Amistar Cuts 5 & 6	Genie	22	23	18	10	8	3
Amistar Cuts 5 & 6	Taipan	30	22	22	10	7	5
Amistar Cuts 5 & 6	Coolabah	22	20	20	20	8	3

2.1.2 Forage yield

Fungicide treatment has a significant effect on forage yield for Cuts 1, 3 and 6, and for the total forage yield across the season (Table 2). The choice of variety or cultivar/genotype had a highly significant effect on forage yield for each cut and also for total forage yield. There were no interactions between fungicide treatment and genotype.

Table 2: F probabilities and co-efficient of variation (cv%) from analysis of variance of forage yield at Gatton in 2012 (F values less than 0.05 are statistically significant - shaded).

Source of variation	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Total
Fungicide	0.024	0.077	0.002	0.052	0.795	0.008	0.009
Genotype	<.001	0.009	<.001	<.001	<.001	<.001	<.001
Fungicide x Genotype	0.809	0.796	0.38	0.457	0.43	0.271	0.729
cv%	12.1	24.5	23.1	9.7	8.4	15.6	9.4

The effect of fungicide and genotype on forage yield for each cut is presented in graphical form in Appendix 7.4, and in Tables 3 and 4 below. The application of Tilt and Folicur produced a significant increase in forage yield when compared with the control for Cuts 1, 3 and 6, and for total forage yield (Table 3). The yield increase above the control ranged from around 10% when leaf rust levels were low to around 40% when rust levels were moderate. The application of Amistar also produced a significant increase in yield when applied prior to Cut 6 late in the season.
The cultivar Genie produced the highest forage yield in most cuts and the highest forage yield overall (Table 4). Coolabah produced more forage yield than Genie for Cut 3 when Genie did not recover as well from the previous cut. The application of Tilt and Folicur to the cultivar Genie produced the highest increase in forage yield, both in relative and absolute terms (Appendix 7.4.)

Table 3: Effect of four fungicide treatments on the mean forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars (Genie, Taipan and Coolabah) at Gatton in 2012.

Treatment	Cut 1		Cut 2		Cut 3		Cut 4		Cut 5		Cut 6		Total	
Control	2283	*0*	1592	*0*	576	*0*	2688	*0*	2132	*0*	1950	*0*	11222	*0*
Tilt	2591	*13*	2039	*28*	815	*41*	3093	*15*	2279	*7*	2404	*23*	13221	*18*
Folicur	2504	*10*	1866	*17*	826	*43*	3114	*16*	2242	*5*	2718	*39*	13270	*18*
Amistar*	2163	*-5*	1762	*11*	624	*8*	2653	*-1*	2276	*7*	2786	*43*	12263	*9*
LSD (5%)	262		ns		103		ns		ns		401		1057	

** Amistar was only applied prior to Cuts 5 and 6.*

Table 4: Forage yield (kg/ha dry weight) and yield relative to Genie (% in italics) of three forage oat cultivars at Gatton in 2012.

Genotype	Cut 1		Cut 2		Cut 3		Cut 4		Cut 5		Cut 6		Total	
Genie	2991	*0*	2150	*0*	467	*0*	3058	*0*	2780	*0*	2882	*0*	14328	*0*
Taipan	2342	*-22*	1503	*-30*	453	*-3*	2378	*-22*	2076	*-25*	2809	*-3*	11561	*-19*
Coolabah	1822	*-39*	1792	*-17*	1211	*159*	3225	*5*	1840	*-34*	1703	*-41*	11593	*-19*
LSD (5%)	249		385		142		242		162		334		1016	

b. Wellcamp 2012

2.1.3 Leaf rust incidence

The level of leaf rust at the Wellcamp site in 2012 remained low throughout the season, even in the control treatments, despite the presence of leaf rust in the spreader rows (Table 5). This was indicative of the lower rainfall conditions and reduced opportunity for infection events during the 2012 season.

Table 5: Mean leaf rust infection of forage oat plots (as percentage leaf area infected) prior to cutting at Wellcamp in 2012 (where 0 = no infection, 20-30 = moderate infection).

Fungicide	Genotype	Cut 1	Cut 2	Cut 3	Cut 4
Control	Genie	5	0	5	10
Control	Taipan	5	0	5	10
Control	Coolabah	5	0	5	10
Tilt	Genie	0	0	0	0
Tilt	Taipan	0	0	0	0
Tilt	Coolabah	0	0	0	0
Folicur	Genie	0	0	0	0
Folicur	Taipan	0	0	0	0
Folicur	Coolabah	0	0	0	0
Amistar Cut 4	Genie	5	0	5	0
Amistar Cut 4	Taipan	5	0	5	0
Amistar Cut 4	Coolabah	5	0	5	0

2.1.4 Forage yield

None of the fungicide treatments at Wellcamp in 2012 produced a significant increase in forage yield (Table 6). However, there was a significant difference in genotype for forage yield in each cut and for total forage yield.

Table 6: F probabilities and co-efficient of variation (cv%) from analysis of variance of forage yield at Wellcamp in 2012 (F values less than 0.05 are statistically significant - shaded).

Source of variation	Cut 1	Cut 2	Cut 3	Cut 4	Total
Fungicide	0.513	0.43	0.31	0.304	0.096
Genotype	<.001	<.001	<.001	<.001	<.001
Fungicide x Genotype	0.609	0.087	0.215	0.112	0.308
cv%	6.1	4.4	15.7	17.7	6.1

The effect of fungicide and genotype on forage yield for each cut is presented in graphical form in Appendix 7.5, and in Tables 7 and 8 below. Although there were slight differences in the forage yield of fungicide-treated plots compared with the control plots, none of these differences were statistically significant (Table 7).

Table 7: Effect of four fungicide treatments on the mean forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars (Genie, Taipan and Coolabah) at Wellcamp in 2012.

Treatment	Cut 1		Cut 2		Cut 3		Cut 4		Total	
Control	2607	*0*	2418	*0*	2493	*0*	1888	*0*	9407	*0*
Tilt	2823	*8*	2199	*-9*	2778	*11*	1862	*-1*	9661	*3*
Folicur	2800	*7*	2113	*-13*	2733	*10*	2137	*13*	9782	*4*
Amistar*	2616	*0*	2184	*-10*	2193	*-12*	1955	*4*	8949	*-5*
LSD (5%)	ns		ns		ns		ns		ns	

* Amistar was only applied prior to Cut 4.

Genie produced significantly more forage yield for all cuts except Cut 2 (Table 8). Genie also produced 16% more total forage yield than Taipan and 24% more forage yield than Coolabah. In Cut 2, Coolabah recovered more quickly after the first cut and produced more forage than Genie.

Table 8: Forage yield (kg/ha dry weight) and yield relative to Genie (% in italics) of three forage oat cultivars at Wellcamp in 2012.

Genotype	Cut 1		Cut 2		Cut 3		Cut 4		Total	
Genie	3325	*0*	1959	*0*	2988	*0*	2614	*0*	10886	*0*
Taipan	2798	*-16*	1529	*-22*	2262	*-24*	2589	*-1*	9177	*-16*
Coolabah	2011	*-40*	3198	*63*	2398	*-20*	679	*-74*	8286	*-24*
LSD (5%)	142		85		347		301		497	

c. Gatton 2013

2.1.5 Leaf rust incidence

Leaf rust incidence in the Gatton trial in 2013 was low to moderate for most cuts (Table 9). Leaf rust incidence in the susceptible controls (Genie and Coolabah) ranged from 5–23% and was highest during the August/September period (Cuts 4 and 5). A very low level of leaf rust appeared in the resistant control (Drover) from Cut 2 onwards. This was caused by the appearance of a new pathotype of leaf rust that infected the cultivar Drover in Jan 2013, and that gradually spread into the trial during the season. Amistar reduced the incidence of leaf rust in treated plots to a greater degree than Tilt or Folicur. Jockey reduced the incidence of leaf rust prior to the first and second cuts, compared to the control plots, but had no effect later in the season.

Table 9: Mean leaf rust infection of forage oat plots (as percentage leaf area infected) prior to cutting at Gatton in 2013 (where 0 = no infection, 20-30 = moderate infection).

Treatment	Genotype	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8
Control	Drover	0	2	3	2	2	0	5	5
Control	Genie	5	7	17	20	23	7	8	10
Control	Coolabah	10	10	20	18	23	3	17	17
Tilt	Drover	0	0	0	0	0	0	0	0
Tilt	Genie	0	0	7	7	7	2	0	0
Tilt	Coolabah	5	3	7	7	10	2	2	0
Folicur	Drover	0	0	0	0	0	0	0	0
Folicur	Genie	0	0	5	7	7	0	0	0
Folicur	Coolabah	5	3	5	8	10	2	2	2
Amistar	Drover	0	0	0	0	0	0	0	0
Amistar	Genie	0	0	0	2	3	2	0	0
Amistar	Coolabah	0	0	2	3	5	0	0	0
Jockey	Drover	0	0	0	2	3	2	2	3
Jockey	Genie	5	0	13	20	20	3	10	10
Jockey	Coolabah	5	2	20	22	23	8	10	13

2.1.6 Forage yield

Fungicide treatment had a significant effect on forage yield (Table 10) during the middle part of the season (Cuts 3–5) and towards the end of the season (Cut 7 and Total). Genotype effects were significant throughout the season, except for Cuts 4 and 7. The interaction between genotype and fungicide was also significant for Cuts 4 and 5.

Table 10: F probabilities and co-efficient of variation (cv%) from analysis of variance of forage yield at Gatton in 2013 (F values less than 0.05 are statistically significant - shaded).

Source of variation	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Total
Fungicide	0.601	0.212	0.002	<.001	0.001	0.141	0.017	0.146	<.001
Genotype	<.001	<.001	<.001	0.207	<.001	<.001	0.397	<.001	<.001
Fungicide x Genotype	0.93	0.265	0.47	<.001	0.013	0.572	0.76	0.379	0.239
cv%	9.4	6.6	8.7	5.2	5.9	5.9	8.4	13.5	5.1

The effect of fungicide and genotype on forage yield for each cut is presented in graphical form in Appendix 7.6, and in Tables 11 and 12 below. The application of Tilt, Folicur and Amistar had no effect early in the season (Cuts 1 and 2), but produced significantly higher forage yields for most of the remaining cuts, and for total forage yield (Table 11). This response was very large for Cuts 4 and 5, when leaf rust levels in the control plots were at a moderate level. Seed treatment with Jockey did not produce any effect on forage yield.

Table 11: Effect of five fungicide treatments on the mean forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars (Drover, Genie, and Coolabah) at Gatton in 2013.

Treatment	Cut 1		Cut 2		Cut 3		Cut 4		Cut 5		Cut 6		Cut 7		Cut 8		Total	
Control	945	*0*	1583	*0*	1151	*0*	1019	*0*	1027	*0*	1734	*0*	1535	*0*	1840	*0*	10834	*0*
Tilt	913	*-3*	1599	*1*	1249	*9*	1392	*37*	1233	*20*	1817	*5*	1761	*15*	2089	*14*	12053	*11*
Folicur	926	*-2*	1608	*2*	1288	*12*	1343	*32*	1249	*22*	1828	*5*	1729	*13*	2040	*11*	12012	*11*
Amistar	921	*-2*	1556	*-2*	1366	*19*	1495	*47*	1249	*22*	1871	*8*	1751	*14*	2068	*12*	12139	*12*
Jockey	909	*-4*	1649	*4*	1109	*-4*	996	*-2*	1054	*3*	1698	*-2*	1601	*4*	1951	*6*	10965	*1*
LSD (5%)	ns		ns		99		88		101		ns		137		ns		542	

Genie produced around 10% more total forage yield than Drover or Coolabah (Table 12), and produced higher forage yield than the other cultivars for most cuts, with the exception of Cuts 3 and 5, where both Drover and Coolabah had better recovery than Genie.

Table 12: Forage yield (kg/ha dry weight) and yield relative to Genie (% in italics) of three forage oat cultivars at Gatton in 2013.

Genotype	Cut 1		Cut 2		Cut 3		Cut 4		Cut 5		Cut 6		Cut 7		Cut 8		Total	
Drover	814	-27	1699	-15	1074	16	1246	1	1186	12	1638	*-17*	1696	*0*	2053	*-12*	11406	*-8*
Genie	1121	0	2005	0	924	0	1229	0	1060	0	1969	*0*	1696	*0*	2334	*0*	12337	*0*
Coolabah	833	-26	1093	-45	1700	84	1272	4	1242	17	1762	*-11*	1634	*-4*	1605	*-31*	11058	*-10*
LSD (5%)	66		80		81		ns		52		80		ns		206		452	

d. Wellcamp 2013

2.1.7 Leaf rust incidence

Leaf rust incidence was low to moderate at the Wellcamp trial site during 2013 (Table 13). The application of Tilt, Folicur and Amistar reduced the incidence of leaf rust to virtually nil for all cuts. The seed treatment, Jockey, also reduced leaf rust incidence for the first cut, but had no effect later in the season.

Table 13: Mean leaf rust infection of forage oat plots (as percentage leaf area infected) prior to cutting at Wellcamp in 2013 (where 0 = no infection, 20-30 = moderate infection).

Treatment	Genotype	Cut 1	Cut 2	Cut 3
Control	Drover	0	5	10
Control	Genie	5	5	20
Control	Coolabah	10	10	20
Tilt	Drover	0	0	0
Tilt	Genie	0	0	5
Tilt	Coolabah	0	0	5
Folicur	Drover	0	0	0
Folicur	Genie	0	0	5
Folicur	Coolabah	0	0	5
Amistar	Drover	0	0	0
Amistar	Genie	0	0	0
Amistar	Coolabah	0	0	0
Jockey	Drover	0	0	10
Jockey	Genie	0	5	20
Jockey	Coolabah	0	10	20

2.1.8 Forage yield

The effect of genotype on forage yield was significant for all cuts and for total forage yield at Wellcamp in 2013 (Table 14). The effect of fungicide treatment on forage yield was only significant for Cut 3 and for total forage yield. There were also significant treatment interactions between genotype and fungicide for Cuts 2, 3 and total forage yield.

Table 14: F probabilities and co-efficient of variation (cv%) from analysis of variance of forage yield at Wellcamp in 2013 (F values less than 0.05 are statistically significant - shaded).

Source of variation	Cut 1	Cut 2	Cut 3	Total
Fungicide	0.571	0.237	<.001	<.001
Genotype	<.001	<.001	<.001	<.001
Fungicide x Genotype	0.878	0.011	0.001	<.001
cv%	7.3	6.2	11.4	5.3

The effect of fungicide and genotype on forage yield for each cut is presented in graphical form in Appendix 7.7, and in Tables 15 and 16 below. Fungicide treatment has no effect on forage yield in the first and second cuts; however Tilt, Folicur and Amistar produced a large increase in forage yield for the third cut (Table 15). This effect was greatest in the most susceptible cultivars Genie and Coolabah, but was much lower in Drover, producing the significant interaction between genotype and fungicide. The effect of Amistar was significantly higher than Tilt, but not significantly different from Folicur.

Table 15: Effect of five fungicide treatments on the mean forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars (Drover, Genie, and Coolabah) at Wellcamp in 2013.

Treatment	Cut 1		Cut 2		Cut 3		Total	
Control	1703	*0*	2500	*0*	2358	*0*	6561	*0*
Tilt	1735	*2*	2715	*9*	3094	*31*	7554	*15*
Folicur	1771	*4*	2723	*9*	3410	*45*	7916	*21*
Amistar	1808	*6*	2675	*7*	3813	*62*	8309	*27*
Jockey	1704	*0*	2659	*6*	2370	*1*	6740	*3*
LSD (5%)	ns		ns		432		634	

Genie produced the highest total forage yield and the highest forage yield for Cuts 1 and 3 (Table 16). Both Drover and Coolabah recovered better than Genie for Cut 2

Table 16: Forage yield (kg/ha dry weight) and yield relative to Genie (% in italics) of three forage oat cultivars at Wellcamp in 2013.

Genotype	Cut 1		Cut 2		Cut 3		Total	
Drover	1466	*-33*	2858	*23*	2863	*-28*	7187	*-15*
Genie	2189	*0*	2318	*0*	3976	*0*	8484	*0*
Coolabah	1577	*-28*	2787	*20*	2188	*-45*	6552	*-23*
LSD (5%)	97		126		262		301	

5. Discussion

a. Relevance of field trials to commercial crops

Leaf rust was established in the spreader rows for each trial using artificial inoculation, but this rust inoculum did not transfer onto the treatment plots as effectively as anticipated. In addition, there was a lack of infection events (cool wet conditions) particularly in the dryland trials at Wellcamp, and the regular timing of the cuts did not allow the infection level on leaves to increase to a high level. However, there was a persistent low level of infection in control plots at both sites in both years, and this rose to a moderate level when conditions were suitable. This is a common situation in commercial crops of forage oats using susceptible varieties, where a low level of leaf rust will persist on the lower crop canopy for several months, and this can increase to a moderate to high level if weather conditions are suitable.

Trials in this project were conducted under either irrigated conditions (Gatton) or under dryland conditions (Wellcamp). The level of forage yield achieved from both trials is representative of what can be achieved in commercial situations, assuming that crop establishment is good and that adequate nutrition is provided. Results from individual cuts from the irrigated trials are representative of commercial crops grown under centre pivot irrigation, under high rainfall conditions in coastal areas, or under good rainfall conditions on deep clay soils. Results from individual cuts from the dryland trials are representative of commercial crops grown under good rainfall conditions on shallow soils or under tougher conditions in more marginal growing areas. Therefore, the results of these field trials are relevant to commercial situations, both in terms of the level of leaf rust infection, and the level of forage yield achieved.

b. Effect of genotype

The cultivars used in these trials, Drover, Genie, Coolabah and Taipan, are broadly representative of the cultivars used for most commercial forage oat crops in Queensland and northern New South Wales. Drover was chosen as a leaf-rust resistant variety, although it became susceptible during the conduct of the trials due to the appearance of a new race of leaf rust which attacks this cultivar. Genie is a recent commercial release from the DAFF program, which was originally resistant to leaf rust, but is now susceptible. It was selected under local environmental conditions and has very high forage yield and late maturity. Coolabah is a dual purpose variety with medium maturity, intended for sheep grazing and grain production, and released from New South Wales DPI in 1967. Coolabah is representative of a large number of dual purpose oat varieties which are planted for cattle grazing in large areas of Queensland and northern New South Wales, despite having much lower forage yield and being highly susceptible to leaf rust. Seed of these older public cultivars (i.e. cultivars not registered under the Plant Breeder's Rights) is much cheaper than proprietary cultivars. Taipan is a popular proprietary cultivar released in 2002 with late maturity, moderate forage yield and has been susceptible to leaf rust for many years.

In these trials, Genie consistently produced the highest total forage yield at both sites and both years. The total forage yield advantage of Genie over Coolabah ranged from 10% at Gatton in 2013 (Table 12) to 24% at Wellcamp in 2012 (Table 8). Similarly, Genie out-yielded Taipan by 16–19% in 2012 (Tables 4 and 8), and Genie out-yielded Drover by 8-15% in 2013 (Tables 12 and 16). Coolabah and Drover produced higher forage yield than Genie for some individual cuts (e.g. Gatton 2013 Cut 3 – Table 12) due to better recovery during the cooler winter months, but this not sufficient to overcome the yield advantage of Genie early and late in the season.

This inherent yield advantage of Genie demonstrates the importance of cultivar selection in determining the forage yield of a commercial crop, irrespective of the presence of a leaf rust infection or the use of fungicide treatments to control rust. In some instances, control plots of Genie without fungicide treatment and low to moderate levels of leaf rust, produced a similar level of total forage yield to plots of Coolabah treated with fungicide (e.g. Gatton 2012 Appendix 7.4; Wellcamp 2013 Appendix 7.7). This suggests that continued selection for forage yield *per se*, and the continued release of well-adapted, high yielding, late maturity cultivars will help to overcome the yield loss associated with leaf rust, even in the absence of management strategies such as fungicide application.

c. Effect of fungicide

The application of fungicide to susceptible cultivars in the presence of low levels of leaf rust (0–10% leaf area infected) did not produce a significant increase in forage yield. However, the application of fungicide in the presence of moderate levels of leaf rust (20–30% leaf area infected) did produce a significant increase in forage yield, ranging from around 10% to over 60%, although the response was not consistent across all cuts. In Cut 5 of the Gatton 2012 trial, level of leaf rust was moderate in the control plots (Table 1), but the application of fungicide did not significantly increase forage yield (Table 3).

Clearly, there are other factors influencing the effect of leaf rust infection on forage yield in addition to the response to fungicide application. The relative virulence (or aggressiveness) of leaf rust in response to temperature at different times of the season will influence the severity of the effect of leaf rust infection on forage yield.

For example, comparing Cuts 3 and 4 at Gatton in 2013 (Tables 9 and 11), the level of leaf rust infection in control plots and the level of forage yield were very similar for both cuts. However, the response to fungicide application was much higher (32–47%) for Cut 4 than the response for Cut 3 (9–19%).

The application of fungicide is also likely to have a beneficial effect on general plant health, which will extend well beyond the normal cutting interval of 4 – 6 weeks. For example, in Cut 3 of the Wellcamp 2013 trial, the increase in forage yield from the application of fungicide (Table 15) was much greater than would be expected from the moderate level of leaf rust infection (Table 13). The interval between Cuts 2 and 3 was much longer in this trial, about 10 weeks as compared to 4–6 weeks normally, and the trial experienced severe moisture stress during this period. The application of fungicide earlier in the season probably improved plant health and encouraged development of the root system, although it did not produce a significant increase in forage yield. Healthier plants with deeper root systems may respond better to drought stress, producing the large response in forage yield, as seen for Cut 3 (Table 15). The application of the three fungicide treatments did not cause a significant reduction in forage yield in any of the trials suggesting that there are no negative or phytotoxic effects of these active ingredients.

The application of Amistar produced a lower level of leaf rust infection and a higher level of forage yield in comparison to the application of Tilt or Folicur, although this effect was only statistically significant in a small number of cuts. Amistar is known to have a longer period of bio-efficacy (i.e. it provides a longer window of protection) than Tilt and Folicur, and is likely to provide a better degree of control in commercial situations. However, Amistar also has a longer withholding period for grazing (21 days) and is significantly more expensive than Tilt or Folicur (Appendix 8.2). Amistar is not currently registered for commercial application on forage oats, but may be registered when it is off-patent and becomes more affordable. The effects of Tilt and Folicur on leaf rust infection or forage yield were not significantly different to each other, suggesting there is no relative advantage to either chemical. Tilt has a lower withholding period (7 days) in comparison to Folicur (14 days), but Folicur has a lower application cost.

The use of the Jockey seed treatment produced a slight decline in leaf rust incidence for the early cuts at both sites in 2013, compared with the untreated control. This is consistent with the period of 4–6 weeks of suppression as suggested on the chemical label. However, this decline in leaf rust incidence did not translate into a significant increase in forage yield in either of the two trials in 2013. It is possible that the protective effect of the Jockey seed treatment may be more useful for early planted crops of forage oats (e.g. February planting, compared with an April planting date used in these trials) that are susceptible to leaf rust and are exposed to high disease pressure.

d. Interaction between genotype and fungicide

Interactions between genotype and fungicide occurred in some cuts of the 2013 trials. In both cases, this was mostly due to the fact that Drover, a previously resistant variety that only had a low level of leaf rust incidence in these trials, did not respond to the application of fungicide treatments in the same way as the susceptible cultivars Genie and Coolabah. In Cuts 4 and 5 at Gatton in 2013 (Table 17) and also in Cuts 2 and 3 at Wellcamp in 2013 (Table 18), the application of fungicide produced a very large increase in forage yield for Genie and Coolabah, but only a small increase in yield of Drover.

Table 17: Forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars and four fungicide treatments at Gatton in 2013.

Genotype	Fungicide	Cut 4		Cut 5	
Drover	Control	1208	*0*	1080	*0*
Drover	Tilt	1260	*4*	1143	*6*
Drover	Folicur	1265	*5*	1271	*18*
Drover	Amistar	1327	*10*	1289	*19*
Drover	Jockey	1168	*-3*	1146	*6*
Genie	Control	825	*0*	903	*0*
Genie	Tilt	1460	*77*	1174	*30*
Genie	Folicur	1460	*77*	1157	*28*
Genie	Amistar	1541	*87*	1098	*22*
Genie	Jockey	860	*4*	966	*7*
Coolabah	Control	1025	*0*	1098	*0*
Coolabah	Tilt	1457	*42*	1383	*26*
Coolabah	Folicur	1303	*27*	1320	*20*
Coolabah	Amistar	1617	*58*	1417	*29*
Coolabah	Jockey	960	*-6*	1049	*-4*
LSD (5%)		119		131	

Table 18: Forage yield (kg/ha dry weight) and yield relative to control (% in italics) of three forage oat cultivars and four fungicide treatments at Wellcamp in 2013.

Genotype	Fungicide	Cut 2		Cut 3		Total	
Drover	Control	2887	*0*	2676	*0*	6987	*0*
Drover	Tilt	2945	*2*	2776	*4*	7143	*2*
Drover	Folicur	2852	*-1*	2876	*7*	7297	*4*
Drover	Amistar	2601	*-10*	3346	*25*	7487	*7*
Drover	Jockey	3007	*4*	2641	*-1*	7031	*1*
Genie	Control	2160	*0*	2741	*0*	7065	*0*
Genie	Tilt	2432	*13*	4136	*51*	8769	*24*
Genie	Folicur	2421	*12*	4904	*79*	9487	*34*
Genie	Amistar	2410	*12*	5182	*89*	9901	*40*
Genie	Jockey	2167	*0*	2918	*6*	7239	*2*
Coolabah	Control	2454	*0*	1659	*0*	5632	*0*
Coolabah	Tilt	2767	*13*	2370	*43*	6753	*20*
Coolabah	Folicur	2896	*18*	2449	*48*	6969	*24*
Coolabah	Amistar	3014	*23*	2911	*76*	7543	*34*
Coolabah	Jockey	2803	*14*	1552	*-6*	5948	*6*
LSD (5%)		303		608		790	

e. Timing of fungicide application

In this study, fungicide treatments were applied around 7–10 days after cutting and plots were cut every four weeks under irrigated conditions, and every 6–8 weeks under dryland conditions. This cutting interval allowed sufficient time for the fungicide to be translocated through the plant tissue, to visibly reduce the level of fungal infection and produce a measureable improvement in forage yield. Since Tilt and Folicur have a withholding period for grazing of 7 days and 14 days respectively the timing of fungicide application will be important in managing a leaf rust infection while avoiding possible contamination problems.

Experience in these trials suggests that, in commercial crops, fungicides should be applied as soon as there is sufficient leaf area to ensure good uptake of the active ingredient. This would normally be 7–14 days after grazing, assuming sufficient soil moisture to promote recovery from grazing. Grazing should then commence only after the withholding period has expired, but this would normally be less than the time required for the crop to recover for further grazing. This assumes that strip grazing or rotational grazing is practiced, where cattle are removed from some sections of the crop to allow recovery, while grazing other sections. If continuous grazing is used, timing of fungicide application would be more difficult to achieve without some level of contamination. However, strip grazing tends to be more common in higher yielding environments where fungicide application is more likely to be beneficial, and continuous grazing tends to be more common in lower yielding environments where fungicide application is unlikely to have a net benefit.

f. Summary of fungicide response

In summary of the treatment responses in these trials, a low level of leaf rust infection (less than 10% of leaf area affected) generally caused only a small decline in forage yield (8-10%), compared with fungicide treated plots. A moderate level of leaf rust infection (15–30%) produced a moderate decline in forage yield, ranging from 10–60% depending on the time of infection, the length of time between cuts and environmental conditions.

The application of fungicide was generally effective in increasing forage yield when leaf rust infection had occurred, and the size of the increase in forage yield was proportional to the level of leaf rust infection. The size of the increase in forage yield is likely related to other factors such as the time of year, the length of time between cuts, seasonal conditions, and the presence of other disease or nutritional constraints. The application of fungicide did not completely remove the symptoms of infection, but reduced the level of symptoms to below the level likely to cause significant yield loss. The application of fungicide is also likely to have general benefits to plant health beyond the normal period of leaf rust suppression.

The fungicides Tilt and Folicur were equally effective and both significantly reduced leaf rust incidence and increased forage yield, particularly when leaf rust infection was moderate. The fungicide Amistar was slightly more effective and produced a slightly higher forage yield, but is more expensive to apply than Tilt and Folicur, and is not registered for oats at this time.

6. Economic value of fungicide application

a. Simple model using marginal comparison

An important aspect of this project was to calculate the economic value of the increase in forage yield as a result of fungicide application, and to compare this with the cost of fungicide application. This information would be used to develop a set of recommendations on the circumstances where fungicide application to control rust on forage oat is likely to be economically beneficial.

After consultation with beef extension officers and agricultural economists in DAFF Queensland with experience in forage oats, a simple spreadsheet model was developed to make a marginal comparison between the economic value of yield loss in forage oat crops due to leaf rust infection with the cost of fungicide application. The sensitivity of the model was also examined over a range of forage yield levels and liveweight prices at different levels of leaf rust infection.

To calculate the amount of liveweight gain for a given level of forage yield, a simple equation taken from Bowen, Buck et al. (2011) was used:

$$\text{Total liveweight production (kg/ha)} = \text{Available biomass}^{1}\ \text{(kg DM/ha)} \times \text{Biomass utilisation}^{2} \times \text{Efficiency of feed utilisation}^{3}$$

[1] Estimated total biomass less residual for 100 day grazing period
[2] Proportion consumed by animal after trampling and other wastage
[3] Amount of liveweight gain in cattle per unit plant biomass consumed

For the purpose of this exercise, it was assumed that a reduction in available biomass caused by a given level of leaf rust infection will cause a proportional reduction in carrying capacity of the forage oat crop and a proportional reduction in gross income from total liveweight production.

$$\text{Loss of gross income (\$/ha)} = \text{Total liveweight production (kg/ha)} \times \text{Livestock price (\$/kg)} \times \text{Yield loss (\%)}$$

A simple model was set up to examine the economic benefit from the application of fungicide to control leaf rust infection in a commercial forage oat crop. The model assumed a 100 day period of grazing across three different sets of growing conditions: (a) irrigated - 6000 kg DM/ha; (b) good dryland – 4000 kg DM/ha; and (c) marginal dryland – 2000 kg DM/ha. Figures for biomass utilisation and efficiency of feed utilisation were obtained from DAFF extension staff and are indicative of young cattle grazing forage oat crops. Liveweight price for young steers was assumed to be around $2.00/kg. The model used two levels of leaf rust infection: (a) low infection – causing 10% yield reduction; and (b) moderate infection – causing 25% yield reduction. These figures for the level of yield reduction were arbitrary but were estimated from the overall trend of data from the field trials, and are indicative of yield loss likely in commercial crops. It was also assumed that a low level of infection will require one fungicide application to prevent yield loss, and a moderate infection would require two applications. The cost of application was assumed to be around $10.00/ha for chemical plus $10.00/ha for machinery and fuel, although fungicide can be applied at a lower cost in commercial situations.

The results of the simulation are shown in Table 19. Application of fungicide to control leaf rust was shown to be of most benefit in irrigated crops with a high level of forage yield, particularly when leaf rust infection was moderate. Application of fungicide is also beneficial in good dryland crops, particularly when leaf rust infection was moderate. In marginal dryland crops, with a low level of forage yield, the benefit of fungicide application was either very low or negative. The results suggest that application of fungicide is likely to be economically beneficial when forage oat crops are grown under irrigation or under high yielding dryland conditions. The size of the benefit also depends on the level of leaf rust infection, with a higher level of infection giving a greater economic benefit.

A simple sensitivity analysis was constructed to further examine the effect of forage yield, leaf rust infection and liveweight price of cattle on the net benefit of fungicide application. The net benefit of fungicide application was calculated for a range of biomass yields, liveweight prices and two levels of leaf rust infection (Tables 20 and 21). The results show that the net benefit of fungicide application is highly sensitive to the level of forage yield of the crop. The net benefit of fungicide application increases significantly as the forage yield of the crop increases. The level of leaf rust infection also determines the size of the net benefit for fungicide application. The net benefit of fungicide application is much larger as the level of rust infection increases. However, changes in the liveweight price did not have a large effect on the net benefit of fungicide application. An increase in the liveweight price led to a slight increase in net benefit of fungicide application, but the threshold level at which application of fungicide becomes economically beneficial did not change significantly. The threshold of forage yield at which fungicide application becomes economically beneficial appears to be around 3000 kg DM/ha for crops with a low level of leaf rust infection and around 2500 kg DM/ha for crops with a moderate level of infection.

For this analysis, it was assumed that a reduction in available biomass caused by a given level of leaf rust infection will cause a proportional reduction in carrying capacity of the forage oat crop and a proportional reduction in gross income from total liveweight production. This assumption was not tested but is believed to be acceptable for this analysis. However, leaf rust infection is known to reduce the palatability of forage oats, particularly at high levels of infection. It is possible that the reduction in liveweight gain of cattle grazing leaf rust infected crops may be greater than the levels assumed here, due to a greater than expected reduction in forage intake caused by reduced palatability. This effect is likely to increase rather than decrease the net benefit from application of fungicide.

Table 19: Results of simple model for estimation of net economic benefit of fungicide application on forage oat crops infected with leaf rust.

Growing Conditions	Available biomass[1] (kg DM/ha)	Biomass Utilisation[2]	Efficiency of feed utilisation[3]	Total liveweight production (kg/ha)	Liveweight price ($/kg)	Gross income ($/ha)	Level of rust infection	Estimate of yield loss %	Income loss[4] ($/ha)	No. applications required for control	Application cost of Tilt & Folicur ($/ha)	Net benefit ($/ha)	Benefit?
Irrigated	6000	0.4	0.11	264	$2.00	$528	Low	10	$53	1	$20	$33	Yes
							Moderate	25	$132	2	$40	$92	Yes
Good Dryland	4000			176		$352	Low	10	$35	1	$20	$15	Yes
							Moderate	25	$88	2	$40	$48	Yes
Marginal Dryland	2000			88		$176	Low	10	$18	1	$20	-$2	No
							Moderate	25	$44	2	$40	$4	Yes

[1] Estimated total biomass less residual for 100 day grazing period
[2] Proportion consumed by animal after trampling and other wastage
[3] Amount of liveweight gain in cattle per unit plant biomass consumed
[4] Assuming that the reduction in liveweight production and gross income is proportional to reduction in available biomass from rust infection

Table 20: Sensitivity of liveweight price and available biomass on net benefit ($/ha) of fungicide application when leaf rust infection is low (10% yield loss and one fungicide application) – cells shaded grey indicate no net benefit.

Liveweight Price ($/kg)	Available biomass (kg DM/ha)												
	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
$1.80	-$12	-$8	-$4	$0	$4	$8	$12	$16	$20	$24	$28	$31	$35
$1.90	-$12	-$7	-$3	$1	$5	$9	$13	$18	$22	$26	$30	$34	$39
$2.00	-$11	-$7	-$2	$2	$6	$11	$15	$20	$24	$28	$33	$37	$42
$2.10	-$11	-$6	-$2	$3	$8	$12	$17	$22	$26	$31	$35	$40	$45
$2.20	-$10	-$5	-$1	$4	$9	$14	$19	$24	$28	$33	$38	$43	$48

Table 21: Sensitivity of liveweight price and available biomass on net benefit ($/ha) of fungicide application when leaf rust infection is moderate (25% yield loss and two fungicide applications) – cells shaded grey indicate no net benefit.

Liveweight Price ($/kg)	Available biomass (kg DM/ha)												
	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
$1.80	-$20	-$10	$0	$10	$19	$29	$39	$49	$59	$69	$79	$89	$99
$1.90	-$19	-$9	$2	$12	$23	$33	$44	$54	$65	$75	$85	$96	$106
$2.00	-$18	-$7	$4	$15	$26	$37	$48	$59	$70	$81	$92	$103	$114
$2.10	-$17	-$5	$6	$18	$29	$41	$52	$64	$76	$87	$99	$110	$122
$2.20	-$16	-$4	$8	$21	$33	$45	$57	$69	$81	$93	$105	$117	$129

b. Detailed model using gross margin analysis

A detailed model was also used to estimate the net benefit of fungicide application in forage oat, using comparisons of gross margin analysis as suggested by Chudleigh 2014 (pers. comm.) and based on the standard procedures outlined in Makeham and Malcolm (1993).

This simulation used the same three sets of growing conditions with corresponding levels of biomass production, and the same two sets of leaf rust infection and reduction in total liveweight production as used by the simple simulation model above. All other parameters and estimates were the same as those used in the simple model. A gross margin budget was prepared for each of these scenarios with a leaf rust infected crop, firstly without fungicide application, and secondly with fungicide application. A sample gross margin for a moderate leaf rust infection under good dryland conditions is shown in Appendix 8.8. The gross margin for each example, with leaf rust infection and with fungicide application, were compared in each case to give a figure for net benefit ($/ha). A summary of results is shown in Table 22.

An application of fungicide to control leaf rust infection produced a net economic benefit under both irrigated and good dryland conditions and under low and moderate level of leaf rust infection. Under marginal dryland conditions, the application of fungicide did not produce a net economic benefit. The size of the net benefit using the detailed gross margin model was smaller than the net benefit predicted by the simple model. However, both models predicted that a net benefit for fungicide application was more likely under irrigated and good dryland conditions, and less likely under marginal dryland conditions. Similarly, both models predicted that a net benefit of fungicide application was more likely when the level of leaf rust infection was moderate, except under marginal dryland conditions where there was no net benefit.

c. Industry recommendations

This analysis shows that application of fungicide to control leaf rust is likely to be beneficial when the crop is grown under irrigated or good dryland conditions, particularly when the level of leaf rust is at least moderate. However, if the crop is grown under marginal dryland conditions, application of fungicide to control leaf rust is not likely to be economically worthwhile, even if leaf rust is at a moderate level.

It is recommended that more forage oat growers be made aware of the potential for use of fungicides to control leaf rust, and the likely economic benefits especially under irrigated and good dryland conditions. Numerous generic versions of the two main active ingredients, propiconazole and tebuconazole are widely available and many forage oat growers have the required equipment for broad acre application. However, growers should be cautious of the withholding period after applying fungicide to forage oat crops to ensure no contamination.

Also, the use of fungicides should only be regarded as one option in a range of strategies that forage oat growers can use to minimise the effects of leaf rust. Other options for rust management include:

- grazing or cutting rusted crops before the disease becomes severe
- selection of cultivars with good resistance to leaf rust
- selection of high yielding, late maturity cultivars
- avoiding planting too early (before mid March) or too late (after June)
- controlling out-of-season oat plants and wild oats
- planting in wider rows to produce an open canopy and reduce losses from trampling
- maintaining good soil and crop nutrition with nitrogen which will minimise the effects of leaf rust.

Table 22: Results of detailed gross margin analysis for estimation of net economic benefit of fungicide application on forage oat crops infected with leaf rust.

Growing Conditions	Available biomass[1] (kg DM/ha)	Biomass Utilisation[2]	Efficiency of feed utilisation[3]	Total liveweight production (kg/ha)	Level of rust infection	Estimate of yield loss %	No. applications required for control	Application cost of Tilt & Folicur ($/ha)	Gross margin with leaf rust present	Gross margin with fungicide treatment	Net benefit ($/ha)	Benefit?
Irrigated	6000	0.4	0.11	264	Low	10	1	$20	$38	$53	$15	Yes
					Moderate	25	2	$40	-$13	$33	$46	Yes
Good Dryland	4000			176	Low	10	1	$20	$76	$79	$3	Yes
					Moderate	25	2	$40	$42	$59	$17	Yes
Marginal Dryland	2000			88	Low	10	1	$20	-$27	-$35	-$8	No
					Moderate	25	2	$40	-$44	-$55	-$12	No

[1] Estimated total biomass less residual for 100 day grazing period
[2] Proportion consumed by animal after trampling and other wastage
[3] Amount of liveweight gain in cattle per unit plant biomass consumed

7. Conclusions

The application of fungicide to susceptible forage cultivars in the presence of low levels of leaf rust (0–10% leaf area infected) did not produce a significant increase in forage yield. However, the application of fungicide in the presence of moderate levels of leaf rust (20–30% leaf area infected) did produce a significant increase in forage yield, although the size of the response varied according to other factors such as the time of year, seasonal conditions and the length of time between cuts.

Cultivar selection is important in determining the forage yield of a commercial crop, irrespective of the presence of a leaf rust infection or the use of fungicide treatments to control rust. Selection of high yielding, late maturity cultivars will help to overcome the yield loss associated with leaf rust, even in the absence of management strategies such as fungicide application.

The application of fungicide to control leaf rust is likely to have a beneficial effect on general plant health, which will extend beyond the normal cutting or grazing interval. Healthier plants with deeper root systems may respond better to drought stress, producing a larger response in forage yield than would be expected from the level of leaf rust infection.

The fungicides, Tilt and Folicur, were both satisfactory in reducing the level of leaf rust infection in susceptible varieties to a level where there was no significant reduction in forage yield. The effects of Tilt and Folicur on leaf rust infection or forage yield were not significantly different to each other, suggesting there is no relative advantage to either chemical.

The fungicide Amistar produced a lower level of leaf rust infection and a slightly higher level of forage yield in comparison to the application of Tilt or Folicur, but Amistar has a longer withholding period for grazing, is significantly more expensive than Tilt or Folicur and is not currently registered for commercial application on forage oats. The seed treatment, Jockey Stayer, produced a slight decline in leaf rust incidence but did not produce a significant increase in forage yield. There were no negative or phytotoxic effects from these fungicides in these trials.

Fungicides should be applied as soon as there is sufficient leaf area to ensure good uptake of the active ingredient. This would normally be 7–14 days after grazing, assuming sufficient soil moisture to promote recovery from grazing. Grazing should then commence only after the withholding period has expired, but this would normally be less than the time required for the crop to recover for further grazing.

Economic modelling showed that the application of fungicide to control leaf rust is most likely to produce an net economic benefit when the crop is grown under irrigated conditions or under good dryland conditions, and unlikely to produce a net benefit under marginal dryland conditions. The threshold of forage yield at which fungicide application becomes economically beneficial appears to be around 3000 kg DM/ha for crops with a low level of leaf rust infection and around 2500 kg DM/ha for crops with a moderate level of infection.

The application of fungicide to control leaf rust is most likely to produce a net economic benefit when the level of leaf rust infection is at least moderate, except under marginal dryland conditions. If leaf rust infection is low, the application of fungicide will only produce a small economic benefit under irrigated or very good dryland conditions.

The size of the net benefit from fungicide application will depend on the level of forage yield of the crop and the level of leaf rust infection. Cattle liveweight prices only have a small marginal effect on the net benefit of fungicide application.

8. Appendices

a. **Forage oat cutting trial plots containing fungicide treatments and leaf rust spreader rows (taller uncut plots) on Gatton in 2012 (top) and Wellcamp in 2013 (bottom).**

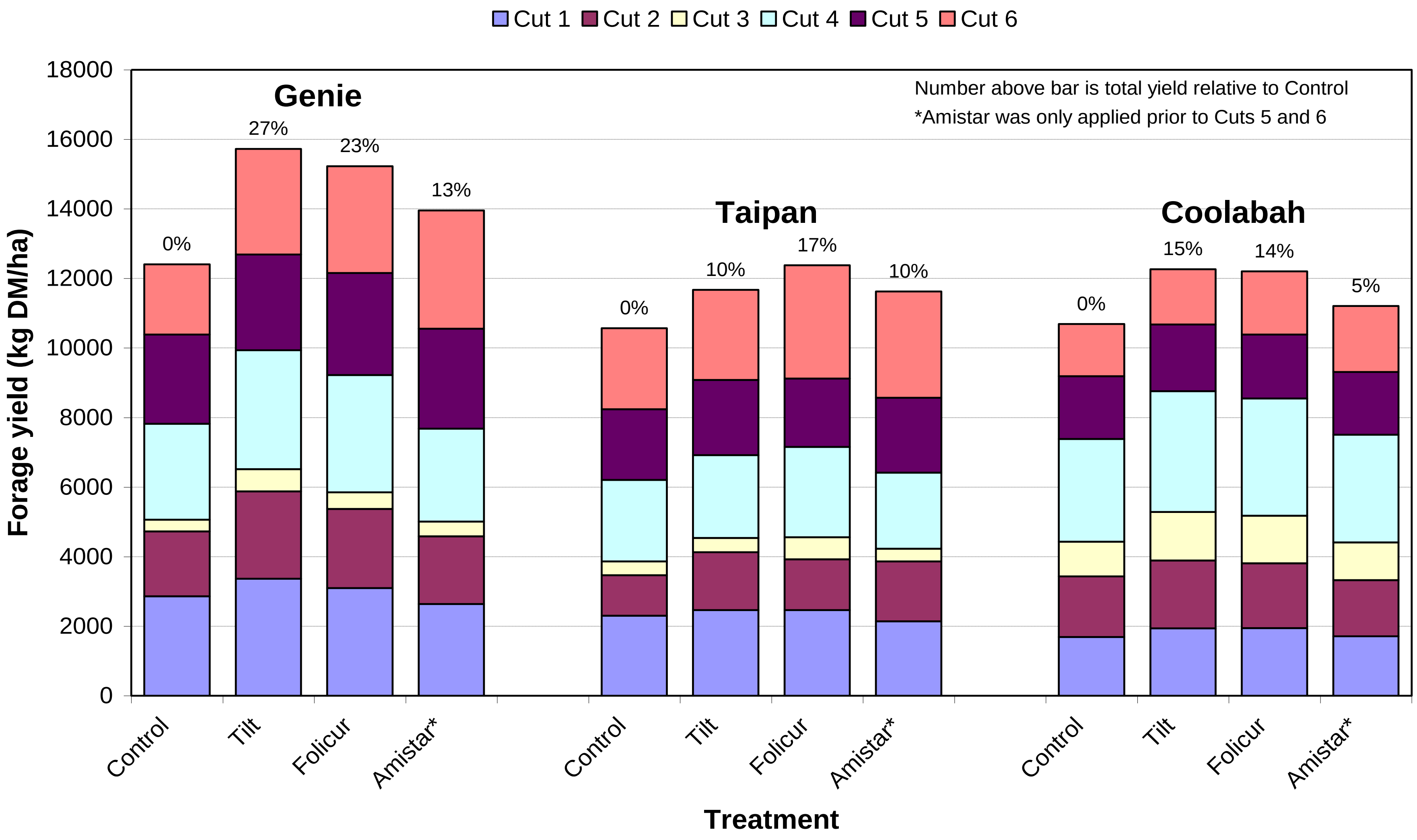
b. Commercially available foliar fungicides for control of rust disease in cereals in Australia.

Product Name	Active ingredient	Company	Indicative Purchase Cost	Application Rate	Application Cost	Withholding Period	Registered for oats
Tilt 250SC	Propiconazole	Syngenta Various generic	$14/L	500 mL/ha	$7/ha	Grazing: 7 days	Yes
Folicur 430SC	Tebuconazole	Bayer Various generic	$13/L	290 mL/ha	$4/ha	Grazing: 14 days	Yes
Prosaro 420SC	Prothioconazole +Tebuconazole	Bayer	--	300 mL/ha	--	Grazing: 14 days	Yes
Tilt Xtra	Propiconazole + Cyproconazole	Syngenta	$46/L	500 mL/ha	$23/ha	Grazing: 21 days	No
Amistar Xtra	Azoxystrobin + Cyproconazole	Syngenta	$54/L	800 mL/ha	$43/ha	Grazing: 21 days	No

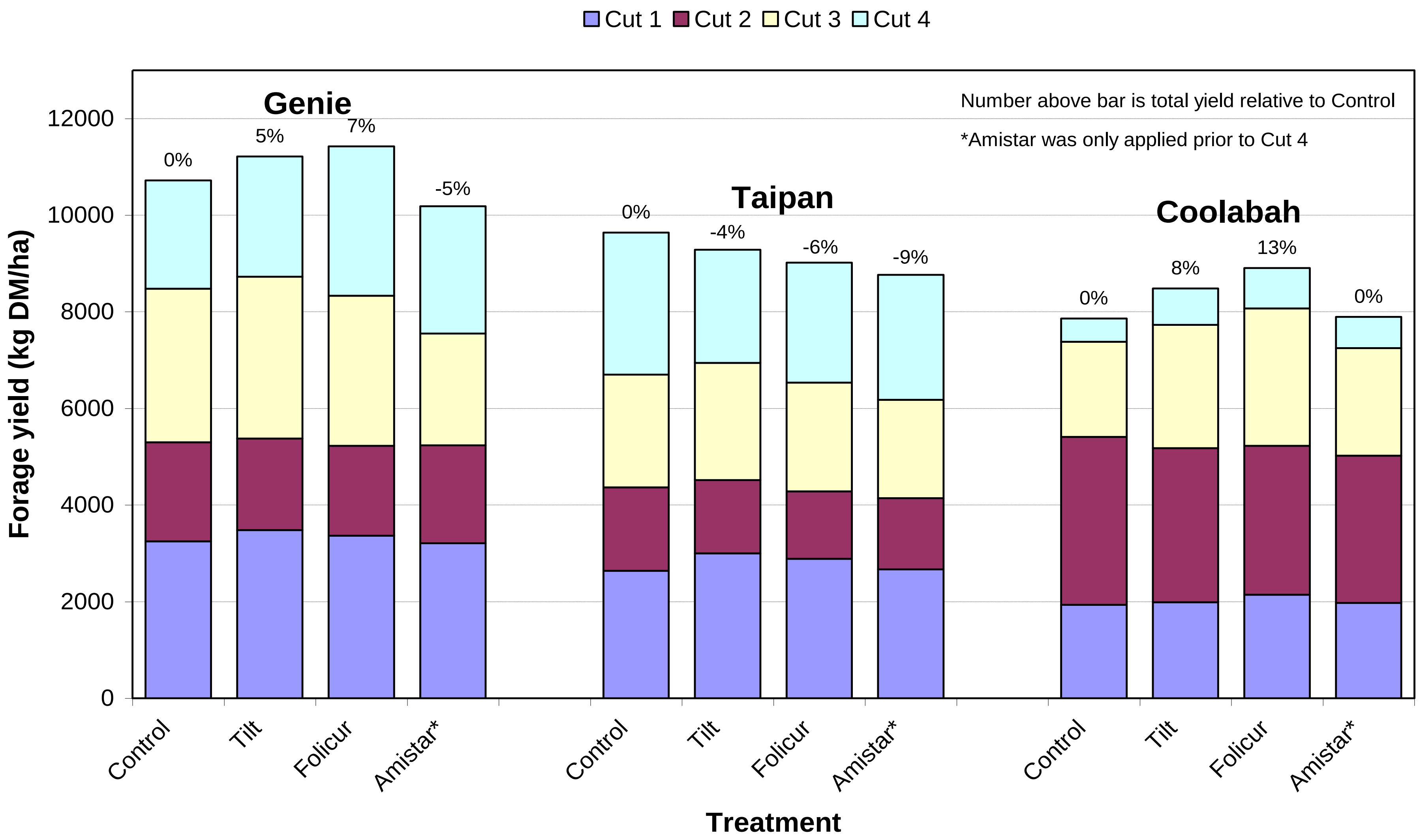
c. Commercially available seed treatments for control of rust disease in cereals in Australia.

Product Name	Active ingredient	Company	Target	Purchase Cost	Application Rate	Application Cost	Withholding Period	Registered for oats
Jockey Stayer	Fluquinconazole	Bayer	Bunts, smuts, leaf rust, stripe rust	$54.45/L	4.5L / tonne of seed	$9.80/ha	Grazing: 12 weeks from planting	No
Hombre	Imidacloprid + Tebuconazole	Bayer	Bunts, smuts, aphids (BYDV)		4.0L / tonne of seed		Grazing: 9 weeks from planting	Aphid control and smuts only
Zorro	Imidacloprid + Triadimenol	Bayer	Bunts, smuts, aphids (BYDV), and stripe rust		4.0L / tonne of seed		Grazing: 9 weeks from planting	Aphid control and smuts only

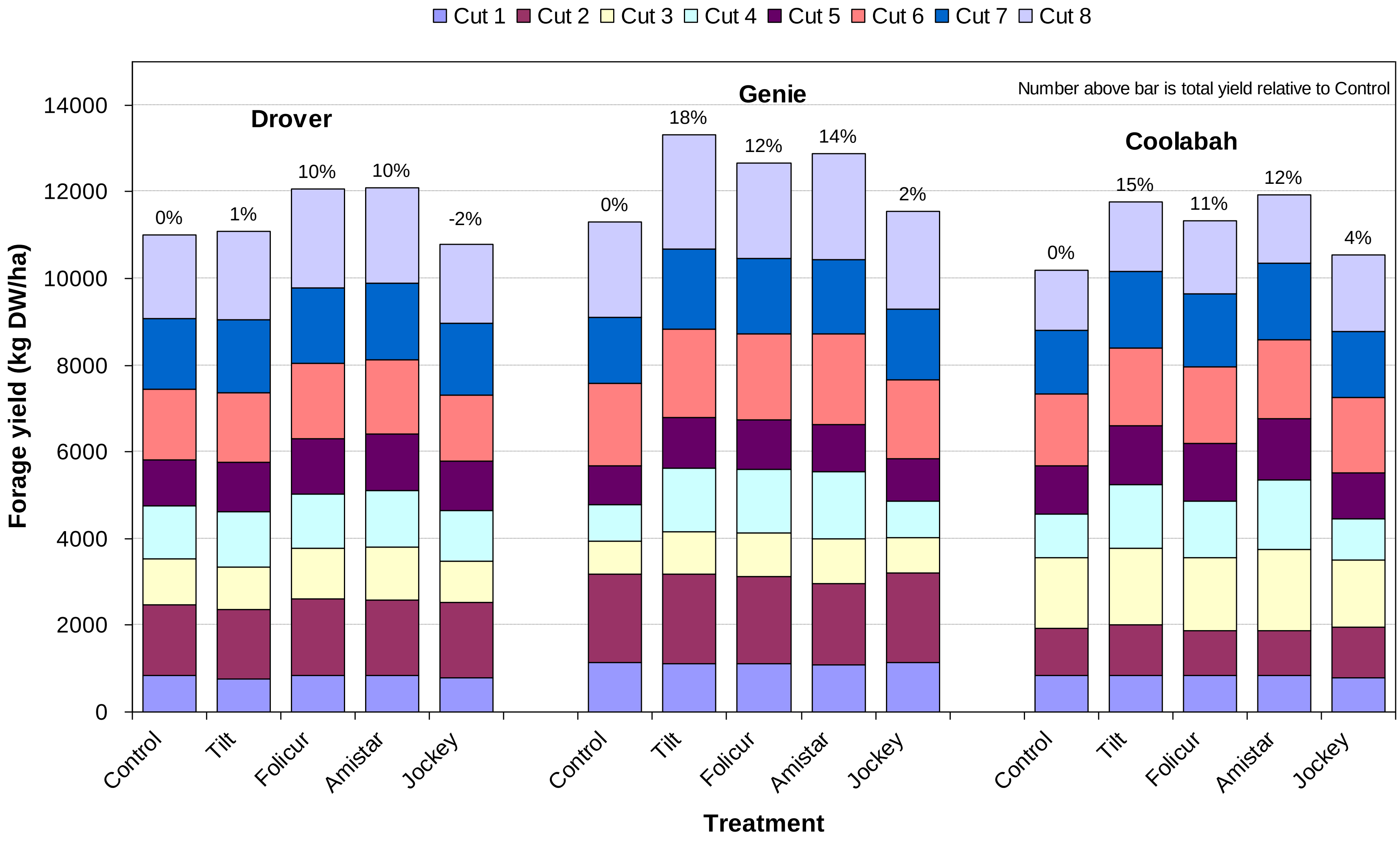
d. Forage yield of three forage oat cultivars and three fungicide treatments at Gatton in 2012.



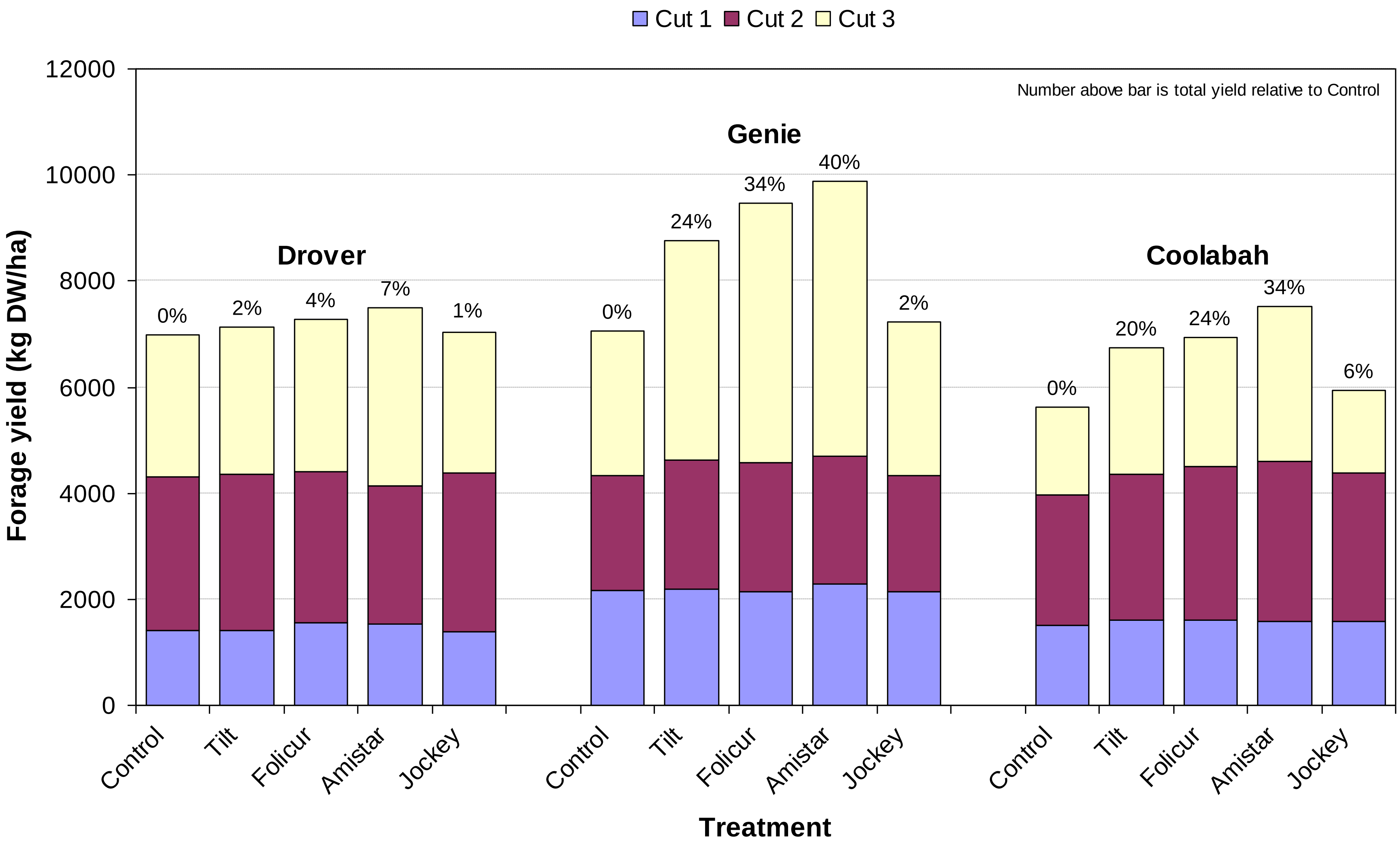
e. Forage yield of three forage oat cultivars and three fungicide treatments at Wellcamp in 2012.



f. Forage yield of three forage oat cultivars and four fungicide treatments at Gatton in 2013.



g. Forage yield of three forage oat cultivars and four fungicide treatments at Wellcamp in 2013.



h. Sample gross margin analysis for a moderate leaf rust infection of forage oat grown under good dryland conditions.

Dryland oats with a moderate level of rust infestion									
Gross margin with the disease	**$41.52**	per hectare							
Gross margin with the treatment	**$58.54**	per hectare							
Benefit of treatment	**$17.01**	per hectare							
Forage Oats with disease									
Paddock area		100	hectares						
Potential biomass production		4000	kilograms dry matter per hectare						
Biomass utilisation		0.4	Proportion consumed by animal after trampling and other wastage						
Feed efficiency		0.11	Amount of liveweight gain in cattle per unit plant biomass consumed						
Potential liveweight production		176	net liveweight kilograms of beef produced per hectare						
Reduction due to disease		25%							
Liveweight produced with disease		132.00	net liveweight kilograms of beef produced per hectare						
Gross Margin estimate of liveweight production		132.00	net liveweight kilograms of beef produced per hectare						
INCOME						**per head**		**per Ha**	**TOTAL**
Steer Selling Price		$2.00	$/kg live	596.3	kg liveweight	$1,193	/ head		
less: Livestock levy		$5.00	per head			$5.00	/ head		
Commission on sale of steers		0%	of final value			$0.00	/ head		
Yards fees		$0.00				$0.00			
Freight cost outwards		$25.00	per head			$25.00	/ head		
ON-FARM PRICE ($/head)						$1,163	/ head	**$1,681**	**$168,089**
GROSS INCOME						**$1,163**	**/head**	**$1,681**	**$168,089**
VARIABLE COSTS									
Steer Cost	$2.00	per kg live times	505	kg starting live		**$1,010**	per head	**$1,460**	**$146,026**
Steer Gain									
Stocking Rate	1.45	**head per hectare**							
Number of steers to be fattened	145	head	0.00%	**steer losses pre sale**					
Number of hectares to be grazed	100	hectares							
Average weight gain per day	1.10	kg/day							
Estimated days of grazing	83	days							
Total Gain	**91.3**	**kg per head**	**132.00**	**kilograms gained per hectare**					
Final live weight	**596.3**	**kg**							
Expected dressing percentage	52%	**310**	kg dressed weight						
Other livestock costs						per head		per hectare	
	Interest on steer capital		5%	per annum		$11.48		$16.60	$1,660
			Growth promotants			$0.00		$0.00	$0
			Induction costs			$0.00		$0.00	$0
			Veterinary costs			$0.38		$0.55	$55
			Other			$0.00		$0.00	$0
	Freight costs inwards					$22.50		$32.53	$3,253
	Commission on sale of steers		0%	of final value		$0.00		$0.00	$0
Total livestock variable costs						**$1,044**		**$1,510**	**$150,994**
Machinery Operations (Fuel Oil Repairs & Maintenance)						per head		per hectare	total
Chisel plough	0.90	workings X	$30.26	each		$18.83		$27.23	$2,723
Tyne cultivator	0.90	workings X	$16.23	each		$10.10		$14.60	$1,460
Linkage spray rig	1.80	workings X	$3.38	each		$4.21		$6.08	$608
No till seeder	0.90	workings X	$12.30	each		$7.66		$11.07	$1,107
Linkage spray rig	0.90	workings X	$3.38	each		$2.10		$3.04	$304
								Total	**$6,202**
Seed	litres, kgs or grams / ha		Treatment times	Cost / unit					
Oats seed	40.0	x	0.9	$1.00	$/kg	$24.90		$36.00	$3,600
								Total	**$3,600**
Fertilizer	litres, kgs or grams / ha		Treatment times	Cost / unit					
		x		$0.00	$/kg	$0.00		$0.00	$0
								Total	**$0**
Herbicide	litres, kgs or grams / ha		Treatment times	Cost / unit					
Amicide 625	0.75	x	1.8	$6.82		$6.37		$9.21	$921
Glyphosate 450 CT	1.50	x	1.8	$4.64		$8.66		$12.52	$1,252
MCPA LVE	1.00	x	0.9	$10.75		$6.69		$9.68	$968
								Total	**$3,140**
Fungicide	litres, kgs or grams / ha		Treatment times	Cost / unit					
		x		$0.00		$0.00		$0.00	$0
TOTAL VARIABLE COSTS						**$1,134**		**$1,639**	**$176,879**
GROSS MARGIN						**$29**		**$42**	**$4,152**
						per head		per hectare	total

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