WEED MANAGEMENT STRATEGIES IN CAVALCADE

RESEARCH CONDUCTED AT MT. KEPPLER STATION 1997 – 2004

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SUMMARY

Weed invasion, particularly by broadleaf weeds, is a major constraint to Cavalcade (*Centrosema pascuorum* cv Cavalcade) production[1]. A project was initiated in the 1997-98 wet season to assess long-term weed management options in Cavalcade on a levee soil near Adelaide River, NT. This site was selected because it was easily accessible and had a wide range of weeds.

This Technical Bulletin documents the results of research conducted between 1997-2004 to provide recommendations and guidelines for weed management strategies in Cavalcade. The research examined a range of weed control practices, including herbicide application, grazing and mulch management, no-till farming systems, and grass legume rotation.

As no herbicides were registered for use in Cavalcade, one aim of the project was to evaluate suitable herbicides for label registration. The efficacy of Spinnaker®, Flame®, Raptor®, Brodal® and Stomp®, was assessed in the first year as these herbicides had been recognised as potentially suitable in previous plot trials[2]. When Spinnaker® was applied post-plant, pre-emergence (PPPE), it produced the best results. However, no herbicide was considered commercially acceptable due to the high grass weed burden, since no grass selective herbicide had been applied post-emergence.

The same herbicide treatments were used during the second season, 1998-99. Conventional till and no-till methods were used to examine the interaction between tillage and herbicide efficacy on Cavalcade and weed dynamics. Spinnaker® and Flame® applied PPPE gave the best weed control and the greatest yield of Cavalcade by the final harvest. Low residual weed control was observed, which was attributed to rapid herbicide degradation from an above average wet season[3]. The no-till treatments had a lower weed biomass, particularly of senna and calopo, than the conventional till treatments.

Herbicide treatments were modified in the 1999-2000 season to evaluate strategies to extend residual weed control. There were no satisfactory herbicide treatments by the time of final harvest, irrespective of tillage treatment, with poor Cavalcade yields and an increasing dominance of broadleaf weeds, particularly senna. Consequently, the area was sown with Jarra grass to evaluate the role of a grass rotation in modifying the weed spectrum.

The grass phase was maintained for two seasons, during which broadleaf weeds were effectively controlled by the application of selective herbicides and conservative grazing pressure. Half the Jarra area was resown with Cavalcade in the sixth season of the project (2002-03). Cavalcade and weed yields were compared under cultivated versus no-till farming practices in conjunction with the application of Spinnaker® versus no Spinnaker®.

Cultivation resulted in an increase in weed germination of both broadleaf and grass weeds, compared with the no-till treatment. Application of Spinnaker® pre-emergence significantly reduced weed establishment in both cultivated and no-till plots. Final Cavalcade yields of 8 t/ha with relatively few weeds were achieved in the no-till+Spinnaker® treatment.

The same treatments were tried in the 2003-04 season, with the addition of a post-emergence application of Spinnaker®. There were differences in mulch levels between treatments at sowing due to differences in biomass from the previous season. Tillage continued to have an effect on weed dynamics, where no-till produced significantly fewer broadleaf and grass weeds than the respective conventional till treatments. Results for Spinnaker® pre-emergence in 2003-04 were not as good as for the previous season due to very high rainfall in the month after sowing. However, this still remains the best-bet practice. No-till plots treated with Spinnaker® post-emergence produced the highest yields of

Cavalcade by the final harvest. Assessment of Spinnaker® post-emergence will continue and may show to be a suitable option to progress to label registration.

It is intended to sow the remaining Jarra area with Cavalcade in the 2004-05 season to compare the effect of time on a grass rotation with Cavalcade on weed dynamics.

This project has conclusively demonstrated that sustainable Cavalcade production can be achieved by implementing a long-term weed management strategy. Appendix 4 lists the crop husbandry practices carried out during the project and the estimated approximate costs. This included a number of complementary weed control practices such as in-crop herbicide use in legume and grass phases, a grass rotation, appropriate grazing management, mulch management and no-till farming practices.

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① A list of common and scientific names of plant species is provided in Appendix 1.

② A list of herbicide trade names and active ingredients is provided in Appendix 2.

③ Rainfall data is supplied in Appendix 3.

BACKGROUND

The value of locally produced hay to support the live cattle export trade had grown to $2.4 million in 1997. Cavalcade was the major pasture species sown, utilised for both grazing and hay production. Cube and pellet manufacturers were major users of hay for the live cattle export trade. Invasion by weeds was a major constraint to production. Broadleaf weeds were particularly difficult to control in Cavalcade. There was a need to evaluate suitable herbicides for use on pasture legumes.

Plot trials before 1997 had identified a number of potentially suitable herbicides. The most promising herbicide due to its low crop damage (phytotoxicity) and effective control of a range of weeds was Spinnaker®, but further research was needed to register this herbicide in the NT. Information was needed about its efficacy on different weeds, how this varied between pre- and post-emergent applications, and phytotoxicity to Cavalcade under a range of conditions.

Flame® was also identified as a useful herbicide. Although it caused early crop damage, yields recovered by final harvest, so further evaluation was warranted. It was decided to continue with Flame® to control senna (*Senna obtusifolia*), a significant weed in Cavalcade. Another herbicide in the same imidazolinone group as Spinnaker® and Flame®, designated as AC299,263 and subsequently registered as Raptor®, was also potentially suitable. Brodal® also showed potential as a pre-emergent herbicide. Stomp® had been used on Cavalcade without crop damage, but there was uncertainty as to which weeds it controlled. These five herbicides formed the basis of the initial evaluation of chemical weed control.

However, chemical control practices are only one method in a suite of weed control options. Sustainable production systems should be based on an integrated weed management strategy incorporating chemical, cultural, physical and biological weed control alternatives. These would include cultivation, mulch management, slashing, grazing management, burning and crop rotation.

Cultivation is a commonly used physical method to control weeds, but it can expose the soil surface to erosion, particularly during heavy rainfall, a characteristic of the wet season in northern Australia. No-till practices are recognised for sustainable farming systems in the Top End. Weed dynamics had been observed to differ between no-till and conventional till systems, where soil disturbance stimulated germination of some hard-seeded species, such as senna and calopo (*Calopogonium mucunoides*). As mulch may reduce herbicide efficacy, the project compared conventional tillage and no-till systems on weed dynamics and the interaction with herbicide activity. In the first year of Cavalcade production, the crop is generally sown using conventional tillage. However, in subsequent seasons, producers may have the option (depending on available machinery) to sow without tilling, thus providing an alternative option to manage weeds.

Invasion by broadleaf weeds that could not be controlled by in-crop herbicides had been observed in Cavalcade where it had been cropped for a number of years. Weeds that are continually targeted with a single herbicide, such as Spinnaker® in continuous Cavalcade, can develop resistance. Inclusion of a grass rotation provides for control of broadleaf weeds, particularly senna, through the use of different selective herbicides and reduces resistance. A rotation of Cavalcade with Jarra finger grass (*Digitaria milanjiana* cv Jarra) was tried to assess its effectiveness in reducing broadleaf weed burden in a subsequent Cavalcade crop.

Farming systems research in northern Australia has traditionally been conducted on government research stations. To involve farmers in a commercial situation, a weed management project was conducted on a levee soil at Mt. Keppler Station, approximately 3 km SE of Adelaide River. It had a large number of weeds, it was close to Darwin with good seasonal accessibility, the owner was producing Cavalcade, and he was willing to provide a fenced off area on his property for the duration of the project.

The project started in the 1997-98 wet season to provide information for registration of Spinnaker® in the NT and an integrated weed management system for Cavalcade production. This report presents the results of the project at Mt. Keppler from 1997 to 2004. It also describes options for an integrated weed management strategy for sustainable Cavalcade production.

1997-98 ESTABLISHMENT OF THE PROJECT AREA

INTRODUCTION

Weed management strategies for sustainable Cavalcade production had been evaluated primarily in plot trials on Research Farms managed by the Department. To increase farmer relevance and interest, evaluation was conducted on a commercial property. A trial to evaluate herbicides suitable for use on Cavalcade was established on Mt. Keppler in the 1997-1998 wet season. Cultivation was required to break down existing weed biomass, and Cavalcade was sown by conventional tillage.

MATERIALS AND METHOD

Site description, land preparation, sowing and herbicide application

A suitable site was selected in August 1997. The paddock was ploughed and harrowed by station personnel in late October to reduce the biomass of large stands of predominantly gamba grass (*Andropogon gayanus*), grader grass (*Themeda quadrivalvis*), Hamil Guinea grass (*Panicum maximum* cv Hamil), senna, and calopo, in preparation for sowing Cavalcade. An area of 150 m by 60 m was fenced within this paddock and designated as the project area. Glyphosate (360 g/L) was applied (at 7 L/ha[#] + 0.5% LI 700®) in early November to further reduce weeds. Fertiliser was applied (200 kg/ha of DalFert® 0-10-20+trace) on 10 December. The area was then cultivated (one discing and one scarification) and sown with Cavalcade (12 kg/ha) on 11 December. Pre-emergent herbicides were applied immediately after sowing using a 4 m boom (Figure 1). The post-emergent herbicide treatments were applied on 29 December, 18 days after sowing (DAS), when Cavalcade was at the three-five true leaf stage. Weeds ranged from two to seven leaf stage and grasses were up to 20 cm in diameter.

Experimental design

The trial was a randomised complete block with four blocks of 11 treatments. These are listed in Table 1. Plot size was 8 m by 10 m.

Table 1. Herbicide treatments assessed at Mt. Keppler in 1997/98 and 1998/99 seasons

Treatment		Active Ingredient (a.i.)	Amount of a.i. applied (g/ha)
Crop only		Hand weeded	
Weed only		No crop	
Crop and weed		Control	
Spinnaker® (300 mL/ha)	Pre-emergence Post-emergence	imazethapyr 240 g/L	72
Flame® (200 mL/ha)	Pre-emergence Post-emergence	imazapic 240 g/L	48
AC 299, 263 (50 g/ha)	Pre-emergence Post-emergence	imazamox 700 g/kg	35
Stomp® (3 L/ha)	Pre-emergence	pendimethalin 330 g/L	1000
Brodal® (200 mL/ha)	Pre-emergence	diflufenican 500 g/L	100

[#] This was higher than commercially practised, e.g. 3 L/ha on young perennial grasses, to ensure a 100% kill.

Measurements

Biomass harvests were taken on 13 January (at 30 DAS) to determine early weed suppression and phytotoxicity to Cavalcade, and on 17 March (at 90 DAS) as indicative of final yield when cut for hay. This was earlier in the season than commercially practiced, but it was necessary to prevent the grader grass seeding.

Samples were separated into Cavalcade, grass weed, broadleaf weed, and calopo (although some may consider it a desirable legume, it effectively acted as a weed and choked out the Cavalcade), and weights were recorded.

The area was mown on 18 March to simulate cutting for hay. Considerable dry matter remained on the surface, so the area was burnt on 8 April 1998. There was regrowth predominantly of grasses: grader grass, summer grasses *Brachiaria* spp, pennisetum (*Pennisetum pedicellatum*) and Hamil Guinea. The site was burnt again, accidentally, in August.

Figure 1. Applying herbicide treatments in the first year of the project at Mt. Keppler, 12 December 1997

RESULTS AND DISCUSSION

The major weeds that emerged and established in all plots were grader grass, Hamil Guinea grass, gamba grass, calopo, crowsfoot grass (*Eleusine indica*) and summer grasses (*Brachiaria* spp and *Digitaria* spp). Broadleaf weeds were not as invasive as the grasses, but included senna, flannel weed (*Sida cordifolia*), sida (*Sida acuta*) and hyptis (*Hyptis suaveolens*). The high invasion by grass weeds is illustrated in Figure 2.

Figure 2. Grass weeds such as grader grass illustrated here, dominated the Mt. Keppler site by final harvest, March 1998

Biomass results for the two harvest times for Cavalcade and weeds are illustrated in Figures 3a and 3b below.

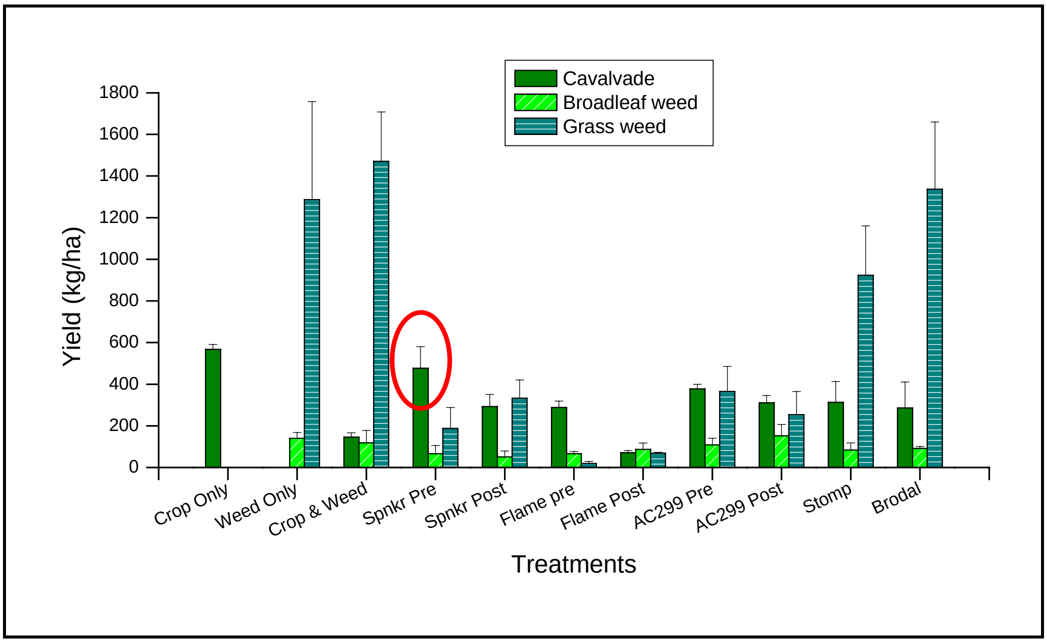


Figure 3a. Biomass yields for Cavalcade, broadleaf weed and grass weed at first harvest at Mt. Keppler January 1998 (error bars are + standard error)

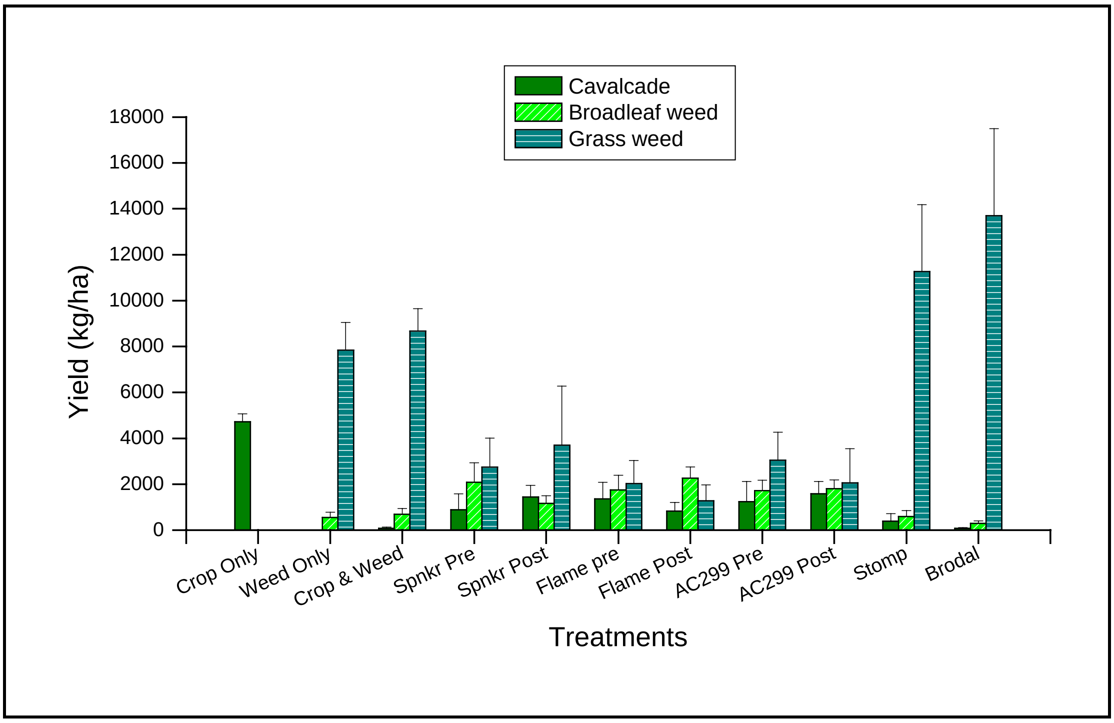


Figure 3b. Biomass yields for Cavalcade, broadleaf weed and grass weed at final harvest at Mt. Keppler March 1998 (error bars are + standard error)

Spinnaker® pre-emergence treated plots produced both the best Cavalcade biomass and reduced weed biomass early, as shown in Figure 3a. However, competing weed species dominated later in the season, which was reflected in poor Cavalcade yields at final harvest (Figure 3b). Flame® caused most damage to all weeds, including senna, but also damaged Cavalcade, particularly post-emergence. AC299,263 was very effective against grass weeds. However, calopo effectively competed against Cavalcade, which made it difficult to determine if the reduction in Cavalcade yield was due to herbicide phytotoxicity, or to competition from calopo. Similarly with Brodal®, which has no effect on grass, it was difficult to determine if Cavalcade yield was reduced due to herbicide effect, or to competition from a high grass weed burden.

All treatments (except the hand-weeded crop only treatment) showed unsatisfactory weed control by the final harvest, with excessive weed biomass due to high yielding grasses, including gamba grass, Hamil Guinea grass and grader grass which resulted in poor Cavalcade yield. The obvious poor residual effect of herbicide may have been due to well above average rainfall in the month after application (700 mm compared to the long-term average of 300 mm for January), which may have accelerated herbicide breakdown (see Appendix 2).

It was important to determine if the herbicide treatments could adequately control grass weeds, so that expensive post-emergence grass selective herbicides would be unnecessary. In hindsight, the post-emergence herbicide treatments should have been applied two weeks after sowing, and the effect specifically on grass weeds determined prior to a subsequent application of a grass selective herbicide approximately four to six weeks later. This would have allowed a better interpretation of the effect of the herbicide on broadleaf weeds and on Cavalcade yield due to phytotoxicity.

Although calopo was a significant weed in all treatments, its proportion to other weeds was low in the weed only, crop and weed, Brodal® and Stomp® treatments. The proportion of calopo was highest in the Spinnaker®, Flame® and AC299,263 treatments, which indicated that this group of herbicides had little effect on calopo, a tropical pasture legume. This suggested that the effectiveness of the imidazolinone herbicides on other weeds may have increased the invasineness of calopo. The results may not necessarily be consistent in other areas where the weed spectrum does not include calopo. This group of herbicides showed the most potential for use in Cavalcade.

1998-99 TILLAGE FOR HERBICIDE BY TILLAGE INTERACTION

INTRODUCTION

Cultivation is the best way to reduce large amounts of standing biomass and to facilitate sowing into a good seedbed, and may be necessary in the initial production year in a ‘rough’ paddock. However, cultivation exposes the soil surface to erosion, and stimulates germination of a number of weed species. No-till practices are advocated to prevent erosion and reduce soil temperatures, as a basis for sustainable farming systems in northern Australia. Appropriate mulch management is a precursor to optimum Cavalcade establishment. However, some herbicides are ineffective when applied over mulch. Consequently, in the second year of the project, the plots were divided into no-till and conventional till treatments to compare the interaction between herbicide efficacy and weed dynamics between the two systems.

Results from the previous season continued to show that the imidazolinone herbicides were the most promising for use in Cavalcade. Brodal® was again examined in this season to assess whether the reduction in Cavalcade biomass in the previous season was due to the herbicide or competition from grass weed dominance. Stomp® was included again to assess differences in efficacy between tillage treatments, as incorporation is a label recommendation, which is not mechanically feasible under a dryland no-till situation.

MATERIALS AND METHOD

The experimental design was modified from the previous season to a split plot design but retained the same block and 11 herbicide treatment structure. The main plot treatment was tillage and the sub-plot treatment was herbicide. Thus, the plot size of 8 m by 10 m in the previous year was reduced to 4 m by 10 m. A schematic diagram of the experimental design is provided in Figure 4.

Spnkr post	Brodal pre	AC299 post	Weed only	Flame pre	Crop & weed	AC299 pre	Flame post	Crop only	Spnkr pre	Stomp pre
Flame pre	Stomp pre	Spnkr pre	Spnkr post	Crop only	Flame post	AC299 post	AC299 pre	Brodal pre	Crop & weed	Weed Only
Weed only	Crop only	Brodal pre	Crop & weed	Spnkr post	Spnkr pre	AC299 post	Flame pre	Flame post	Stomp pre	AC299 pre
AC299 post	Spnkr pre	Spnkr post	AC299 pre	Stomp pre	Flame post	Brodal pre	Crop only	Weed only	Flame pre	Crop & weed

Figure 4. Experimental design for tillage and herbicide interaction treatments, Mt. Keppler 1998-99 (conventional tillage plots are shaded grey)

For the no-till strips, the area was sprayed with glyphosate (360 g/L a.i.) at 6 L/ha on 22 October to reduce the biomass at the time of sowing, as Guinea grass, a high-yielding species, was dominating the area by this time. Glyphosate (360 g/L a.i.) was again applied (3 L/ha +0.5% LI 700®) to these strips on 11 December, and the conventional tillage strips were also disced at this time in preparation for sowing. Fertiliser was applied (200 kg/ha of DalFert® 0-10-20+trace) on 14 December. The conventional tillage strips were disced, the area was sown with Cavalcade (16 kg/ha), and the pre-emergent herbicide treatments were applied on 15 December at the same rates as used in the previous season. Figure 5 illustrates the level of mulch at planting for the no-till strips, and adjoining cultivated strips.

The post-emergent herbicide treatments were applied on 6 January 1999 (21 DAS). The first biomass harvest was done on 14 January (30 DAS). The second and final harvest was done on 5 May 1999 (140 DAS).

Figure 5. Cultivated and no-till strips at sowing (15 December 1998). Note the high biomass of Hamil Guinea grass and gamba grass outside the experiment area, illustrating the importance of early season mulch management in preparation for no-till sowing.

RESULTS AND DISCUSSION

At the January harvest, Spinnaker® pre-emergence had provided the best weed control of both broadleaf and grass weeds, and helped produce excellent Cavalcade yields, consistent with the previous year’s results. AC299,263 also displayed good efficacy on weeds and minimal Cavalcade phytotoxicity. These two herbicides were effective in both no-till and conventional till treatments (Figures 6a and 6b).

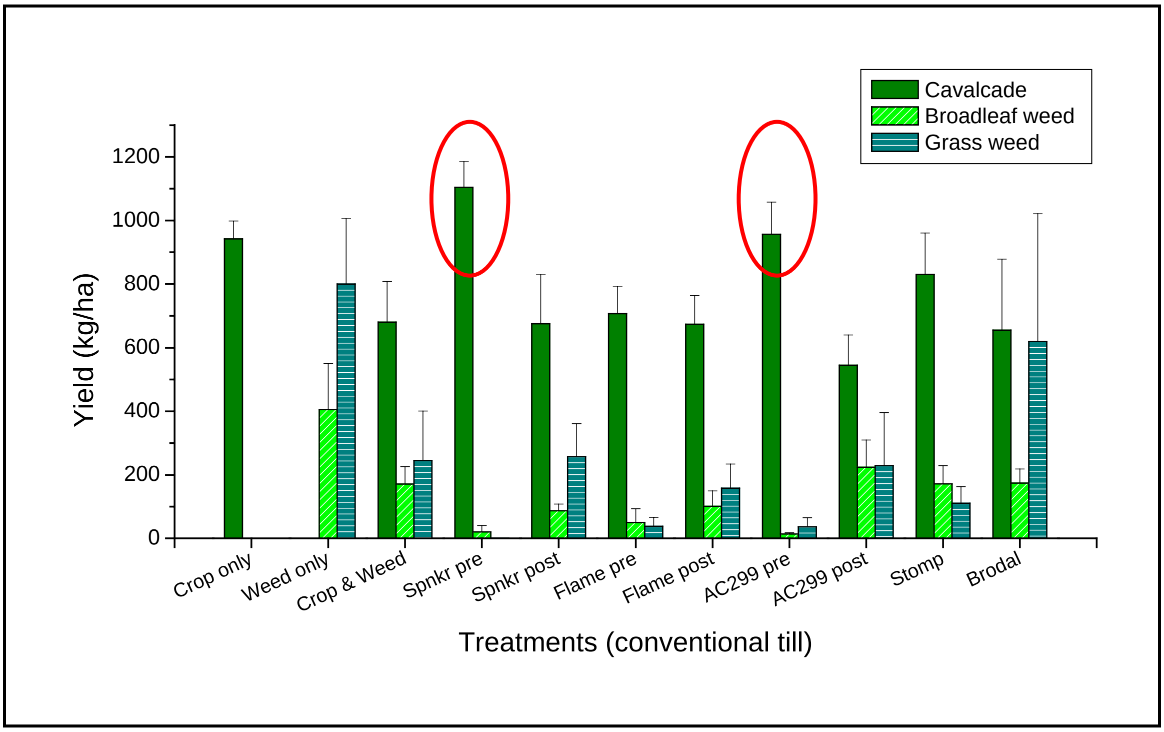


Figure 6a. Biomass yields for Cavalcade, broadleaf weed and grass weed at the January harvest for the conventional tillage treatments at Mt. Keppler 1998-99 (error bars are + standard error)

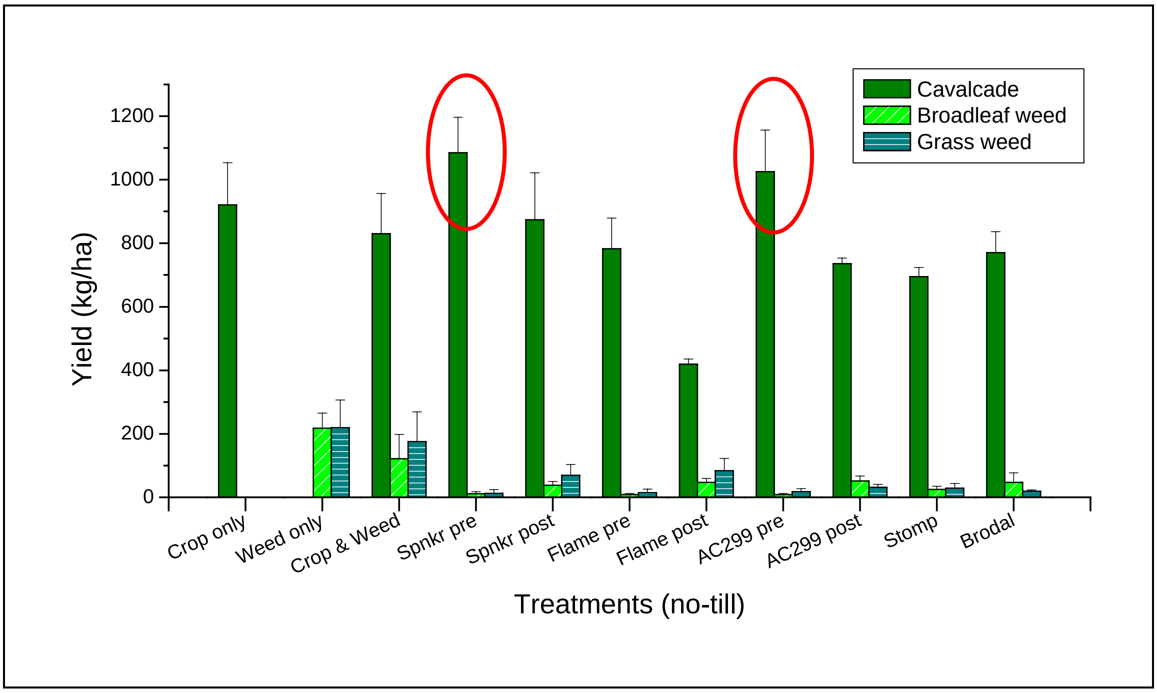


Figure 6b. Biomass yields for Cavalcade, broadleaf weed and grass weed at the January harvest for the no-tillage treatments at Mt. Keppler 1998-99 (error bars are + standard error)

By the final harvest, Spinnaker® and Flame®, applied pre-emergence, provided the best weed control (Figure 8). However, some weed burden remained across all treatments (Figures 7a and 7b), which was attributed to poor herbicide residual activity later in the growing season. This led to assessment of methods to control weeds later in the season such as using split applications of Spinnaker®, and Flame®/Spinnaker® (although this was contrary to label recommendations), in the following season.

If these herbicides are present later in the season, then the plant-back period for following susceptible crops must also be considered. For example, the Flame® label states that it should not be applied in areas where rainfall from spraying to sowing of sorghum is expected to be below 500 mm. While this is unlikely to be the situation in the Top End, it does illustrate that carry-over soil residue can affect susceptible crops or pastures.

Tillage treatments gave poor weed control, with a lower weed biomass in the no-till treatments than the conventional till treatment, particularly in early crop growth (Figures 6a and 6b), and to a lesser extent by final harvest (Figures 7a and 7b). The no-till treatments appeared to be effective in suppressing the number of senna, and a proportion of calopo (Figure 7c).

Calopo was the dominant broadleaf weed (>70%) in the Flame® post-emergence treatments due to the excellent control of all other weeds and Cavalcade, effectively reducing all other plant competition. Calopo also formed a major component (>40%) of the broadleaf weed biomass for all the other imidazolinone treatments for the conventional plots only. Calopo may be a major weed of Cavalcade on levee soils, but is unlikely to be significant in other regions such as Katherine or the Douglas Daly. Consequently, calopo was removed as a component of the broadleaf weed biomass to provide a better indication of weed control. The results are presented separately (Figure 7c).

It was intended to apply a grass selective herbicide post-emergence to remove the grass competition, which had complicated interpretation of the results the previous season. This did not happen, as grass weeds were not a major problem as in the 1998/99 season. Brodal® caused some yellowing of the Cavalcade, and did not satisfactorily control broadleaf weeds.

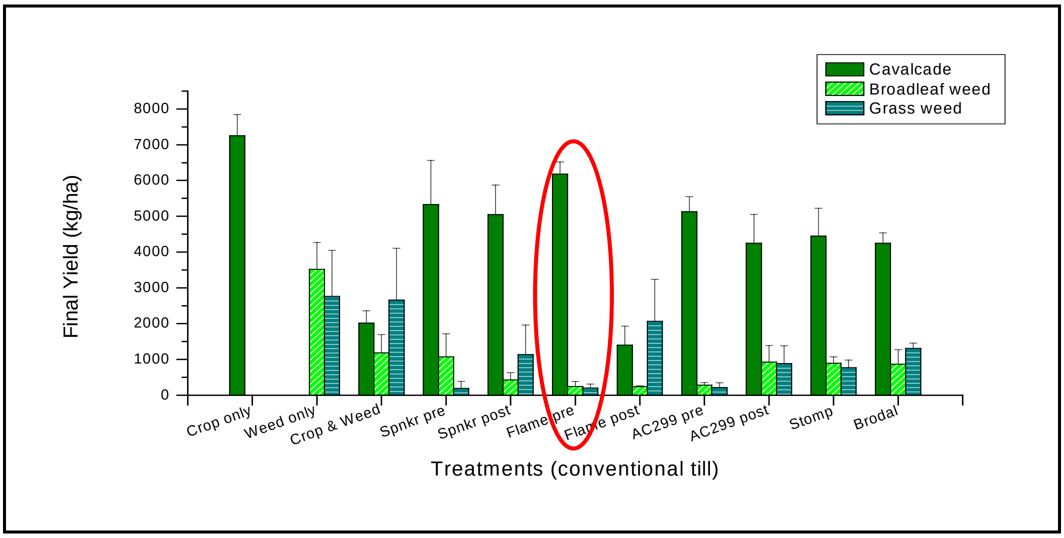


Figure 7a. Biomass yields for Cavalcade, broadleaf weed (excluding calopo) and grass weed at final harvest for the conventional tillage treatments at Mt. Keppler, May 1999 (error bars are + standard error)

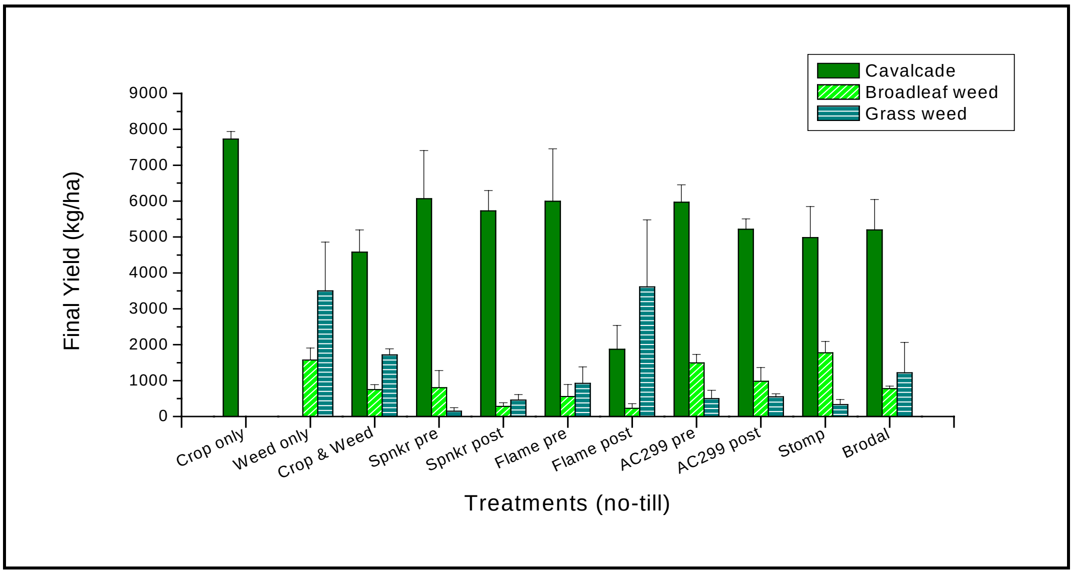


Figure 7b. Biomass yields for Cavalcade, broadleaf weed (excluding calopo) and grass weed at final harvest for the no-till treatments at Mt. Keppler, May 1999 (error bars are + standard error)

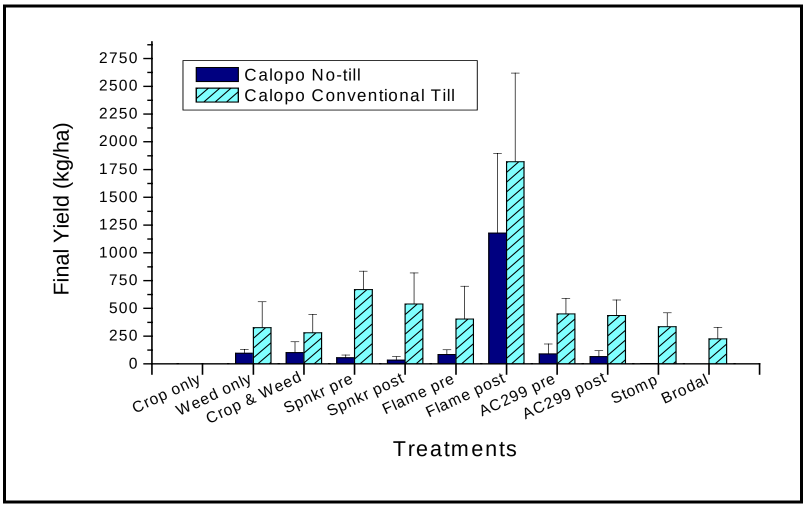


Figure 7c. Calopo biomass yields for conventional and no-till treatments at final harvest, Mt. Keppler, May 1999 (error bars are + standard error)

Figure 8. The Flame® pre-emergent treatment produced promising results, displaying some level of efficacy on senna, as evidenced by the relatively weed free plot at final harvest at Mt. Keppler on 5 May 1999

1999-2000 CONTINUED ASSESSMENT OF HERBICIDE BY TILLAGE INTERACTION

INTRODUCTION

Results from the 1998-99 season for the interaction between herbicide efficacy and tillage treatment on weed dynamics needed to be confirmed in a second season when weather, soil moisture conditions and mulch characteristics could vary, and the weed spectrum could be modified by previous treatments.

The adequate weed control early in crop growth in the 1998-99 season did not continue until the final harvest, as there was by then an unacceptable weed burden, although it varied between treatments. This suggested that there was a minimum herbicide residual activity maintained by harvest time. To extend the period of adequate weed control, it was decided in the third season to split applications of herbicides.

Brodal® and Stomp® controlled weeds poorly in the 1998-99 and were not assessed this season. Linuron had showed some promise in other plot trials so was included. Flame® post-emergence treatments were not applied due to the unacceptable damage to Cavalcade.

MATERIALS AND METHOD

Experimental design and herbicide treatments

The design was maintained as a split-plot, with four blocks, and 11 herbicide treatments. However, three of the herbicide treatments were modified from the previous season: 1) Brodal® plots were treated with linuron (2 kg/ha of 500 g/kg a.i.) applied pre-emergence, 2) Stomp® plots were treated with a split application of Spinnaker® (300 mL/ha applied pre-emergence plus 300 mL/ha applied post-emergence), and 3) Flame® post emergence treatments were treated with a split application of Flame® pre-emergence (200 mL/ha) followed by Spinnaker® post-emergence (400 mL/ha). Also, the Spinnaker® rates of 300 mL/ha both pre- and post-emergence the previous season were increased to 400 mL/ha.

The no-till strips were sprayed with glyphosate on 23 November and the conventional till strips were disced on 11 December in preparation for sowing on 14 December 1999. Pre-emergent herbicide treatments were applied on 17 December (3 DAS).

Post-emergent treatments were applied on 11 January 2000 (28 DAS). Crop only treatments were sprayed with Verdict® at 1 L/ha (a.i. 520 g/L) to minimise the need for hand weeding.

Biomass harvest on two 0.5 m x 1 m quadrats was conducted on 11 April 2000 (160 DAS). Botanal® was also applied and the proportion of each weed species was quantified.

RESULTS AND DISCUSSION

Weed biomass for all herbicide treatments was lower in the no-till treatments than the conventional treatments (Figure 9). The proportion of senna to the total weed biomass was consistently lower in the no-till than the conventional till treatment across all treatments, as indicated in italics in Table 2. Cultivation stimulated the establishment of senna, Figure 10, where senna dominated the cultivated half of the Spinnaker® treatment plot.

The proportion of Cavalcade in the herbicide treatments was greater in the no-till than conventional till plots, although the Cavalcade biomass in all treatments was low, with weed species dominating all plots except those hand-weeded. The two no-till treatments where Spinnaker® was applied pre-emergence had the greatest Cavalcade yield (Figure 9), although this was still unsatisfactory. There did not appear to be any additional benefit from split application of Spinnaker®.

Application of a grass selective herbicide may have reduced total weed, particularly in the crop and weed treatment, but did not result in a satisfactory Cavalcade yield, as broadleaf weeds, particularly senna, dominated the weed spectrum in all herbicide treatments (Table 2). Results indicate that the imidazolinone herbicides are effective in reducing grass weed biomass, particularly of *P.pedicellatum*, so that the application of a post-emergence grass selective herbicide may be unnecessary, depending on the specific grass weed spectrum.

Poor weed control by herbicides over the previous wet seasons was evident again this season. Due to the poor effect of all herbicides on senna and calopo, final Cavalcade yields were unsatisfactory in all treatments (Figure 11). Herbicides alone therefore cannot be relied on to provide adequate weed control in Cavalcade. Other measures need to be included. The increasing dominance of difficult-to-control broadleaf weeds required that a grass rotation be included in the following season.

The Mt. Keppler site had been used to assess imidazolinone herbicide efficacy for three years by the end of this season. It was decided that the site be sown with a grass or cereal next season. This was for four reasons: to prevent the development of herbicide resistance to Group B herbicides; to assess possible cereal or grass damage from extended herbicide persistence and soil residue effects; to enable a phase to target broadleaf weeds and modify the weed spectrum; and to provide diversity in on-farm enterprises.

Table 2. The three most dominant weed species present at final harvest. The proportion of Cavalcade is included for comparison

Treatment		Dominant species (%dry matter of total biomass)			
		1st	2nd	3rd	Cavalcade
Crop only	CT	Cavalcade (93%)	Ludwigia (5%)	Calopo (1%)	93
	NT	Cavalcade (91%)	Ludwigia (6%)	Scoparia (3%)	91
Crop and Weed	CT	Pennisetum (48%)	*Senna (26%)*	Hyptis (10%)	2
	NT	Pennisetum (41%)	Hyptis (18%)	*Senna (16%)*	7
Spinnaker® pre	CT	*Senna (63%)*	Calopo (29%)	Cavalcade (5%)	5
	NT	Ludwigia (27%)	Calopo (23%)	*Senna (20%)*	14
Spinnaker® post	CT	*Senna (60%)*	Calopo (25%)	Grader grass (4%)	4
	NT	*Senna (26%)*	Crowsfoot (22%)	Pennisetum (20%)	8
Flame® pre	CT	*Senna (44%)*	Pennisetum (22%)	Guinea grass (6%)	4
	NT	Pennisetum (36%)	*Senna (18%)*	Hyptis (13%)	13
Flame®/ Spinnaker	CT	*Senna (59%)*	Calopo (23%)	Grader grass (4%)	3
	NT	Calopo (26%)	*Senna (25%)*	Gamba grass (19%)	9
AC299263 pre	CT	*Senna (66%)*	Calopo (23%)	Cavalcade (4%)	4
	NT	*Senna (43%)*	Hyptis (23%)	Cavalcade (11%)	11
AC299263 post	CT	*Senna (64%)*	Grader grass (19%)	Calopo (9%)	2
	NT	*Senna (60%)*	Guinea grass (9%)	Cavalcade (8%)	8
Spinnaker®/ Spinnaker®	CT	*Senna (55%)*	Calopo (40%)	Cavalcade (6%)	6
	NT	*Senna (48%)*	Cavalcade (29%)	Calopo (16%)	29
Linuron	CT	Hyptis (35%)	Senna (28%)	Calopo (4.5%)	3
	NT	Pennisetum (39%)	Hyptis (32%)	Cavalcade (5%)	5

CT = Conventional
NT = No tillage

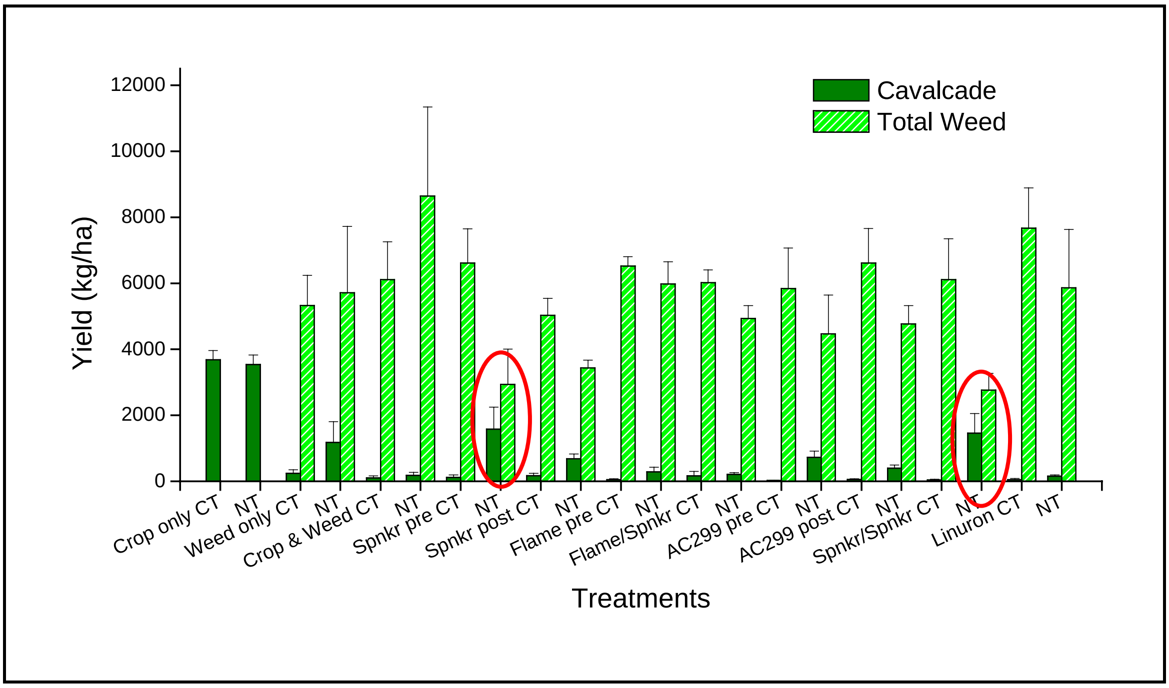


Figure 9. Biomass yields for Cavalcade and total weed at final harvest for the conventional and no-tillage treatments at Mt. Keppler April 2000 (error bars are + standard error)

Figure 10. Cultivation was observed to stimulate broadleaf weed emergence, as illustrated in this Spinnaker pre-emergence treatment taken two months after sowing (10 February 2000); the cultivated area is on the left hand side of the figure

Figure 11. There were no satisfactory herbicide treatments by the time of final harvest (11 April 2000), with weeds dominant in all plots irrespective of cultivation method

2000 – 01 GRASS ROTATION IMPLEMENTED

INTRODUCTION

The increasing dominance of difficult-to-control broadleaf weeds, particularly senna, made it necessary to include a grass rotation this season. Imidazolinone herbicides had been applied under experimental conditions for three preceding seasons. The use of a grass rotation allowed for the application of a different range of herbicides known to be effective against broadleaf weeds such as senna, whilst utilising different modes of action between the herbicide groups. Weed management should involve the rotation of chemical groups to minimise the development of resistance and the build-up of tolerant or resistant weed species to the particular herbicide group.

A grass rotation also facilitates the use of cultivation in preparation for sowing, as this will stimulate germination of weed seeds, particularly of broadleaf weeds, which can be selectively killed in the grass pasture phase, contributing to a gradual reduction of the weed seed bank over time.

MATERIALS AND METHOD

The experimental area was burnt during the dry season, sprayed with glyphosate to manage biomass at the onset of the wet season, then cultivated and sown with Jarra grass at 6 kg/ha on 12 December 2000. Fertiliser (12-6-16-8) was applied at 200 kg/ha.

The Jarra grass was slashed (to approximately 30 cm) on 9 February 2001 after it had seeded so emerging broadleaf weeds could be more effectively targeted (Figure 12). The main weed species were senna, calopo, scoparia (*Scoparia dulcis*) and ludwigia (*Ludwigia octovalvis*). The area was sprayed on 20 February (11 weeks after sowing) with a combination of Grazon® (500 mL/ha) and 2,4-D Amicide 500 (1 L/ha).

Half the experimental area was again slashed on 5 April to determine whether slashing was effective in the control of *P. pedicellatum*, which was at the early flowering stage.

Biomass cuts were taken on 21 May, and the area was disc-mowed on 21 June to simulate cutting for hay, although the material was not removed from the site.

RESULTS AND DISCUSSION

Slashing was conducted at two times at this site; initially for better spray coverage of weeds, and second, to evaluate slashing for pennisetum control. Broadleaf weed control by the Grazon®/Amicide mix after the initial slashing was excellent. Ideally, weeds should have been sprayed at an earlier stage, for both optimum coverage and when younger weeds are easier to kill, and at potentially lower rates. Also, in a situation where weeds and pasture have 'got away', grazing could be used to decrease grass biomass prior to herbicide application.

Slashing was ineffective in the control of seed set of pennisetum, as the plants had recovered and recommenced flowering by 24 April (three weeks after slashing). Slashing also reduced the end-of-season biomass of the Jarra grass: 7.9 t/ha compared with 7.2 t/ha for the non-slashed and slashed areas, respectively.

The application of Grazon® and amicide with no subsequent grazing pressure, successfully eliminated the presence of broadleaf weeds by the end of the 2000-01 wet season. In hindsight, control of pennisetum, an annual grass, may have been achieved through application of low rates of diuron, but it was uncertain how much damage the Jarra grass may have sustained. Further studies on suitable herbicides, adjuvants and rates on newly established pasture species are being evaluated elsewhere.

Figure 12. Broadleaf weeds had established in the Jarra early in the 2000-01 wet season, so the area was slashed on 9 February 2001 to enable more effective coverage of broadleaf weeds when sprayed with Grazon®/2,4-D mix on 20 February

2001 – 02 GRASS ROTATION CONTINUED

INTRODUCTION

The grass pasture phase established in the previous season was effective in reducing the amount of broadleaf weed present by the end of the wet season. This was due to the application of suitable herbicides, and the maintenance of a competitive sward over the wet season, which minimised further germination allowing a relatively weed free pasture to be grazed over the following dry season.

It was decided to maintain the grass pasture for another wet season, to allow another phase of selective broadleaf weed control, and to distribute the cost of the grass establishment over a number of seasons.

MATERIALS AND METHOD

The Jarra grass was managed as in the previous season. It was slashed on 27 November 2001 to enable more effective herbicide coverage. It was sprayed with Grazon® (200 mL/ha) on 11 December; and top-dressed with Fertico blue fertiliser (12-6-16) at 200 kg/ha on 13 December.

Cattle were allowed access to the experimental area in the late wet season to simulate real pasture utilisation and soil disturbance (Figure 13). It would have been better to graze the Jarra grass prior to the application of herbicide so that slashing would not have been required.

RESULTS AND DISCUSSION

Broadleaf weeds were effectively controlled by the Grazon® application. There were no broadleaf weeds observed on 16 January 2002 (five weeks after application). Cattle grazed the area in the dry season until the beginning of the wet season (November 2002). There were very few broadleaf weeds present from the time of introduction of cattle to the site, to when they were removed. Thus, the use of suitable herbicides and dry season grazing minimised weed colonisation, as happened in the previous season.

Grazing management is a critical component of a weed management strategy. Overgrazing will reduce the competitiveness of the grass sward, expose bare ground susceptible to weed colonisation and erosion at the onset of the wet season. It will also reduce levels of biomass required for suitable mulch for sowing subsequent crops using no-till practices. Cattle contribute to soil disturbance, which exposes weed seed to predation over the dry season or stimulates germination at the onset of the wet season. Broadleaf weed germination may provide a long-term advantage in that these weeds can be controlled early in the wet season in a grass phase, gradually reducing the weed seed bank over time. However, grazing and herbicide management should aim to maintain a competitive pasture throughout the wet season and into the dry season.

Figure 13. Cattle grazed the Jarra area on 18 March 2002. Grazing has an important role in mulch management for subsequent no-till sowing

2002 – 03 GRASS ROTATION/SPINNAKER/TILLAGE DEMONSTRATION

INTRODUCTION

By the end of the 2002 dry season, the area had been under Jarra grass for two years. It was uncertain how the duration of a grass rotation affected weed dynamics in a following Cavalcade crop. We decided to sow half the area with Cavalcade, while retaining the other half with Jarra grass to continue the grass rotation. It was intended that this Jarra area would be sown with Cavalcade after an additional period of time to compare the effects of two different periods of grass pasture on weed dynamics.

One of the prime objectives of the grass rotation, while having to be productive in its own right, was to reduce weed species to allow subsequent establishment of a productive Cavalcade crop. The decision when to progress from the grass phase to the Cavalcade phase under a commercial scenario could be based on a number of factors. These may include the deterioration of the grass pasture and reduced productivity, diversification as a component of a risk management strategy to have some paddocks with grass and some with Cavalcade to allow for variations in the hay market, paddock rotation as a component of whole farm management incorporating hay production and livestock trading, or just high demand for Cavalcade in a particular year.

We aimed to compare Cavalcade establishment using no-till and conventional till practices after a grass rotation with suitable mulch management. Weed control between the two tillage practices using Spinnaker® pre-emergence was also assessed.

MATERIALS AND METHOD

Cattle grazing the Jarra grass over the dry season were removed in November to allow the vegetation to recover prior to application of glyphosate (Round-up CT® at 4 L/ha + 0.5% LI 700®) on the designated no-till area on 5 December 2002. There was a large amount of unutilised grass remaining, so mulch levels were higher (4 t/ha) than desirable (2 t/ha) which provided some difficulties with sowing. Similarly, the designated conventional till area which had a large amount of dry matter, was burnt, then chisel ploughed and disced. The area was fertilised (200 kg/ha High Fert Blue TE mix 12-5-14-13), sown with Cavalcade (15 kg/ha), and Spinnaker® (140 g/ha) applied immediately after sowing (10 December). A schematic representation of the treatments is shown in Figure 14.

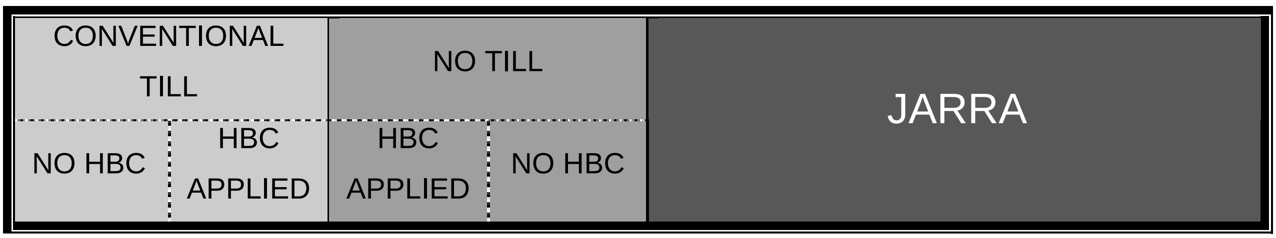


Figure 14. Plan of HBC Spinnaker PPPE/Tillage treatments applied in 2002-03 wet season

Senna and calopo were the major weeds in the Jarra grass area, so a combination of Brushoff® (20 g/ha) and Amicide 625® (1 L/ha) with Chemwett® (0.2%) was applied on 20 December, as shown in Figures 15a and b.

Biomass harvests were collected at three times: 7 January (four weeks after sowing, (WAS)), 11 February (nine WAS) and 14 April 2003 (18 WAS). Two quadrats (0.5 m x 1 m) were cut in each of the treatment areas. Weed species present at each time were also recorded.

The area was mowed and the pasture was baled at the end of May, to simulate a commercial situation removing dry matter and seed.

Figures 15a and b. Applying herbicide to target broadleaf weeds in the Jarra grass rotation in the early wet season: weeds are small and easier to kill than later in the season, when spray coverage has not yet been hampered by growing grass

RESULTS AND DISCUSSION

There were no statistically significant differences because of the large variation within treatments, but the following trends were observed.

Herbicide effects

Spinnaker® reduced the emergence of the broadleaf weeds *Sida* spp, red pigweed (*Portulaca oleracea)* and ludwigia in both conventional and no-till treatments during early crop establishment. However, calopo and senna were not affected. Similarly, Spinnaker® was effective in reducing pennisetum and Jarra grass emergence, although it appeared to have little effect on crowsfoot grass (*Eleusine indica*). Figures 17 a, b and c illustrate the higher weed burden, particularly of grass weed, when no Spinnaker® was applied.

This shows that when Spinnaker® is applied pre-emergence it effectively reduces weeds, with the exception of some legume weeds. In a grass pasture rotation where subsequent invasion of grasses in the Cavalcade phase may be a concern, the effectiveness of Spinnaker® in reducing grass weeds may eliminate the need for post-emergent application of a grass selective herbicide.

Tillage effects

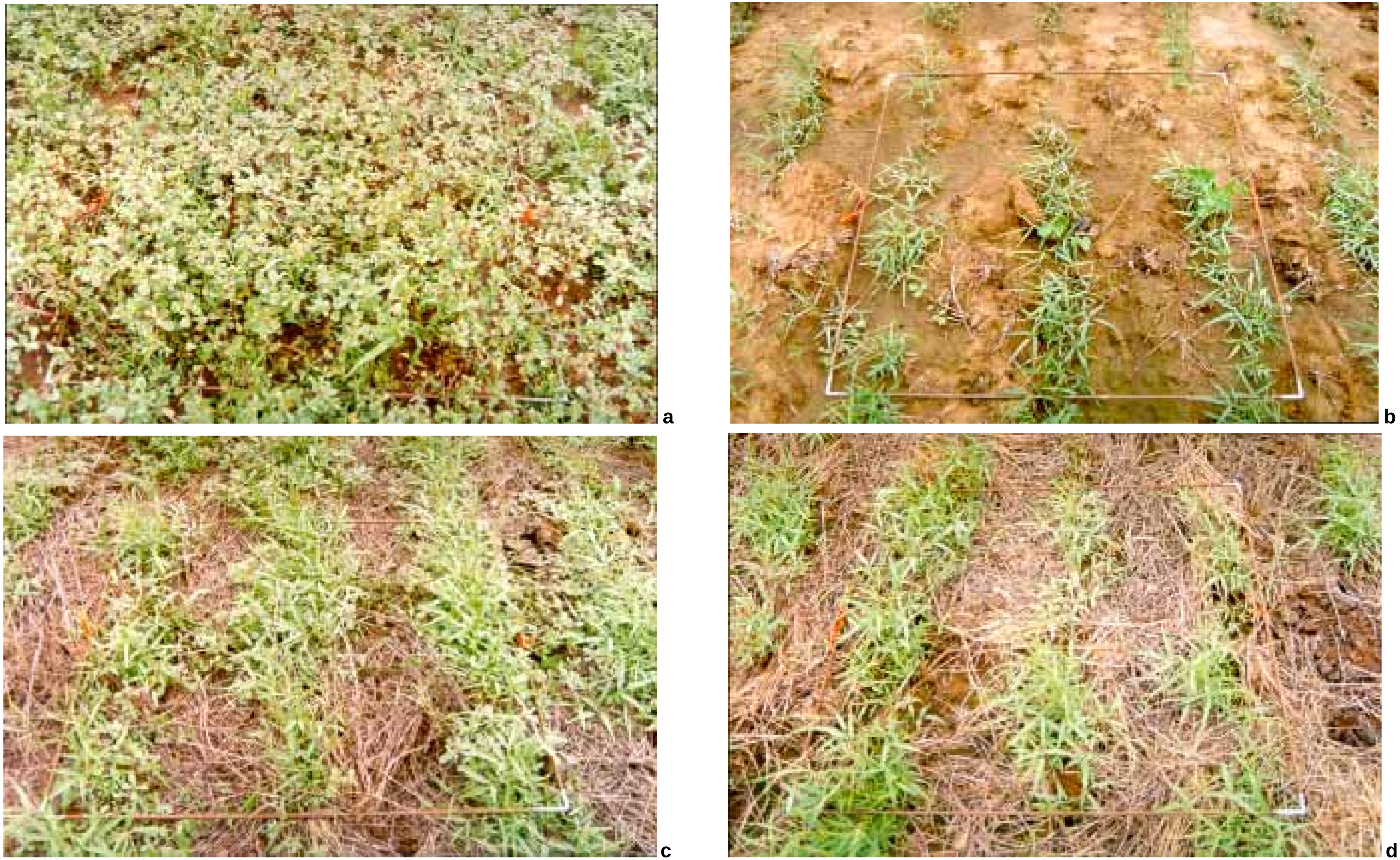
There was a larger amount of broadleaf weed biomass at the final harvest in the conventional tillage treatments than in the no-till treatments. The major broadleaf weeds were senna and calopo, indicating that cultivation preferentially stimulates their germination. Both are difficult to control in Cavalcade by in-crop herbicides.

The interaction between tillage and herbicide treatments at the initial harvest indicated that in early Cavalcade establishment, the no Spinnaker® treatments had the greatest amount of weeds, predominantly red pigweed and some nutgrass, and this was higher in the conventional till than the no-till plots (Figure 17a). The pigweed died during the Cavalcade growing season. Grass weeds such as crowsfoot, lovegrass (*Eragrostis* spp) and barnyard grass (*Echinochloa colona*) increased in dominance, but were brown and not actively growing by the end of the season. This effectively reduced the relative biomass of total weeds in Cavalcade as the season progressed (Figures 17a, b and c).

The no-till treatments produced higher Cavalcade yields than the conventional till treatments at the time of final harvest. Within each tillage treatment, the Spinnaker® applied treatments yielded higher than the no Spinnaker® treatment (Figure 17c). Figures 16a to d compare the effectiveness of no-tillage and Spinnaker® application to cultivation and no herbicide applied at the early crop establishment phase.

The low incidence of broadleaf weed, even in the no herbicide treatments, indicated that the use of a two-year grass rotation was effective in reducing broadleaf weed germination in a following Cavalcade crop. A separate plot area could have been retained as continuous Cavalcade to allow more direct comparison of changes in weed dynamics between continuous Cavalcade and Cavalcade grown in rotation with a grass pasture over different periods of time, but size constraints within the fenced area prevented this.

The Jarra grass area yielded 2.6 t/ha, 5.8 t/ha and 9.5 t/ha at the three harvest times, respectively.



Figures 16a, b, c and d. Cavalcade and weed growth on 7 January 2003 for each of the four treatments; a) Cultivated, no Spinnaker®; b) Cultivated, Spinnaker® applied, c) No-till, no Spinnaker®, d) No-till, Spinnaker® applied

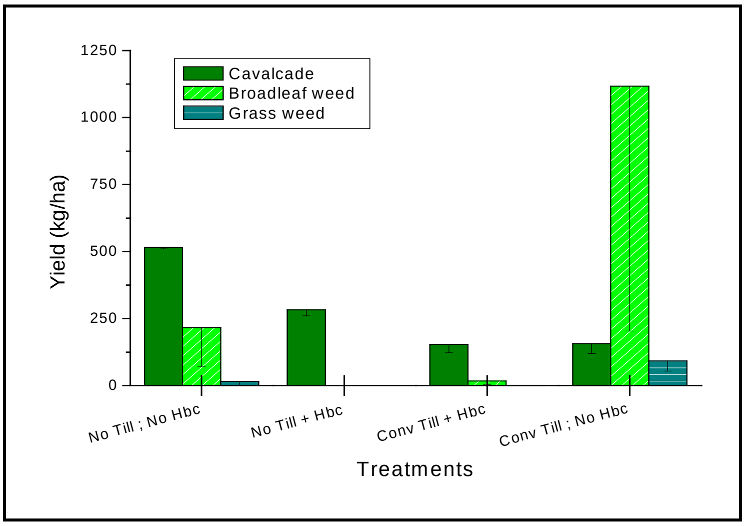


Figure 17a. Yields (kg/ha) at initial harvest, 7 January 2003 (error bars indicate – standard error)

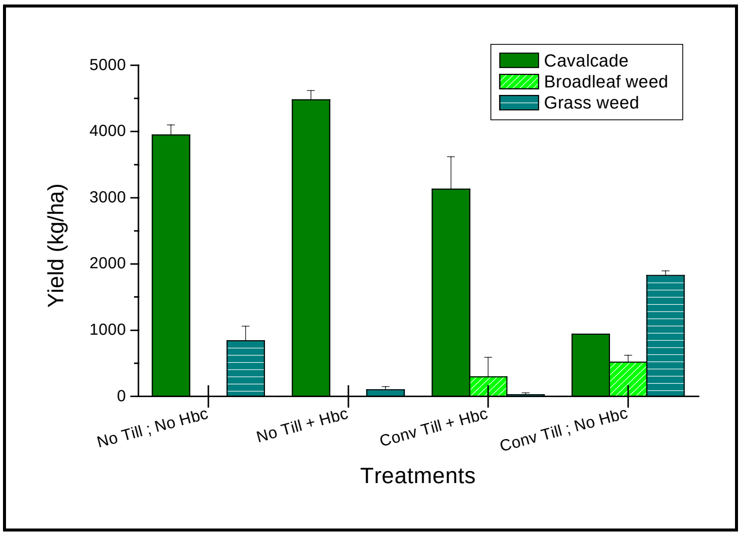


Figure 17b. Yields (kg/ha) at second harvest, 11 February 2003 (error bars indicate + standard error)

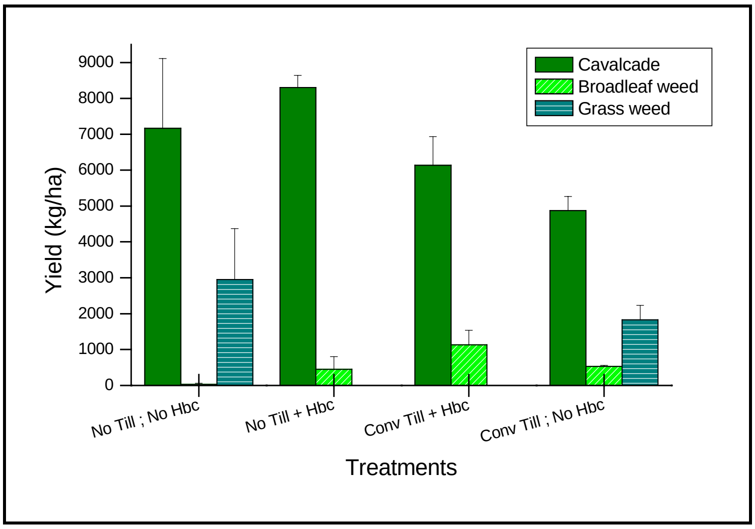


Figure 17c. Yields (kg/ha) at third and final harvest, 14 April 2003 (error bars indicate + standard error)

2003 – 04 GRASS ROTATION/SPINNAKER/TILLAGE CONTINUED

INTRODUCTION

Cavalcade sown no-till into adequate mulch, in conjunction with Spinnaker® applied post-plant pre-emergence, provided the greatest yields and the lowest number of weeds after a grass phase, by the end of the 2002-03 season.

The effect of the grass phase duration on subsequent weed dynamics in a Cavalcade crop had not yet been determined. We decided to maintain the Jarra grass area for another year to allow further broadleaf weed control, and to repeat the tillage and herbicide treatments as done the previous season, with Spinnaker® applied post-emergence.

MATERIALS AND METHOD

Round-up CT® (5 L/ha + 0.5% LI 700®) was applied over the Cavalcade area on 25 November 2003. The conventional till area was cultivated on 5 December, and again a week later to kill newly emerged weeds. Cavalcade was sown on 15 December (16 kg/ha at 46% germination) and Round-up CT® again applied (4 L/ha). Spinnaker® (at 140 g/ha) was added to the tank mix and applied over the herbicide treatment area immediately after sowing. Fertiliser (Hi-Fert® 12:5:14:13 200 kg/ha) was applied over both the Jarra grass and Cavalcade areas.

There were differences in mulch levels and species within the no-till treatment due to herbicide effects from the previous season; the previous Spinnaker® area had low levels of mulch (0.5-1 t/ha) consisting of mainly grass and Cavalcade seedlings, whereas the area where no Spinnaker® had been applied the previous season had large amounts of pigweed, and isolated clumps of pennisetum and Jarra grass.

Spinnaker® was applied post-emergence on 30 December 2003 (140 g/ha + Hasten® at 5 mL per 100 L). Cavalcade was at the two to four leaf stage, broadleaf weeds mainly ludwigia were at the three leaf stage, and grasses were up to 20 cm in diameter.

Biomass harvests were collected at two times; 15 January (four WAS) and a final harvest on 28 April 2004 (14 WAS). Four quadrats (0.5 m x 1 m) were cut in each of the treatment areas and biomass divided into Cavalcade, broadleaf weed and grass weed. Weed species that were present at each time were also recorded.

Biomass differences were analysed using a nested design ANOVA.

The area was mowed and pasture was baled at the end of May, to simulate a commercial situation by removal of dry matter and seed.

RESULTS AND DISCUSSION

There was a significant interaction between tillage and herbicide treatment on Cavalcade biomass at first harvest. There was no effect of herbicide for the no-till treatment, but for conventional till, there was significantly less Cavalcade for the no herbicide treatment than for either of the Spinnaker® treatments.

The greatest grass biomass was for the cultivated no herbicide treatment. The no-till plot, even without herbicide, and the pre- and post- Spinnaker® plots, irrespective of tillage treatment, provided excellent control of grass weeds.

There were significantly fewer broadleaf weeds in both Spinnaker® treatments than in plots with no herbicide applied. Although the effect of tillage was not statistically significant, for plots where no herbicide was applied, there were more broadleaf weeds in the cultivated than in the no-till treatment.

These results are illustrated in Figure 18a.

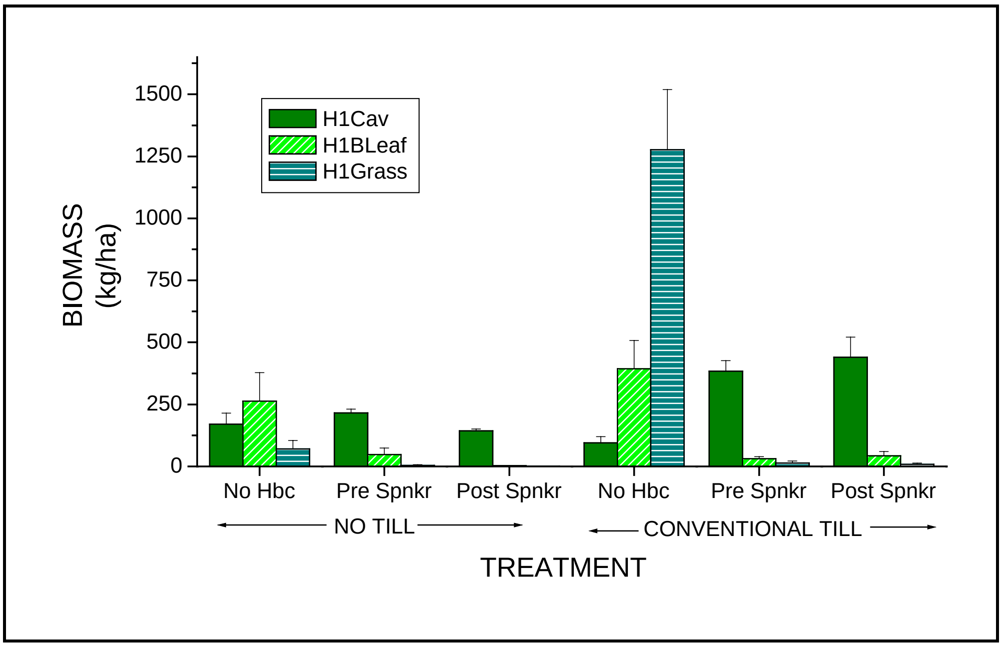


Figure 18a. Yields (kg/ha) at initial harvest, 15 January 2004 (error bars are + standard error)

By final harvest, the greatest Cavalcade yield was in the no-till Spinnaker® post-emergence treatment. The no-till no herbicide treatment had the lowest Cavalcade biomass, and correspondingly, the greatest grass biomass, predominantly of pennisetum, which emerged through the crop late in the season.

There was a significant effect of tillage on broadleaf weed biomass by final harvest, with fewer broadleaf weeds in the no-till than the conventional till treatments. Figures 19a and b show the weed spectrum differences between the two tillage treatments. Although there was no statistically significant effect of herbicide, the Spinnaker® treatments had greater broadleaf weed biomass than the no herbicide treatment for the conventional plots. This was due to the presence of calopo and senna, which dominated after cultivation, neither of which are controlled by Spinnaker®. Comparatively, in the no-till plots, the main broadleaf weed was ludwigia, which was controlled by Spinnaker®, although the effect was less when applied pre-emergence, compared to the post-emergence application.

Results for treatment effects at final harvest are illustrated in Figure 18b.

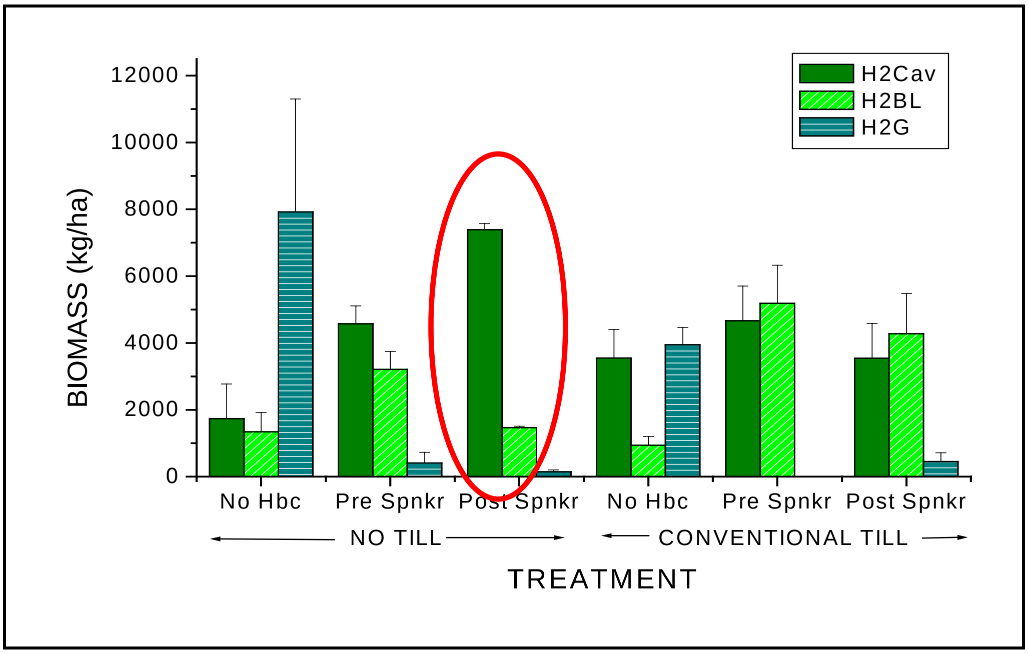


Figure 18b. Yields (kg/ha) at final harvest, 28 April 2004 (error bars are + standard error)

These results indicate that grass species are the major weeds in no-till Cavalcade, and broadleaf weeds are the greater problem under conventional till. This suggests that using no-till practices can reduce weed biomass, particularly of broadleaf weeds which are not effectively controlled by Spinnaker®, such as senna and calopo. This also has another advantage in that the grass weeds, which seem to become dominant under no-till, can be effectively controlled by grass selective herbicides, such as Verdict®, later in the season.

In this season, where more than 400 mm of rain fell in the month after sowing, there was minimal residual effect of Spinnaker® when applied pre-emergence. In such a situation, mulch on the soil surface may play a major role in early weed control due to the absence of soil disturbance and impediment of emerging weed seedlings. A post-emergence application then becomes an option, as supported by the excellent results illustrated in Figure 18b. However, there have been variable results with Spinnaker® post-emergence in other experiments, so this is not a current registered label use.

The Jarra grass area continued to display vigorous growth, yielding 14.4 t/ha at the end of April harvest, although there were isolated patches of gamba grass.

Figure 19a. The weed spectrum at final harvest for the conventional till Spinnaker® pre-emergence treatment consisted mainly of calopo and senna

Figure 19b. The weed spectrum at final harvest for the no- till Spinnaker® pre-emergence treatment consisted mainly of ludwigia. Spinnaker® for both tillage treatments provided extremely effective grass weed control.

GENERAL DISCUSSION AND CONCLUSIONS

Figure 20. Cavalcade and weed growth on 8 April 2003 for the no-till, Spinnaker® PPPE treatment in a below average rainfall year. The main weed was calopo with isolated patches of senna. The suitability of the area for Cavalcade production with reduced weed burden was improved markedly when compared with the area at the commencement of the long-term management strategy in 1997.

This project clearly demonstrated that weed management for long-term sustainable Cavalcade production needs to incorporate a number of complementary weed control practices. These include application of in-crop herbicides, grass rotation, grazing and selective herbicide use, and mulch and no-till farming practices.

Application of Spinnaker® post-plant pre-emergence is the most effective chemical control method for weed in-crop for Cavalcade. Stomp® is not recommended for commercial production because effectiveness is variable and it is not a registered product for use.

Spinnaker® provides soil residual activity, where soil type, soil moisture, and soil temperature influence the persistence in soil, as recognised on the label recommendations for crop safety. For recropping sorghum, at least 800 mm of rainfall are required between application and sowing. The weed control window with Spinnaker® varied between seasons, and appeared to be associated with the amount and timing of rainfall. Residual weed control was high in the 2002-03 wet season, which had below average rainfall, particularly early in the season, allowing Cavalcade to establish a competitive stand and effectively smother weed seedling germination which may have occurred later in the season after the herbicide had degraded. Degradation occurs primarily through the action of micro-organisms, where higher soil temperatures and high soil moisture increase microbial degradation. Spinnaker® residual carry-over was not observed in the Jarra grass phase following three years of Cavalcade and is unlikely to be a concern under Top End environmental conditions, where soils are typically warm, wet and acidic, which are conducive factors to increased breakdown after application. This does however, pose problems for later season weed control.

Application of grass selective herbicides, such as Verdict® and Falcon® is an effective but expensive option later in the season, but control of established broadleaf weeds is difficult. Spinnaker® applied early post-emergence produced good results for the 2003-04 season, but in previous field studies, efficacy had been variable. However, this may be an option in weed management, especially if circumstances have prevented herbicide application immediately after sowing. Further work on evaluating Spinnaker® applied post-emergence at different Cavalcade and weed growth stages, and with different adjuvants will be conducted at other sites. This work may contribute to submissions for registration of Spinnaker® post-emergence for Cavalcade.

Although Spinnaker® produced the best results across most seasons, when applied post-plant pre-emergence after three years of Cavalcade, difficult-to-control broadleaf weeds were beginning to dominate the area. The implementation of a Jarra grass phase was effective in reducing these weeds through application of selective broadleaf herbicides and appropriate grazing. Monitoring and identification of weed species present within the grass phase are necessary to determine the most appropriate herbicide to use, and the optimum time and rates for application. Application of Brush-Off® and 2,4-D amicide when weeds such as senna and sida were less than 20 cm high was effective in eliminating broadleaf weed establishment in grazed two-year-old Jarra grass. Field studies are being conducted at other sites to further evaluate broadleaf herbicide efficacy in a range of other grass pasture species.

The use of a grass pasture phase grazed judiciously allowed suitable mulch levels to be attained for adequate weed suppression in the following Cavalcade crop.

Mulch management will depend on how the land was previously used. Timing of application of knock-down herbicides varied between plots where (i) Cavalcade followed Jarra grass which had been grazed at different intensities; (ii) Cavalcade followed grazed Cavalcade; (iii) regrowth had been slashed and burnt; and (iv) where biomass was removed as hay. Monitoring of biomass levels will be required to attain optimum mulch levels for sowing subsequent crops.

The use of no-till farming practices resulted in a decrease in the germination and establishment of weed species, particularly senna. A weed species shift from broadleaf weeds under conventional till to grass weeds with no-till practices was also observed, where grass weeds are easier to manage in a Cavalcade crop. This is probably due to a number of factors including changed light and temperature regimes associated with minimal soil disturbance and physical impedance of the emerging seedlings by the mulch layer. The preservation of mulch on the soil surface also provides benefits for the farming system such as the reduction of soil temperature, increase in moisture retention and soil surface stability. Cultivation may be necessary at times to prepare a good seed bed, and may be advantageous prior to sowing a grass phase to stimulate broadleaf weed germination which can then be effectively eliminated with selective herbicides, thereby aiding in the depletion of the weed seed bank. However, for the Cavalcade phase, the crop should be sown with minimal soil disturbance and adequate mulch cover.

A productive, relatively weed-free Cavalcade area had been established by the 2002-03 season, and this provided the basis for a best-bet management system. Cavalcade was established using no-till practices with appropriate mulch management to enable sowing into 2-3 t/ha of dead mulch, and application of Spinnaker® post-plant pre-emergence, after a two-year grass rotation, where broadleaf weeds were effectively controlled. Results for Spinnaker® pre-emergence in 2003-04 were not as good as the previous season, but this still remains the best-bet practice. Spinnaker® post-emergence will continue to be assessed and results may warrant submission to the Australian Pesticides and Veterinary Medicines Authority for a Minor Use permit.

On a whole-farm system, grass pasture and Cavalcade could be grown in rotation between paddocks to allow flexibility between legume hay and grass hay or cattle grazing enterprises.

The weed management strategy demonstrated at Mt. Keppler over several years provides guidelines for a sustainable Cavalcade production system.

SUMMARY OF WEED MANAGEMENT RECOMMENDATIONS FOR A CAVALCADE PRODUCTION SYSTEM

Aim: To develop a productive Cavalcade crop from a weedy unproductive paddock.

1. **Sow grass pasture phase (e.g. Jarra, Strickland (*Digitaria milanjiana* cv Strickland))**

    - Conventional till (where soil conditions were suitable):

        - Required for breakdown of large weed biomass for preparation of suitable seedbed.
        - Also stimulates germination of broadleaf weeds.
        - Apply adequate fertiliser to maximise grass seedling vigour.

    - Spray broadleaf weeds:

        - e.g. ①Amicide 625® at 1.6 L/ha + 1,000 Wetter (0.2%) when pasture is approximately 30 cm high/no less than four weeks old and weeds are young.

    - Allow pasture to establish and seed over the wet season.

        - Light grazing over the dry season (1 head/ha).

2. **Maintain grass phase for a minimum of two years**

    - Cut for hay.

    - And/or graze (can increase stocking rate in years after initial establishment year).

        - Grazing early in the wet season can limit annual grass weed establishment and induce broadleaf weed germination to gradually reduce weed seed bank.

    - Continue broadleaf weed control:

        - e.g. Amicide 625® at 1.6 L/ha + Brush-Off® at 15 g/ha + 1,000 Wetter (1%), when weeds are small (less than 20 cm high).

3. **Cavalcade phase**

- Sow no-till.

  - Requires monitoring of biomass levels towards the end of the dry season/early wet season to ensure optimum mulch cover (2 t/ha) at sowing. Dry season grazing can be used to reduce the amount of vegetation.
  - Application of glyphosate② - timing, number of applications, and rate will depend on a number of factors including weed species present, timing of rainfall and amount of biomass.
  - Establish competitive Cavalcade population – weed-seed free and high germination % seed.

- Apply Spinnaker700WDG® post-plant pre-emergence at 140g/ha.

  - (Spinnaker + Hasten® is being evaluated for efficacy when applied post-emergence to no-till Cavalcade at 1-5 leaf stage).

- Apply grass selective herbicide if necessary. e.g. ③Verdict520® at 200 mL/ha + Uptake (0.5%).

- Established broadleaf weeds are difficult to control in Cavalcade. Use of a herbicide roller is one option that has been used successfully at other Cavalcade sites.

These points outline the general best-bet practice for weed management. Specific herbicide recommendations, rates and efficacy will depend on the pasture and weed species present, relative growth stages, and seasonal conditions. Seek specific advice from Departmental Weed Scientists or Extension Staff.

① Herbicide selectivity varies depending on pasture grass species and broadleaf weeds to be controlled.
② Surfactants are recommended for use with glyphosate – refer to label directions.
③ Verdict520® is currently the only grass selective herbicide registered for use on Cavalcade (PER7310).

ACKNOWLEDGMENTS

Nick Hartley, Weed Technical Officer, and Ben Beumer, Marrakai Extension Officer provided significant technical assistance and long hours in the field. Their dedication and support were instrumental in the implementation of the project, and making those sweaty days seem more enjoyable.

I gratefully acknowledge the assistance and technical support from other staff within DBIRD, particularly Colin Martin, Senior Weed Scientist, for his guidance and advice.

I wish to thank the owner of Mt. Keppler, Mr Bruce White, and his son, Don, the current manager, and the previous manager, Noel Hassel, for their cooperation in the project and for providing the site for a long period of time.

I also acknowledge the provision of herbicide samples by BASF, previously Cyanamid.

I thank Narelle Hill, currently Department of Agriculture Western Australia, for her contribution to the project over the 1999-2000 season.

I appreciate the contribution by Mark Hearnden, for the statistical analyses.

APPENDICES

Appendix 1: Plant species names used in the text

Common Name	Scientific or Botanical Name	Family Name
barnyard grass	*Echinochloa colona*	Poaceae
calopo	*Calopogonium mucunoides*	Fabaceae
Cavalcade	*Centrosema pascuorum* cv Cavalcade	Fabaceae
crowsfoot grass	*Eleusine indica*	Poaceae
flannel weed	*Sida cordifolia*	Malvacea
gamba grass	*Andropogon gayanus*	Poaceae
grader grass	*Themeda quadrivalvis*	Poaceae
guinea grass	*Panicum maximum* cv Hamil	Poaceae
hyptis	*Hyptis suaveolens*	Lamiaceae
Jarra	*Digitaria milanjiana* cv Jarra	Poaceae
lovegrass	*Eragrostis* spp	Poaceae
ludwigia	*Ludwigia octovalvis*	Onagraceae
nut grass	*Cyperus rotundus*	Cyperaceae
pennisetum	*Pennisetum pedicellatum*	Poaceae
red pigweed	*Portulaca oleracea*	Portulacaceae
scoparia	*Scoparia dulcis*	Scrophulariaceae
senna	*Senna obtusifolia*	Caesalpiniaceae
sida	*Sida acuta*	Malvacea
Strickland	*Digitaria milanjiana* cv Strickland	Poaceae
summer grass	*Brachiaria pubigera*	Poaceae
summer grass	*Digitaria ciliaris, D.bicornis*	Poaceae

APPENDIX 2: HERBICIDE AND ADDITIVE NAMES USED IN THE TEXT

Trade name or common name	Active ingredient (a.i.) or chemical name	Amount of a.i.	Chemical group	Herbicide group*
AC299,263#	Imazamox	700 g/kg	Imidazolinone	B
Amicide 500	2,4-D amicide	500 g/L	Phenoxy	I
Amicide 625	2,4-D amicide	625 g/L	Phenoxy	I
Brodal®	Diflufenican	500 g/L	Nicotinanilide	F
Brushoff®	Metsulfuron-methyl	600 g/kg	Sulfonylurea	B
Chemwet 1000®	Nonionic Ethoxylates	1000 g/L		Adjuvant
Falcon®	Butroxydim	250 g/kg	Cyclohexanedione ('Dims')	A
Flame®	Imazapic	240 g/L	Imidazolinone	B
Grazon DS®	Triclopyr and Picloram	300 g/L 100 g/L	Pyridine	I
LI 700®	Soyal phospholipids and Propionic acid	350 g/L 350 g/L		Adjuvant
Linuron	Linuron	500 g/L	Urea	C
Raptor®	Imazamox	700 g/kg	Imidazolinone	C
Round-up®	Glyphosate	360 g/L	Glycine	M
Round-up CT®	Glyphosate	450 g/L	Glycine	M
Spinnaker® / Spinnaker 700WDG®	Imazethapyr	240 g/L or 700 g/kg	Imidazolinone	B
Stomp®	Pendimethalin	330 g/L	Dinitroaniline	D
Verdict®	Haloxyfop	520 g/L	Aryloxyphenoxy-propionate ('Fops')	A

* Rotation of herbicide groups essential to prevent development of herbicide resistance
# subsequently registered as Raptor

APPENDIX 3: RAINFALL DATA FOR OCTOBER 1997 - APRIL 2004 (MM)

Year	Month								Total for year
	Oct	Nov	Dec#	Jan	Feb	Mar	Apr	May	
1997-98	56	99	89/227	706	358	218	110	0	1863
1998-99	185	159	407/191	258	255	481	282	0	2218
1999-00	148	243	22/268	287	296	374	302	14	1954
2000-01	51	219	186	370	607	496	113	0	2042
2001-02	121	260	163	111	485	63	20	0	1223
2002-03	27	115	53/125	281	416	131	4	0	1152
2003-04	13	122	175/427	435	441	425	18	-	2056
Long term average	65	144	316	399	278	244	102	18	1643

December values are divided into rainfall prior to and after pre-emergent herbicide application for years where herbicides were applied.

Rainfall information was supplied by the Bureau of Meteorology, NT Regional Office. The data was from Batchelor Airport, Station number 14233 (October 1997-September 1999), and Station number 14272 (Automatic Weather Station from October 1999).

APPENDIX 4: REPRESENTATIVE COST STRUCTURE

This table presents costs, yields and income estimates from the Mt. Keppler site, and is intended to provide an indication of relative costs associated with a range of practices that may be utilised in a Cavalcade production system. It is intended as a guide only, and producers should develop their own specific cost structure.

Costs given here are approximate only. More details on production costs, including a sensitivity analysis, can be found in the DBIRD Publication Technical Bulletin No. 281 Crop Gross Margin Budgets for the Katherine-Daly Region 1999-2000.

Assumptions:

Cavalcade production targeted the hay market. Other market objectives could include seed production or improved cattle grazing over the dry season.

Yield estimates are from the treatment which produced the best Cavalcade biomass each year, and within each tillage treatment where applicable.

Herbicide, fertiliser and seed rates used experimentally are generally more than those used commercially to ensure there are no confounding factors which may have influenced treatment results.

No endorsement of named products is intended.

Year	Operation / Practice	Cost ($/ha)	Income ($/ha)
YEAR 1 (1997-98) Preparation of weedy cleared area for Cavalcade production	VARIABLE COSTS		
	Land preparation		
	Early plough and harrow	$20	
	Knock-down herbicide (Round-up® @ 7 L/ha @ $6/L + 0.5% LI700)	$47	
	Prior to sowing cultivate (1 x disc; 1 x harrow)	$20	
	Sowing		
	Sowing operation	$6	
	Seed cost (Cavalcade @ 12 kg/ha @ $9/kg)	$108	
	Fertiliser: (200 kg/ha @ $500/t)	$100	
	Application cost	$3	
	Weed control		
	Spinnaker PPPE @ 140 g/ha	$50	
	Application	$2	
	Harvesting		
	Mowing, raking and baling (@ $35/t)	$70	
	TOTAL VARIABLE COSTS	$426	
	INCOME		
	Yield (2 t/ha @ $180/t)		$360
	GROSS MARGIN PER HECTARE	**-$66**	

YEAR 2
(1998-99)
 	
Herbicide by tillage interaction
	<u>VARIABLE COSTS Cultivated Area</u>
	Land preparation
	  2 x cultivation (disc)
	Sowing
	  Sowing operation
	  Seed cost (Cavalcade @ 16 kg/ha @ $8/kg)
	  Fertiliser: (200 kg/ha @ $500/t)
	  Application cost
	Weed control
	  Spinnaker PPPE @ 140 g/ha
	  Application
	Harvesting
	  Mowing, raking and baling (@ $35/t)
		
		$20
		
		$6
		$128
		$100
		$3
		
		$50
		$2
		
		$213.50	

	TOTAL VARIABLE COSTS	$522.50	
	<u>INCOME</u> Yield (6.1 t/ha @ $180/t)		$1098
	GROSS MARGIN PER HECTARE		**$575.50**

YEAR 2
(1998-99)
 	
Herbicide by tillage interaction
	<u>VARIABLE COSTS No-till area</u>
	Land preparation
	  2 x knock-down herbicide (Round-up® @ 6 L/ha @ $6/L + 0.5% LI700 and 3 L/ha + 0.5% LI700)
	Sowing
	  Sowing operation
	  Seed cost (Cavalcade @ 16 kg/ha @ $8/kg)
	  Fertiliser: (200 kg/ha of 0-10-20+trace @ $500/t)
	  Application cost
	Weed control
	  Spinnaker PPPE @ 140 g/ha
	  Application
	Harvesting
	  Mowing, raking and baling (@ $35/t)
		
		$64
		
		$6
		$128
		$100
		$3
		
		$50
		$2
		
		$210	

	TOTAL VARIABLE COSTS	$563	
	<u>INCOME</u> Yield (6 t/ha @ $180/t)		$1080
	GROSS MARGIN PER HECTARE		**$517**

YEAR 3 (1999-2000)
 	
Herbicide by tillage interaction continued
	<u>VARIABLE COSTS Cultivated Area Cavalcade</u>
	Land preparation
	  2 x cultivation (disc)
	Sowing
	  Sowing operation
	  Seed cost (Cavalcade @ 16 kg/ha @ $8/kg)
	  Fertiliser: (200 kg/ha of 0-10-20+trace @ $500/t)
	  Application cost
	Weed control
	  Spinnaker® PPPE @ 140 g/ha
	  Verdict® @ 1 L/ha + Uptake 0.5%
	  2 x Application
	Harvesting
	  Mowing, raking and baling (@ $35/t)
		
		$20
		
		$6
		$128
		$100
		$3
		
		$50
		$223
		$4
		
		$140	

	TOTAL VARIABLE COSTS	$534	
	<u>INCOME</u> Yield (4 t/ha @ $180/t)		$720
	GROSS MARGIN PER HECTARE		**$46**

YEAR 3 (1999-2000)
 	
Herbicide by tillage interaction continued
	<u>VARIABLE COSTS No-till area - Cavalcade</u>
	Land preparation
	  2 x knock-down herbicide (Round-up® @ 3 L/ha @ $6/L + 0.5% LI700 and 3 L/ha + 0.5%LI700)
	Sowing
	  Sowing operation
	  Seed cost (Cavalcade @ 16 kg/ha @ $8/kg)
	  Fertiliser: (200 kg/ha of 0-10-20+trace @ $500/t)
	  Application cost
	Weed control
	  Spinnaker PPPE @ 140g/ha
	  Verdict® @ 1 L/ha + Uptake 0.5%
	  2 x application
	Harvesting
	  Mowing, raking and baling (@ $35/t)
		
		$46
		
		$6
		$128
		$100
		$3
		
		$50
		$223
		$4
		
		$140	

	TOTAL VARIABLE COSTS	$700	
	<u>INCOME</u> Yield (4 t/ha @ $180/t)		$720
	GROSS MARGIN PER HECTARE		**$20**

YEAR 4 **(2000-01)** Establish Jarra grass pasture	VARIABLE COSTS Land preparation Burning 1 x knock-down herbicide (Round-up® @ 3 L/ha @ $6/L + 0.5% LI700) Cultivation Sowing Sowing operation Seed cost (Jarra @ 6 kg/ha @ $20/kg) Fertiliser: (200 kg/ha of 12-6-16-8 @ $500/t) Application cost Weed control GrazonDS® @ 500 mL/ha + Amicide500 @ 1 L/ha 1 x application	 $23 $10 $6 $120 $100 $3 $22 $6 $2	
	TOTAL VARIABLE COSTS	$292	
	INCOME Yield (7.5 t/ha) Grazed lightly @ 80 kg/hd/ha @ $1.60/kg		$128
	GROSS MARGIN PER HECTARE	**-$164**	
YEAR 5 **(2001-02)** Maintain Jarra grass pasture	VARIABLE COSTS Maintain Jarra pasture for grazing Fertiliser: (200 kg/ha of 12-6-16 @ $500/t) Application cost Weed control GrazonDS® @ 200 mL/ha (+wetter) 1 x Application	 $100 $3 $9 $2	
	TOTAL VARIABLE COSTS	$114	
	INCOME Yield (7.5 t/ha) Grazed lightly @ 80 kg/hd/ha @ $1.60/kg		$128
	GROSS MARGIN PER HECTARE		**$14**

YEAR 6 **(2002-03)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS Maintain Jarra pasture for hay Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Brushoff® (20 g/ha) +Amicide 625® (1 L/ha) + Chemwet 1000® (0.2%) 1 x application Harvesting Mowing, raking and baling (@ $35/t)	 $100 $3 $15 $2.50 $2 $332.50	
	TOTAL VARIABLE COSTS	$455	
	INCOME Grazed lightly @ 80 kg/hd/ha @ $1.60/kg Harvested 14 April 2003 Yield (9.5 t/ha @ $100/t)		 $128 $950
	GROSS MARGIN PER HECTARE		**$623**
YEAR 6 **(2002-03)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS Cultivated Area - Cavalcade Land preparation 2 x cultivation (chisel plough + disc) Sowing Sowing operation Seed cost (Cavalcade @ 15 kg/ha @ $8/kg) Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Spinnaker® PPPE @ 140 g/ha Application Harvesting Mowing, raking and baling (@ $35/t @ 6 t/ha)	 $20 $6 $120 $100 $3 $50 $2 $210	
	TOTAL VARIABLE COSTS	$511	
	INCOME Yield (6 t/ha @ $180/t)		 $1080
	GROSS MARGIN PER HECTARE		**$569**
YEAR 6 **(2002-03)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS No-till Area - Cavalcade Land preparation Knock-down herbicide (Round-upCT® @ 4 L/ha @ $7/L + 0.5% LI700) Sowing Sowing operation Seed cost (Cavalcade @ 15 kg/ha @ $8/kg) Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Spinnaker® PPPE @140g/ha Application Harvesting Mowing, raking and baling (@ $35/t @ 6 t/ha)	 $34 $6 $120 $100 $3 $50 $2 $210	
	TOTAL VARIABLE COSTS	$525	
	INCOME Yield (6 t/ha @ $180/t)		 $1080
	GROSS MARGIN PER HECTARE		**$555**

YEAR 7 **(2003-04)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS Maintain Jarra pasture for hay Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Brushoff® (20 g/ha) +Amicide 625® (1 L/ha) + Chemwet 1000® (0.2%) 1 x application Harvesting Mowing, raking and baling (@ $35/t) @ 14.4 t/ha	 $100 $3 $15 $2.50 $2 $504	
	TOTAL VARIABLE COSTS	$626.50	
	INCOME Harvested 28 April 2004 Yield (14.4 t/ha @ $100/t)		$1440
	GROSS MARGIN PER HECTARE		**$813.50**
YEAR 7 **(2003-04)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS Cultivated Area - Cavalcade Land preparation Round-UpCT @ 5 L/ha @ $7/L+ 0.5%LI700 @ $5/ha 2 x cultivation Sowing Sowing operation Seed cost (Cavalcade @ 16 kg/ha @ $8/kg) Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Spinnaker® PPPE @ 140 g/ha Application Harvesting Mowing, raking and baling (@ $35/t @ 5 t/ha)	 $40 $20 $6 $128 $100 $3 $50 $2 $175	
	TOTAL VARIABLE COSTS	$524	
	INCOME Yield (5 t/ha @ $180/t)		$900
	GROSS MARGIN PER HECTARE		**$376**
YEAR 7 **(2003-04)** Jarra maintained / Spinnaker / tillage / Cavalcade	VARIABLE COSTS No-till Area - Cavalcade Land preparation 2 x knock-down herbicide (Round-upCT® @ 4.5 L/ha @ $7/L + 0.5% LI700) Sowing Sowing operation Seed cost (Cavalcade @ 16 kg/ha @ $8/kg) Fertiliser: (200 kg/ha of 12-5-14-13+trace @ $500/t) Application cost Weed control Spinnaker® Post-emergent @ 140 g/ha + Hasten® Application Harvesting Mowing, raking and baling (@ $35/t @ 7.5 t/ha)	 $70 $6 $128 $100 $3 $55 $2 $262.50	
	TOTAL VARIABLE COSTS	$626.50	
	INCOME Yield (7.5 t/ha @ $180/t)		$1350
	GROSS MARGIN PER HECTARE		$723.50

YEAR	Activity	Annual Income ($/ha)			
		Conventional Till		No Till	
1997-98	Clean up paddock, sow and grow Cavalcade	-$66		-$66[#]	
1998-99	Sow and grow Cavalcade	$575.50		$517	
1999-2000	Sow and grow Cavalcade	$46		$20	
2000-01	Sow and grow Jarra	-$164		-$164[#]	
2001-02	Maintain Jarra	$14		$14[#]	
2002-03	Maintain Jarra OR	$623		$623[#]	
	Sow and grow Cavalcade		$569		$555
2003-04	Maintain Jarra OR	$813.50		$813.50[#]	
	Sow and grow Cavalcade		$376		$723.50
AVERAGE AFTER 7 YEARS **($/ha/year)**	Cavalcade / Jarra	$263		$251	
	Cavalcade / Jarra / Cavalcade		$193		$228

#Values include for no-till although plots were not split into tillage treatments for these activities.