Does application timing influence antagonism/synergy with paraquat and glufosinate

Trial location: Mallowa, NSW

Weed target: Barnyard grass (*Echinochloa spp*) (BYG),
Feathertop Rhodes grass (*Chloris virgata*) (FTR)

Crop: Fallow

Application: 100L/ha Rainwater 110015 AIXR @ 2 Bar 6km/hr 4 Reps

Multiple trials were applied at this location, across the following timings

	Date	Weed size at Timing 1	Time	Wind	Temp	RH%	Delta T
Timing 1 (T1)	22/12/2025	2 cohorts 'Tillering' and 'Advanced'	8am	10kph S	30.5°C	83%	3.8
Timing 2 (T2)	23/12/2025		9am	6kph WSW	25°C	98%	0.4
Timing 3 (T3)	29/12/2025		8am	13kph SW	20°C	59%	5
Timing 4 (T4)	29/12/2025		3pm	4kph SSW	32°C	26%	14
Timing 5 (T5)	19/01/2026		9am	4kph W	27°C	50%	7.5

Site background

Summer grass weeds such as feathertop Rhodes and barnyard grasses become more difficult to control as weed size increases and as application conditions deteriorate.

Both feathertop Rhodes grass and barnyard grass were present at this site. Barnyard grass was believed to be predominantly *Echinochloa colona* (awnless barnyard grass) but some *Echinochloa crus-galli* (common barnyard grass) may also be present. For this publication we have referred to the population collectively as barnyard grass (*Echinochloa spp*.). There were two cohorts of each weed. Plots were scored individually for each species and assessments separated into 'tillering' (1-3 tiller) and 'advanced' (3 tiller to commencement of flowering) weed sizes at application.

All plots were crossed sprayed with 2.4 L/ha of paraquat (250 gai/L) to create a double knock for those trials and treatments where this was required. Two paraquat cross spray strips were applied, one at 7 days after the main application timing and the other at 28 days after the first application timing. This created a matrix of no double knock; and double knocks applied at either 7 or 28 days between treatments.

Soil moisture was adequate at the first application timing (local BOM sites report ~50mm 10 days prior to the first application timing). There was a 4-6mm rainfall event the night of the first application timing.

Treatments were assessed for initial brownout 16 days after the first application and scored for biomass reduction at 40 days after the initial application.

No formal resistance testing was conducted on this population, but it is expected that there will be some level of glyphosate resistance present in the feathertop Rhodes grass and 'probably' also in the barnyard grass.

Comparison of application timing of paraquat or glufosinate +/- alternate partner herbicides to investigate synergy or antagonism on feathertop Rhodes grass and barnyard grass.

Prior research into the biochemical pathways that drive paraquat and glufosinate suggests there may be potential interactions with other herbicide modes of action that are also associated with the photosynthetic pathway in plants.

- Atrazine, diuron (Group 5) are commonly mixed with paraquat, with some believing that this mixture improves performance (possibly by slowing down the speed of activity of paraquat)
- Balance (Group 27) has also been shown to be synergistic when in mixtures with paraquat on some summer grass weeds (also possibly by slowing down the speed of activity of paraquat)
- Amitrole (Group 34) is also believed to increase performance of paraquat. Guerrilla® is a co-formulation of these actives
- Atrazine (Group 5) has been shown to be antagonistic to glufosinate in certain situations
- Positive or neutral results have been reported when mixing Group 14 herbicides with glufosinate (which may be dependent on the particular Group 14 herbicide, the rates used and weed species).

Field results of these combinations have been mixed. One hypothesis is that as paraquat and glufosinate are relatively fast acting herbicides, they may be causing significant effect on targeted weeds before the other herbicide in the tank mix is fully able to express its effect on the mix. In this trial we wanted to explore applying the partner herbicide approximately 24 hours prior to the application of paraquat or glufosinate, compared to the herbicides applied as a tank mix.

Treatment list

	Day 1 (Timing 1)	Day 2 (Timing 2)
1	Nil	Nil
2	Nil	Paraquat 250 @ 800 mL/ha
3	Nil	Paraquat 250 @ 1.6 L/ha
4	Nil	Paraquat 250 @ 2.4 L/ha
5	Atrazine 900WG @ 650 g/ha	Paraquat 250 @ 800 mL/ha
6	Nil	Paraquat 250 @ 800 mL/ha + Atrazine 900WG @ 650 g/ha
7	Nil	Guerrilla® @ 2 L/ha
8	Balance 750WG @ 100 g/ha	Paraquat 250 @ 800 mL/ha
9	Nil	Paraquat 250 @ 800 mL/ha + Balance 750WG @ 100 g/ha
10	Nil	Biffo® @ 3.75 L/ha
11	Atrazine 900WG @ 650 g/ha	Biffo® @ 3.75 L/ha
12	Nil	Biffo® @ 3.75 L/ha + Atrazine 900WG @ 650 g/ha
13	Balance 750WG @ 100 g/ha	Biffo® @ 3.75 L/ha
14	Nil	Biffo® @ 3.75 L/ha + Balance 750WG @ 100 g/ha

Weed species and weed size interaction

Tillering (1-3 tiller) and Advanced (3-tiller to start of flowering) of each weed were present in this site, with each combination scored separately. Averages for all ratings for both weed species and weed sizes have been included in the appendix. Where this trial was applied, the FTR population was less consistent, with some plots

not having enough plants to rate (especially the double knock area which was a smaller area of each plot). Treatments with less than 3 data points contributing to the average have been highlighted in blue in the appendix. Additional care needs to be taken when interpreting these.

Results on 'Advanced' cohorts of either weed were not commercially acceptable. Paraquat based treatments were very poor and often provided no effective control on these large plants. Glufosinate based treatments were slightly better on the large plants, although generally did not exceed 40% control.

Primary analysis for the rest of this trial report is focused on the 'Tillering' weed sizes of both species.

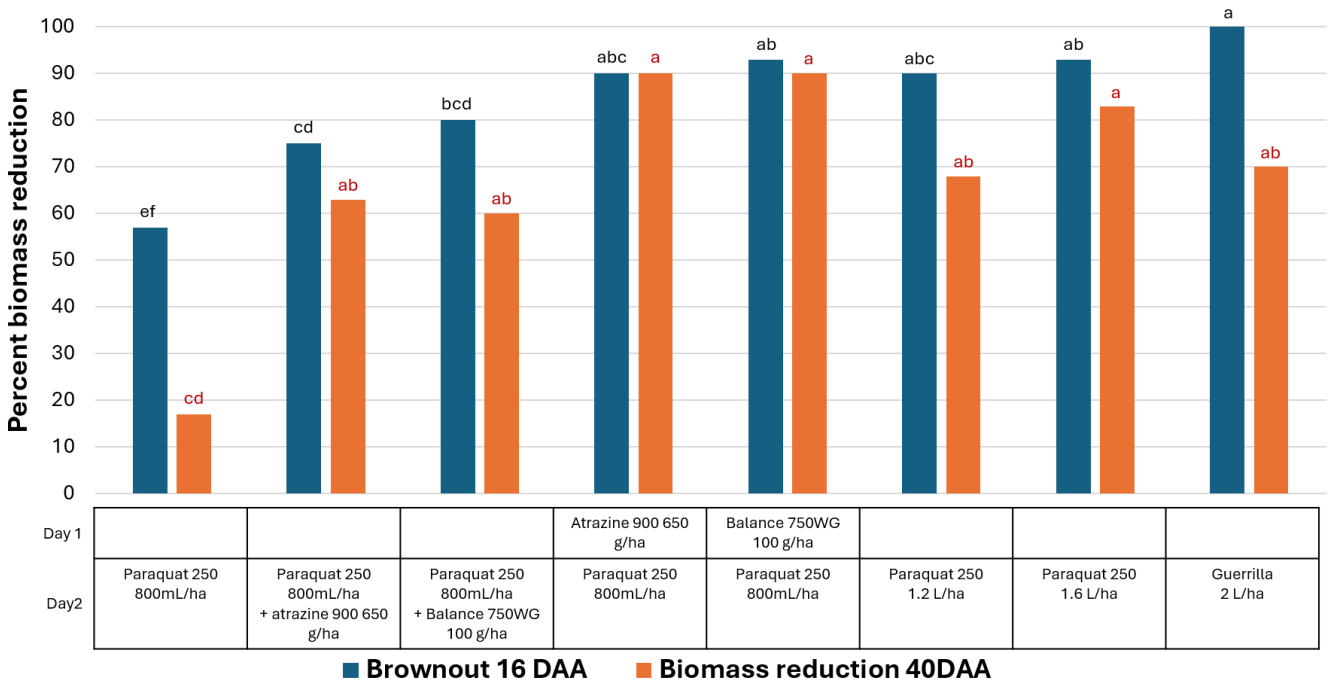
Paraquat

Prior research and commercial experience suggest that paraquat (a PSI herbicide) and atrazine (a PSII herbicide) or paraquat and Balance® (HPPD inhibitor) may be complementary. We planned to test these assumptions, as a tank mix and by splitting the application, to understand if there may be benefit of applying the other herbicide prior to the paraquat, as a result of the different speed of activity of these herbicides.

To test for antagonism/synergy we used 800 mL/ha of a 250 g/L paraquat formulation as the base application rate. While below field rates, this rate was selected to hopefully be sublethal when applied alone, allowing assessment of any interaction with atrazine or Balance®. Paraquat 250 alone at 1.6 L/ha and 2.4 L/ha were also included to be able to compare to paraquat performance at commercial application rates.

Amitrole (a Group 34 lycopene cyclase inhibitor) is also claimed to enhance activity of paraquat. Guerrilla® (a co-formulation of 300 g/L paraquat + 12 g/L amitrole) was also included as a treatment at 2 L/ha (maximum application rate for fleabane in fallow) as a direct comparison to the maximum label rate of 2.4 L/ha of Paraquat 250 (both delivering 600 gai/ha paraquat), to understand the benefit of the addition of the amitrole.

'Tillering' barnyard grass (*Echinochloa spp.*)

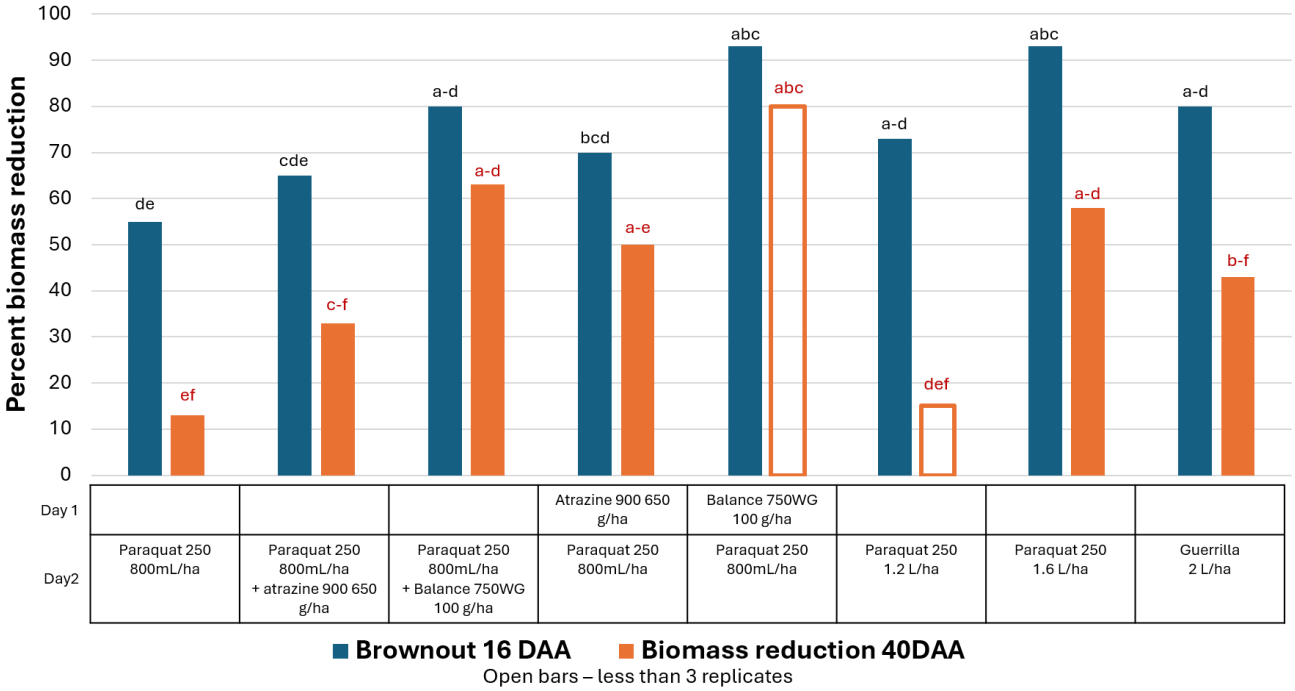


While not statistically significant for brownout, there appeared to be a dose response to increasing paraquat rate (0.8 L/ha to 1.6 L/ha to 2.4 L/ha) when applied alone (treatments 1, 6 & 7 in the graph above). This was particularly evident in the final control assessment, where the 0.8 L/ha rate was inferior to the higher application rates.

Tank mixing atrazine 900WG (at 650 g/ha) or Balance® (at 100 g/ha) with the 0.8 L/ha rate of paraquat resulted in statistically improved brownout and final control, compared to paraquat alone at that rate. Of interest, performance of these tank mixes performed more like the solo application of paraquat 250 at 1.6 L/ha, than the solo application of paraquat at 0.8 L/ha.

Splitting the atrazine and paraquat or Balance® and paraquat applications (atrazine or Balance® applied the day prior to the paraquat treatments) provided a further increase in the levels of brownout and final control over the tank mix and saw these treatments able to achieve an average of 90% control, although the magnitude of this improvement was not statistically better than the tank mix. These split applications performed more similar to the 2.4 L/ha rate of paraquat 250, than the 800 mL/rate of paraquat that was applied.

'Tillering' feathertop Rhodes grass (*Chloris virgata*)



Open bars – less than 3 replicates

While results were slightly reduced for most treatments on 'Tillering' FTR, roughly similar trends for the paraquat and atrazine and paraquat and Balance® interactions were also observed. (Note that the open bars had less than 3 replicates due to lower FTR pressure across this area of the paddock. These results should be taken with more caution).

Again, a dose response to paraquat alone was evident. Tank mixing atrazine or Balance® resulted in increased final control scores, which was statistically significant for the Balance® mix. There appeared to also be some benefit in splitting the application and applying the partner herbicide the day prior, but like the tillering barnyard

grass, this improvement was not significant over the tank mix. This split application again performed similarly to the high rate of paraquat alone.

At the maximum label rates tested in this trial, Guerrilla performed statistically similarly to the same rate of paraquat alone on both weed species. We did not have a valid comparison at lower rates in this trial, so it is not possible to fully understand the benefit of the addition of amitrole.

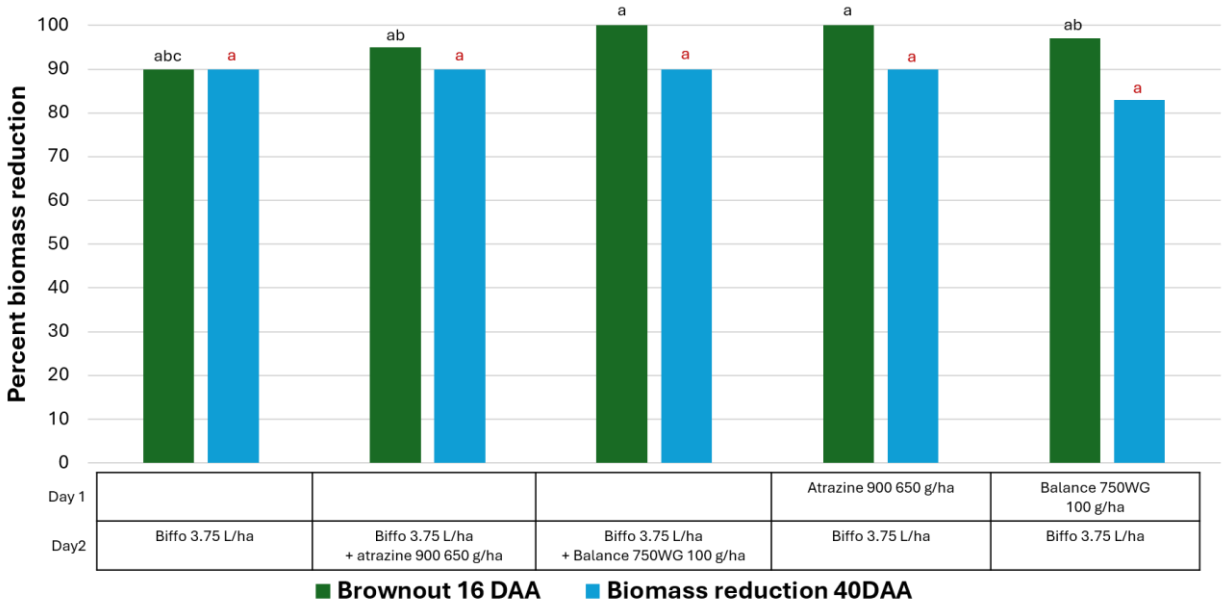
All herbicides in this trial performed poorly on the 'Advanced' cohorts of either weed (data not presented here but is included in the appendix). Paraquat and paraquat + atrazine mixes effectively provided no control on either species at 40DAA. While still not commercially acceptable, the addition of Balance® to paraquat did provide improved control over the untreated, paraquat or paraquat + atrazine treatments on these large plants.

Glufosinate

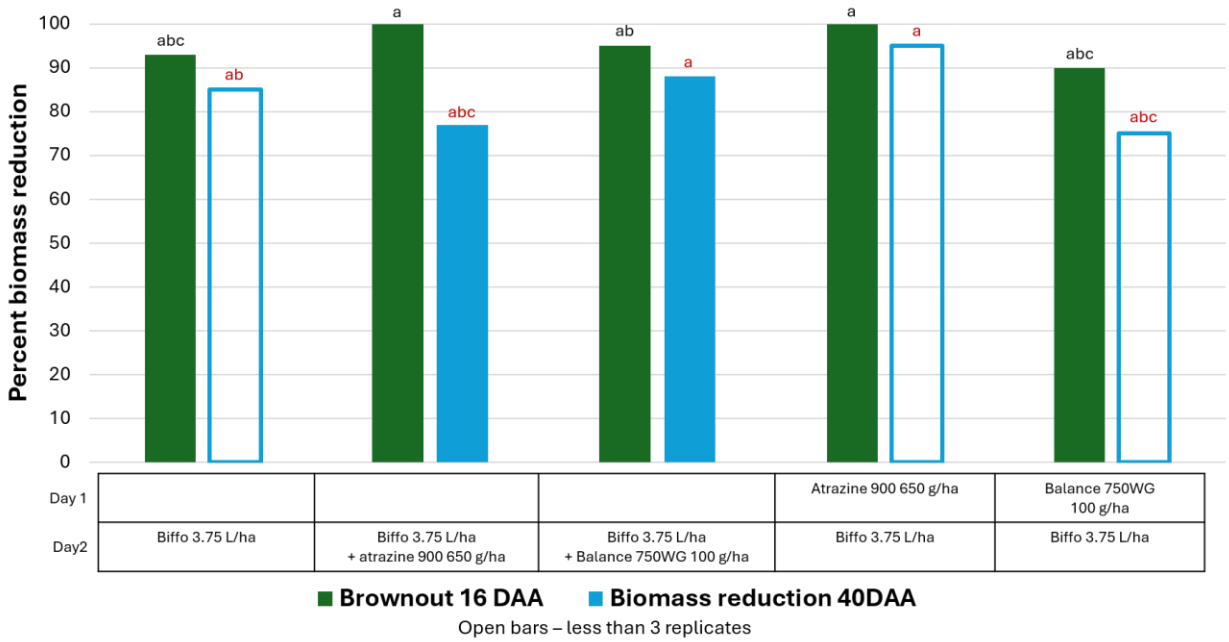
While glufosinate (Group 10) is a different mode of action to paraquat, the efficacy of both herbicides is reported to be influenced by electron transfer through photosystem I (PSI). In the case of paraquat, reduced electron flow is expected to benefit - so the addition of Group 5 (atrazine) or Group 27 (isoxaflutole) may assist control as these herbicides reduce electron transfer to PSI. Whereas for glufosinate, previous research has suggested that reduced electron flow at PSI may be detrimental to glufosinate performance. With this knowledge, we wanted to compare tank mixes of atrazine and isoxaflutole with glufosinate to understand if this affects performance of grass weeds in fallow.

We elected to use the full label rate of Biffo® (200g/L glufosinate) as we expected that this would not provide full control on the grass weeds at this site. As can be seen from the data below on both 'tillering' weeds, the label rate of glufosinate alone provided high levels of control in this trial (and better than was expected due to the weed size). As a result, there was no significant difference between treatments for either tillering species.

'Tillering' barnyard grass (*Echinochloa spp.*)



‘Tillering’ feathertop Rhodes grass (*Chloris virgata*)



Open bars – less than 3 replicates

Results for tillering FTR below should be taken with more caution, due to the low number of FTR plants in some treatments.

Control was poor for the ‘Advanced’ plants (data not shown here, but available in the appendix). Pre-treating ‘Advanced’ barnyard grass with atrazine did provide a significant increase in control over Biffo® alone, while the tank mix of Biffo® + Balance® did provide improved control over Biffo® alone on ‘Advanced’ FTR (although all treatments were very poor on these large plants, and no treatment approached a commercially acceptable result). There did not appear to be difference between other treatments.

Summary

This work builds on earlier research, providing additional evidence that the addition of Group 5 (atrazine) or Group 27 (isoxaflutole) may be of benefit in improving paraquat performance on summer grass weeds. While we observed trends in increased performance by tank mixing, the greatest benefit was seen where the alternative herbicide was applied the day prior to the paraquat application.

This information may be important should regulatory activity see paraquat use rates reduced.

Response differed with glufosinate. This might be reflective of the dose rate used, and may be compounded by results that were either very good on the smaller plants or very poor on the larger plants, and therefore masking any herbicide interaction. Lack of FTR pressure in this part of the paddock may have also had an impact on the ability to separate treatment differences.

Atrazine did not appear to have any major influence on the performance of glufosinate (which is contrary to research published by Takano et. al. 2020 that shows strong antagonism on Palmer amaranth in the USA https://doi.org/10.1007/s11120-020-00749-4).

Likewise, no major impact of Balance® on the performance of glufosinate was observed.

Herbicides used in this trial

Paraquat 250	250 g/L paraquat
Atrazine 900WG	900 g/kg atrazine
Guerrilla®	300 g/L paraquat + 12 g/L amitrole
Balance® 750WG	750 g/kg isoxaflutole
Biffo®	200 g/L glufosinate

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Trial site managed by AMPS Research on behalf of ICAN

Appendix – treatments applied at trial site timing 1 & 2

DK = Double knock of 2.4 L/ha paraquat 250 applied 7 or 28 days after the initial application.

Results highlighted in blue had less than 3 replicates included in the average, due to no plants available to be assessed in the remaining replicates. These results should be viewed with caution.

Tillering feathertop Rhodes grass (*Chloris virgata*)

All herbicide rates per hectare			Brownout 16 DAA		Biomass reduction 40DAA1					
					Alone		DK @7DAA		DK @28DAA	
1	Nil	Nil	0	f	0	f	30	cd	30	bc
2	Nil	Paraquat (800mL)	55	de	13	ef	0	d	10	c
3	Nil	Paraquat (1.6L)	73	a-d	15	def			60	abc
4	Nil	Paraquat (2.4L)	93	abc	58	a-d	90	a	70	ab
5	Atrazine (650g)	Paraquat (0.8L)	70	bcd	50	a-e	90	a	73	ab
6	Nil	Paraquat (0.8L) + Atrazine (650g)	65	cde	33	c-f	80	a	67	ab
7	Nil	Guerrilla (2L)	80	a-d	43	b-f			35	abc
8	Balance (100g)	Paraquat (800mL)	93	abc	80	abc	95	a	100	a
9	Nil	Paraquat (800mL) + Balance (100g)	80	a-d	63	a-d	80	ab	80	ab
10	Nil	Biffo (3.75L)	93	abc	85	ab	70	ab	80	a
11	Atrazine (650g)	Biffo (3.75L)	100	a	95	a	100	a	77	ab
12	Nil	Biffo (3.75L) + Atrazine (650g)	100	a	77	abc	70	abc	60	ab
13	Balance (100g)	Biffo (3.75L)	90	abc	75	abc	70	abc	20	bc
14	Nil	Biffo (3.75L) + Balance (100g)	95	ab	88	a	100	a	90	a

Tillering barnyard grass (*Echinochloa spp.*)

All herbicide rates per hectare			Brownout 16 DAA		Biomass reduction 40DAA1					
					Alone		DK @7DAA		DK @28DAA	
1	Nil	Nil	0	g	0	d	35	d	73	ab
2	Nil	Paraquat (800mL)	57	ef	17	cd	93	ab	60	ab
3	Nil	Paraquat (1.6L)	90	abc	68	ab	80	abc	80	ab
4	Nil	Paraquat (2.4L)	93	ab	83	a	77	abc	78	ab
5	Atrazine (650g)	Paraquat (0.8L)	90	abc	90	a	93	ab	73	ab
6	Nil	Paraquat (0.8L) + Atrazine (650g)	75	cd	63	ab	80	abc	75	ab
7	Nil	Guerrilla (2L)	100	a	70	ab	87	abc	75	ab
8	Balance (100g)	Paraquat (800mL)	93	ab	90	a	100	a	90	a
9	Nil	Paraquat (800mL) + Balance (100g)	80	bcd	60	ab	90	abc	87	a
10	Nil	Biffo (3.75L)	90	abc	90	a	90	ab	88	a
11	Atrazine (650g)	Biffo (3.75L)	100	a	90	a	88	abc	83	a
12	Nil	Biffo (3.75L) + Atrazine (650g)	95	ab	80	a	90	ab	80	ab
13	Balance (100g)	Biffo (3.75L)	97	ab	83	a	90	abc	93	a
14	Nil	Biffo (3.75L) + Balance (100g)	100	a	90	a	100	a	80	ab

Advanced feathertop Rhodes growth (*Chloris virgata*)

All herbicide rates per hectare			Brownout 16 DAA		Biomass reduction 40DAA1					
					Alone		DK @7DAA		DK @28DAA	
1	Nil	Nil	0	i	0	e	0	b	0	d
2	Nil	Paraquat (800mL)	25	h	0	e	0	b	0	d
3	Nil	Paraquat (1.6L)	50	ef	0	de	0	b	0	d
4	Nil	Paraquat (2.4L)	75	bcd	0	de	0	b	40	abc
5	Atrazine (650g)	Paraquat (0.8L)	50	ef	0	e	0	b	0	d
6	Nil	Paraquat (0.8L) + Atrazine (650g)	60	def	0	e	0	b	0	d
7	Nil	Guerrilla (2L)	68	cde	0	de	0	b	0	d
8	Balance (100g)	Paraquat (800mL)	90	ab	45	a	70	a	80	a
9	Nil	Paraquat (800mL) + Balance (100g)	68	cde	15	cde	0	b	60	ab
10	Nil	Biffo (3.75L)	87	abc	17	cde	0	b	17	cd
11	Atrazine (650g)	Biffo (3.75L)	90	ab	20	bcd			20	bcd
12	Nil	Biffo (3.75L) + Atrazine (650g)	95	a	20	bc	0	b	20	bcd
13	Balance (100g)	Biffo (3.75L)	93	ab	10	cde		b	10	cd
14	Nil	Biffo (3.75L) + Balance (100g)	88	abc	35	ab	50	b	47	ab

Advanced barnyard grass (*Echinochloa spp.*)

All herbicide rates per hectare			Brownout 16 DAA		Biomass reduction 40DAA1					
					Alone		DK @7DAA		DK @28DAA	
1	Nil	Nil	0	g	0	d	0	d	37	b-f
2	Nil	Paraquat (800mL)	55	ef	0	d	50	bc	13	ef
3	Nil	Paraquat (1.6L)	58	def	0	d	47	bc	25	ef
4	Nil	Paraquat (2.4L)	80	bc	23	abc	0	d	35	c-f
5	Atrazine (650g)	Paraquat (0.8L)	65	cde	0	d	10	cd	33	def
6	Nil	Paraquat (0.8L) + Atrazine (650g)	45	f	0	d	23	cd	23	ef
7	Nil	Guerrilla (2L)	83	abc	7	cd	50	bc	40	b-e
8	Balance (100g)	Paraquat (800mL)	75	bcd	33	ab	90	a	73	ab
9	Nil	Paraquat (800mL) + Balance (100g)	68	cde	20	abc	63	ab	67	a-d
10	Nil	Biffo (3.75L)	93	ab	18	bcd	50	bc	68	abc
11	Atrazine (650g)	Biffo (3.75L)	100	a	37	a	75	ab	43	b-e
12	Nil	Biffo (3.75L) + Atrazine (650g)	90	ab	25	ab	63	ab	40	b-e
13	Balance (100g)	Biffo (3.75L)	90	ab	33	ab	43	bc	70	abc
14	Nil	Biffo (3.75L) + Balance (100g)	90	ab	30	ab	80	ab	70	abc