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Control of Flaxleaf Fleabane (*Conyza bonariensis*) in Wheat and Sorghum

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Flaxleaf fleabane is a difficult-to-control weed in dryland minimum tillage farming systems in the northeast grains region of Australia. Experiments were conducted between 2003 and 2005 to identify effective control strategies on flaxleaf fleabane in wheat and sorghum. A preplant application of chlorsulfuron at 15 g ai/ha in wheat controlled flaxleaf fleabane ≥ 90%. The efficacy of early postemergent applications of metsulfuron–methyl at 4.2 g ai/ha varied between years. However, the flaxleaf fleabane was controlled > 85% with metsulfuron–methyl at 4.2 g ai/ha plus MCPA at 420 g ae/ha plus picloram at 26 g ae/ha, or metsulfuron–methyl followed by late postemergent 2,4-D amine at 300 g ae/ha. In sorghum, a preplant application of glyphosate at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha or dicamba at 500 g ae/ha at 1 mo before sorghum planting provided ≥ 95% control. Preplant atrazine at 2,000 g ai/ha controlled flaxleaf fleabane 83 to 100% in sorghum. At-planting atrazine at 2,000 or 1,000 g ai/ha can be applied to control new emergence of flaxleaf fleabane and grasses, depending on the weed pressure and spectrum. Flaxleaf fleabane reduced sorghum yield 65 to 98% if not controlled.

Nomenclature: 2,4-D; atrazine; chlorsulfuron; dicamba; fluroxypyr; glyphosate; MCPA; metsulfuron–methyl; picloram; paraquat and diquat; flaxleaf fleabane, *Conyza bonariensis* (L.) Cronq. ERIBO; sorghum, *Sorghum bicolor* (L.) Moench SORVU; wheat, *Triticum aestivum* L.

Key words: Flaxleaf fleabane, herbicides, weed management.

La *Conyza bonariensis* es una maleza difícil de controlar en tierra seca con un sistema de labranza mínima en la región productora de granos del noreste de Australia. Se llevaron al cabo experimentos entre 2003 y 2005 para identificar las estrategias de control más efectivas para *Conyza bonariensis* en trigo y sorgo. Una aplicación en pre-siembra de chlorosulfuron a 15 g ia/ha en el trigo, controló *Conyza bonariensis* ≥ 90%. La eficacia de las aplicaciones tempranas post-siembra de metsulfuron-methyl a 4.2 g ia/ha varió de un año a otro. Sin embargo, la *Conyza bonariensis* fue controlada >85% con metsulfuron-methyl a 4.2 g ia/ha más MCPA a 420 g ea/ha más picloram a 26 g ea/ha, o metsulfuron-methyl fb LPOST 2,4-D amine a 300 g ea/ha. En el caso del sorgo, una aplicación de glifosato en pre-siembra a 900 g ea/ha más 2,4-D amine a 900 g ea/ha o dicamba a 500 g ea/ha un mes antes de la siembra proporcionó ≥ 95% de control. En el cultivo de sorgo, la aplicación de atrazine en pre-siembra a 2000 g ia/ha controló la *Conyza bonariensis* de 83 al 100%. La aplicación de atrazine en la siembra a 2000 o 1000 g ia/ha puede ser usada para controlar nueva emergencia de la *Conyza bonariensis* y otros zacates, dependiendo de la presión y el espectro de la maleza. La *Conyza bonariensis* redujo el rendimiento del sorgo entre un 65 y un 98% cuando no se controló.

Flaxleaf fleabane or hairy fleabane is an annual plant in the Asteraceae family, native to South America (Michael 1977). It was reported as a weed in northern New South Wales (NSW) in the 1980s (Wicks et al. 2000). Flaxleaf fleabane has since become one of the problem weeds in northern NSW and southern Queensland, coinciding with the increased adoption of no-till farming systems during the last 25 yr (Felton et al. 1994). Flaxleaf fleabane increased in importance in a 1990 survey compared to a survey conducted in 1985 (Martin et al. 1988). By 2001, flaxleaf fleabane was found in 21% of summer fallows and dryland cotton (*Gossypium hirsutum* L.) of northern NSW and southern Queensland (Walker et al. 2005), and was considered a main weed of grain farming systems by 18 and 15% of surveyed growers in the same areas, respectively (Osten et al. 2007). By 2004, flaxleaf fleabane was considered to be one of the most difficult-to-control weeds of dryland cropping in the northeast grain region of Australia (Walker et al. 2004).

Flaxleaf fleabane infests both winter and summer crops. The weed is more problematic in summer row crops, such as sorghum and cotton, than in winter cereals that utilize narrow row spacing. Little information is available on the economic impact of flaxleaf fleabane on crop production. A similar species, horseweed [*Conyza canadensis* (L.) Cronq.], caused up to 83% yield reduction in a no-till soybean [*Glycine max* (L.) Merr.] at 150 plants/m^2 (Bruce and Kells 1990). In addition, flaxleaf fleabane has also evolved resistance to glyphosate (Urbano et al. 2007), which could limit the adoption of no-till farming systems and affect crop production.

Flaxleaf fleabane is a winter or summer annual (Wu et al. 2007). It emerges predominantly in autumn and early winter, forms a basal rosette during winter, and produces seed the following spring or summer. A small fraction of flaxleaf fleabane also germinates in spring and bolts without an overwintering growth stage. The emergence pattern is a consequence of its germination temperature requirements. Flaxleaf fleabane germinates at temperatures between 10 and

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25 C (Zinzolker et al. 1985), with minimum, optimum, and maximum germination temperatures of 5, 20, and 35 C, respectively (Wu et al. 2007). Germination is stimulated by light (Michael 1977; Zinzolker et al. 1985). Major rainfall events will trigger germination resulting in sequential flushes. Thus, flaxleaf fleabane is often present at several growth stages at a particular point in time in individual fields. The variability of plant growth stage makes application timing difficult.

Management of flaxleaf fleabane is restricted by limited biology and ecology information. Flaxleaf fleabane is a prolific seed producer. It was capable of producing up to 357,600 wind-dispersed seeds/plant in Kern County, California (Kempen and Graf 1981). Average seed production was estimated at 400 seeds/head and 119,100/plant from southern Queensland (Wu et al. 2007). Andersen (1992) reported that flaxleaf fleabane has a low settling velocity of 0.323 m/s in the air, indicating the seed may travel some distance before settling to the ground. These two key biological features indicate that the spread of flaxleaf fleabane across agricultural landscapes could be very rapid over long distances via wind, surface runoff, and water movement in irrigation channels and waterways.

The high fecundity, high potential level of dispersability, and staggered emergence are key biological features of flaxleaf fleabane (Andersen 1992; Kempen and Graf 1981; Procopio et al. 2003; Wu et al. 2007) influencing persistence and management. Previous research has generated biological information useful for the management of horseweed (Keeling et al. 1989; Moseley and Hagood 1990; VanGessel et al. 2001; Wiese et al. 1995). However, similar information is lacking for flaxleaf fleabane. Management information is not available on flaxleaf fleabane in wheat or sorghum. The objective of this study was to identify effective control options for flaxleaf fleabane in wheat and sorghum.

Materials and Methods

Flaxleaf Fleabane Control in Wheat. The residual effects of chlorsulfuron and metsulfuron–methyl on flaxleaf fleabane were assessed in on-farm experiments at Cecil Plains (27°31′26.78″S, 150°20′47.63E) in 2004 and at Moonie (27°45′11.11″S, 150°20′23.66E) in 2005. Both sites were located in southern Queensland. Initial flaxleaf fleabane densities were 450 and 320 plants/m^2 at Cecil Plains and Moonie when assessed on April 15, 2004 and May 25, 2005, respectively. Based on previous experiments (Wu et al. 2008), a sequential application of glyphosate at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha followed by (fb) a prepackaged herbicide mixture[1] of paraquat at 270 g ai/ha plus diquat at 130 g ai/ha was used to control established fleabane plants prior to the experiments. A split plot design with three replications was used in both experiments with wheat density as the main plot (70 and 100 plants/m^2) and six herbicide treatments as subplots. Herbicide treatments are listed in Table 1 as preplant (PP) chlorsulfuron at 15 g ai/ha, PP chlorsulfuron at 15 g ai/ha fb an early postemergent (EPOST) application of a prepackaged mixture[2] of MCPA at 420 g ae/ha plus picloram at 26 g ae/ha, EPOST metsulfuron–methyl at 4.2 g ai/ha, EPOST metsulfuron–methyl at 4.2 g ai/ha plus the mixture of MCPA at 420 g ae/ha plus picloram at 26 g ae/ha, and EPOST metsulfuron–methyl at 4.2 g ai/ha fb late postemergent (LPOST) application of 2,4-D amine 300 g ae/ha. 'Baxter' wheat was no-tillage drilled at 35 and 50 kg/ha to achieve wheat densities of 70 and 100 plants/m^2, respectively, on July 20, 2004 and May 27, 2005. A composite fertilizer[3] (10.9% N, 19.2% P, 2.2% S, and 2.5% Zn) at 40 kg/ha and a urea fertilizer[4] at 60 kg/ha (46% N) were applied at planting. Wheat planting in July 2004 was late because of a dry winter season. Irrigation was applied to assist wheat emergence immediately after planting in 2004. The plot size was 20 m in length by eight rows wide, with rows spaced 25 cm apart.

Chlorsulfuron was applied PP at 15 g ai/ha on May 25, 2004, which was 80 d prior to wheat planting because of the late sowing, and on May 27, 2005 immediately before sowing. EPOST and LPOST applications were applied to flaxleaf fleabane seedlings at a rosette stage of < 10 cm across on September 16 and 24, 2004, and July 7 and 18, 2005, when wheat had one to two and three to four tillers, respectively.

Treatments were applied with a tractor-mounted compressed-air sprayer calibrated to deliver 70 L/ha through flat spray nozzles[5] at 200 kPa. A biodegradable surfactant[6] at 0.1% (v/v) was included in all herbicide treatments except for the LPOST 2,4-D amine and the EPOST application of the prepackaged mixture of MCPA and picloram treatments in wheat.

Flaxleaf fleabane density was assessed at 31 d after treatment (DAT) in 2004 and 21 DAT in 2005 after the EPOST metsulfuron–methyl treatments by counting weeds in 25 cm by 20 m quadrats of the two middle rows of each plot. Monthly rainfall data during the growing season are presented in Table 2. Target wheat densities were achieved in both years, but crop growth was poor due to severe drought. Assessment of yield reduction due to weeds was not possible. Wheat was bulk-harvested in both experiments on December 2, 2004 and October 28, 2005.

Flaxleaf Fleabane Control in Sorghum. Atrazine and other POST herbicides were evaluated in one experiment in Cecil Plains in 2004, and two experiments at Moonie (2005-A) and Bowenville (27°17′24.10″S, 151°24′26.62E) (2005-B) in 2005. The initial plant density of flaxleaf fleabane was 850, 450, and 196 plants/m^2 at Cecil Plains, Moonie, and Bowenville when assessed on April 15, 2004, May 25, 2005, and May 25, 2005, respectively. Flaxleaf fleabane was the predominant species at Cecil Plains and Bowenville sites, whereas summer annual grasses (35 plants/m^2), including button grass (*Dactyloctenium radulans* P. Beauv.) and awnless barnyard grass (*Echinochloa colona* L. Link) were also present at the Moonie site. Established weeds at the three experimental sites were controlled by a sequential application of glyphosate at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha fb the prepackaged mixture of paraquat 270 g ai/ha plus diquat at 130 g ai/ha prior to the experiments.

Seven treatments are listed in Table 3 as follows: an early preplant (EPP) application of atrazine at 2000 g ai/ha, PP glyphosate at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha fb an at-planting application (AP) of atrazine at 2,000 g ai/ha, a

Table 1. Flaxleaf fleabane control in wheat.[a,b,c]

Treatment	Description	Rate	Control[d,e] 2004	Control[d,e] 2005
		g ai/ha	%	%
Chlorsulfuron	PP only	15	95 a	90 b
Chlorsulfuron fb MCPA + picloram	PP fb EPOST	15 fb 420 + 26	86 a	99 a
Metsulfuron–methyl	EPOST only	4.2	57 b	98 a
Metsulfuron–methyl + MCPA + picloram	EPOST only	4.2 + 420 + 26	80 ab	100 a
Metsulfuron–methyl fb 2,4-D amine	EPOST fb LPOST	4.2 fb 300	94 a	97 a

[a] Abbreviations: PP, preplant; fb, followed by; EPOST, early postemergent; LPOST, late postemergent.

[b] In 2004, the PP treatments of chlorsulfuron were applied on May 25, 2004, EPOST treatments were applied on September 16, 2004, and LPOST were applied on September 24, 2004. In 2005, PP treatments were applied on May 27, 2005, EPOST treatments were applied on July 7, 2005, and LPOST were applied on July 18, 2005.

[c] The data presented were from the assessment of October 27, 2004 and July 27, 2005, respectively.

[d] Percentage reduction in weed density from control plots.

[e] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at a $P \leq 0.05$ level.

PP application of glyphosate at 900 g ae/ha followed 7 d later by the prepackaged mixture of paraquat at 203 g ai/ha plus diquat at 173 g ai/ha fb an AP application of atrazine at 2,000 g ai/ha, an EPP atrazine application at 1,000 g ai/ha fb an EPOST application of atrazine at 1,000 g ai/ha plus fluroxypyr at 100 g ae/ha, a PP glyphosate application at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha fb an AP application of atrazine at 1,000 g ai/ha, a PP application of glyphosate at 900 g ae/ha plus dicamba at 500 g ae/ha fb an AP application of atrazine at 1,000 g ai/ha, and a PP application of glyphosate at 900 g ae/ha plus 2,4-D amine at 900 g ae/ha. All treatments were applied to flaxleaf fleabane seedlings at the rosette stage (< 10 cm across), except the EPOST application of atrazine plus fluroxypyr, which was applied to mature flowering flaxleaf fleabane plants to stop seed set. 'Buster' sorghum was drill-seeded at 2.9 kg/ha on October 27, 2004 and November 1, 2005 to achieve a population of 60,000 plants/ha. A composite fertilizer[3] at 40 kg/ha was applied at planting. The experiment was designed as a randomized complete block with three replications. Plot size was four 20-m-long rows spaced 1 m apart.

All herbicide applications were made with a compressed-air sprayer at a volume of 70 L/ha, except the premix of paraquat and diquat, which was applied at 100 L/ha, with flat spray nozzles,[5] calibrated to deliver the respective spray volumes. A biodegradable surfactant[5] at 0.1% (v/v) was included in all herbicide treatments.

Mature flaxleaf fleabane plants in control plots and the EPP atrazine (1,000 g ai/ha) plots were manually removed at 2 mo after sorghum planting to prevent massive potential seed production on the farm at Cecil Plains site in 2004. Sorghum was harvested with a mechanical harvester on March 1, 2005 and March 15, 2006, from an area of 4 m by 18 m in each plot.

Weed densities of flaxleaf fleabane and grasses were assessed at 34 to 35 DAT after AP atrazine in sorghum by counting weed species in three rows at 1 m by 20 m quadrats except in the control plots, where three random quadrats (0.5 by 1 m^2) were used because of the high weed density.

Table 2. Monthly rainfall (mm) during experimental periods at all field sites.[a,b,c]

Month	2004 Sorghum	2004 Wheat	2004 LTA[d]	2005-A Sorghum	2005-A LTA[d]	2005-B Sorghum	2005-B Wheat	2005-B LTA[d]
May		0	47		35		33	43
June		0	37		40		145	41
July		0	39		42		3	42
August		13	32		30		0	33
September		16	33		38		13	39
October	75	75	72	90	58	73	73	49
November	53	53	69	73	74	109		60
December	190	190	101	124	93	64		70
January	0		97	132	85	101		79
February	12		85	47	77	56		69
March	0		63	11	66	25		60

[a] Yearly rainfall data were obtained on farms.

[b] 2004, 2005-A, and 2005-B were experiments conducted at Cecil Plains (2004), Bowenville (2005), and Moonie (2005), respectively.

[c] Wheat was planted on July 20, 2004 and May 27, 2005, and harvested on December 2, 2004 and October 28, 2005; sorghum was planted on November 21, 2004 and November 1, 2005, and harvested on March 1, 2005 and March 15, 2006, respectively.

[d] Long-term average (LTA) data were obtained from nearby weather stations, i.e., Cecil Plains (66-yr) from the Department of Natural Resources and Water Queensland, Bowenwille and Moonie (100-yr for both sites) from the Australian Bureau of Meteorology.

Table 3. Flaxleaf fleabane control in sorghum.[a,b,c]

Treatment	Description	Rate	Flaxleaf fleabane[d,e] 2004[f]	Flaxleaf fleabane[d,e] 2005-A[f]	Flaxleaf fleabane[d,e] 2005-B[f]	Grasses[d,e] Pooled[g]
		g ai/ha	%			
Atrazine	EPP	2,000	89 b	83 b	100 a	83 ab
Glyphosate + 2,4-D amine fb atrazine	PP fb AP	900 + 900 fb 2,000	99 a	100 a	100 a	74 b
Glyphosate fb PP paraquat + diquat fb atrazine	PP fb PP fb AP	900 fb 203 + 173 fb 2,000	99 a	83 b	100 a	92 a
Atrazine fb atrazine + fluroxypyr	EPP fb EPOST	1,000 fb 1,000 + 100	60 c	67 c	84 b	73 b
Glyphosate + 2,4-D amine fb atrazine	PP fb AP	900 + 900 fb 1,000	98 a	100 a	96 a	56 c
Glyphosate + dicamba fb atrazine	PP fb AP	900 + 500 fb 1,000	99 a	100 a	100 a	70 b
Glyphosate + 2,4-D amine	PP	900 + 900	87 b	100 a	100 a	46 c

[a] Abbreviations: EPP, early preplant; fb, followed by; PP, preplant; EPOST, early postemergent; AP, at planting.

[b] In 2004, EPP atrazine treatments were applied on August 27, 2004; PP of knockdown herbicides were applied on September 24, 2004; AP were applied on October 27, 2004, and EPOST treatments were applied on November 18, 2004. In 2005, EPP treatments were applied on September 14, 2005, PP treatments were applied on October 11, 2005, AP treatments were applied on November 1, 2005, and EPOST treatments were applied on November 30, 2005.

[c] The data presented were from the assessment of December 1, 2004 and December 14, 2005, respectively.

[d] Percentage reduction in weed density from control plots.

[e] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at a $P \leq 0.05$ level.

[f] 2004, 2005-A, and 2005-B were experiments conducted at Cecil Plains (2004), Bowenville (2005), and Moonie (2005), respectively.

[g] The grass data from the three sorghum trials were pooled due to the absence of site-by-treatment interactions.

Design and Statistical Analysis. All data were subjected to REML variance components analysis with the use of Genstat 10. Weed density data in both wheat and sorghum and sorghum yield were transformed to adhere to the statistical assumptions of homogenous variance and normality. Fleabane and grass density data were natural log transformed as $\ln(x + 1)$, whereas the sorghum yield (kg/ha) was square-root transformed. Original (nontransformed) data are presented, whereas statistical analysis was done on the transformed data. When a significant year-by-treatment interaction existed, data were analyzed separately by year. Grass data from the three sorghum trials were pooled because of the absence of site-by-treatment interactions.

Results and Discussion

Control in Wheat. The target wheat densities of 70 plants and 100 plants/m^2 were achieved in both years. High wheat density at 100 plants/m^2 resulted in significantly less fleabane density than in the low wheat density treatment at 70 plants/m^2 (Figure 1). The fleabane infestation in the high wheat density treatment was 0.4 and 3 plants/m^2 when assessed on August 24, 2004 and on July 27, 2005, whereas the low wheat density treatment had 1 and 6 plants/m^2, respectively. The differences between high and low wheat density treatments diminished as the crop matured as evident in later evaluations (Figure 1). Dry weather conditions after emergence in both experiments resulted in poor wheat growth, which could undermine the competitive advantage of higher seeding rates. Conversely, natural death of fleabane plants due to the dry conditions might also modify the effect of different wheat density treatments.

All herbicide treatments significantly reduced fleabane density. PP chlorsulfuron controlled (> 90%) subsequent flushes of flaxleaf fleabane throughout the season in both years, although chlorsufuron was applied 80 d prior to wheat planting in 2004 and applied immediately before planting in 2005 (Table 1). There was no advantage in applying a follow-up EPOST treatment of MCPA plus picloram in the 2004 experiment, which was mostly due to the severe moisture stress conditions at the time of EPOST application. However, the follow-up application of MCPA plus picloram improved fleabane control in the 2005 experiment as a result of the good soil moisture at the time of spraying.

EPOST metsulfuron–methyl provided variable results, with < 80% control in 2004 and 98% control in 2005, possibly due to activation by rainfall in 2005. Consistent results were obtained with EPOST metsulfuron–methyl either mixed with

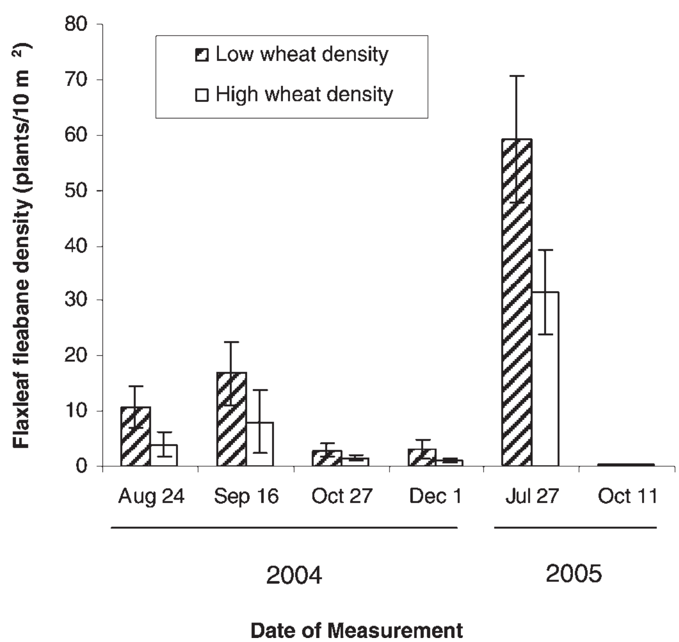

Figure 1. Wheat competitive effects on flaxleaf fleabane (high wheat density treatment at 100 plants/m^2 and low wheat density treatment at 70 plants/m^2). Bars represent standard error of the mean.

Table 4. Sorghum yield as affected by herbicide applications and weed infestations.[a,b]

Treatment	Description	Rate	Sorghum yield[c] 2004[d]	2005-A[d]	2005-B[d]
		g ai/ha	kg/ha		
Atrazine	EPP	2,000	4,472 ab	3,037 ab	1,290 a
Glyphosate + 2,4-D amine fb atrazine	PP fb AP	900 + 900 fb 2,000	5,215 a	2,969 ab	1,094 ab
Glyphosate fb PP paraquat + diquat fb atrazine	PP fb PP fb AP	900 fb 203 + 173 fb 2,000	4,389 ab	3,433 a	1,418 a
Atrazine fb atrazine + fluroxypyr	EPP fb EPOST	1,000 fb 1,000 + 100	4,340 b	2,070 b	900 ab
Glyphosate + 2,4-D amine fb atrazine	PP fb AP	900 + 900 fb 1,000	4,785 ab	2,242 b	558 bc
Glyphosate + dicamba fb atrazine	PP fb AP	900 + 500 fb 1,000	4,868 ab	3,350 a	878 ab
Glyphosate + 2,4-D amine	PP	900 + 900	5,139 ab	2,475 b	115 c
Nontreated			1,556 c	1,872 b	58 c

[a] Abbreviations: EPP, early preplant; fb, followed by; PP, preplant; AP, at planting; EPOST, early postemergent.

[b] In 2004, EPP atrazine treatments were applied on August 27, 2004; PP herbicides were applied on September 24, 2004; AP treatments were applied on October 27, 2004, and EPOST treatments were applied on November 18, 2004. In 2005, EPP treatments were applied on September 14, 2005; PP treatments were applied on October 11, 2005; AP treatments were applied on November 1, 2005, and EPOST treatments were applied on November 30, 2005.

[c] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at a P ≤ 0.05 level.

[d] 2004, 2005-A, and 2005-B were experiments conducted at Cecil Plains (2004), Bowenville (2005), and Moonie (2005), respectively.

a prepackaged mixture of MCPA plus picloram or fb LPOST 2,4-D amine, resulting in 85 to 99% control in both years. The residual activity of picloram might contribute to the suppression of further flushes, whereas the LPOST 2,4-D amine might assist controlling newly emerged seedlings.

Control in Sorghum. Below average rainfall occurred in 2004 and 2005 seasons (Table 2). EPP atrazine at 2,000 g ai/ha applied 2 mo prior to planting was activated by rainfall at 5 to 15 mm received within 3 to 14 d after application at all sites. This treatment controlled flaxleaf fleabane 83 to 100%, whereas EPP atrazine at 1,000 g ai/ha even with a follow-up EPOST atrazine at 1,000 g ai/ha plus fluroxypyr at 100 g ae/ha achieved only 60 to 84% control across the three experiments (Table 3).

Herbicide treatments providing ≥ 95% control of flaxleaf fleabane in all the three experiments were PP glyphosate plus either 2,4-D amine or dicamba, fb an AP application of atrazine either at 1,000 or 2,000 g ai/ha. In addition, PP glyphosate followed 7 d later by the prepackaged mixture of paraquat and diquat at 1 mo prior to sorghum planting, then fb AP atrazine at 2,000 g ai/ha was an effective treatment, controlling flaxleaf fleabane 83 to 100% and grasses 92%. Glyphosate plus 2,4-D applied PP controlled flaxleaf fleabane 87% in 2004 and 100% in 2005. These results indicate that effective flaxleaf fleabane control in sorghum relies heavily on PP glyphosate-based herbicide mixtures on established fleabane plants prior to planting. Limited fleabane emerged in late spring and summer when sorghum is grown, because of high temperatures and low soil moisture (Wu et al. 2007). Without any PP treatments, split applications of EPP atrazine applied at 1,000 g ai/ha fb an EPOST application of atrazine at 1,000 g ai/ha plus fluroxypyr gave poor control of flaxleaf fleabane (60 to 80%), indicating less effective control of established flaxleaf fleabane with this treatment.

An at-planting atrazine application can further improve flaxleaf fleabane control, especially when there is high fleabane pressure as observed at the Cecil Plains site in 2004 or the presence of summer grasses as observed at the Moonie site in 2005. Otherwise, a follow-up application of atrazine at planting might not be necessary due to limited flaxleaf fleabane emergence in the summer season when sorghum is planted (Wu et al. 2007). To achieve effective fleabane control in sorghum, focus should be on established fleabane populations in the fallow period prior to planting. Additionally, PP glyphosate fb the prepackaged mixture of paraquat and diquat fb AP atrazine at 2,000 g ai/ha resulted in fewer grass weeds when compared to the control plots. Other atrazine-based treatments provided less grass control (46 to 83%).

Weeds caused significant yield loss in sorghum (Table 4). Compared to the treatment of a PP glyphosate fb the prepackaged mixture of paraquat and diquat fb AP atrazine at 2,000 g ai/ha (considered here as weed-free plots), weeds in control plots caused a yield loss of 65, 45, and 96% at Cecil Plains (2004), Bowenville (2005), and Moonie (2005), respectively. The 65% yield loss in 2004 was in fact underestimated, because the mature fleabane plants were removed at 2 mo after planting to save the control plots and to prevent massive seed production on the farm. When the plots were manually weeded 3 mo prior to harvest, fleabane plants, present at a density of 14 plants/m^2, had already caused severe moisture deficiency for the sorghum plants. Sorghum plants in control plots in the 2004 experiment were smothered by the vigorous growth of flaxleaf fleabane plants and showed severe nutrition and moisture stress symptoms. Had the flaxleaf fleabane plants not been removed, they would have likely caused 100% yield loss. The lower yield loss in Bowenville was a result of a lower weed pressure, when compared to other field sites. A higher yield loss of 96% at Moonie site in 2005 was a result of dry late-season weather and weed competition due to mixed populations of flaxleaf fleabane and summer grasses. These yield loss data are similar to the 83% yield loss in soybean due to horseweed (Bruce and Kells 1990). Flaxleaf fleabane control with the split applications of EPP atrazine at 1,000 g ai/ha fb EPOST atrazine at 1,000 g ai/ha plus fluroxypyr at 100 g ae/ha resulted in the lowest sorghum yield at the Cecil Plains site (2004) and Bowenville site (2005), and the second lowest at the Moonie site (2005).

The use of residual herbicides, particularly those absorbed through the roots, is an important strategy to overcome reduced foliar uptake by the thick cuticular barrier of flaxleaf fleabane (Procopio et al. 2003). Residual herbicides have been effective in controlling multiple flushes of fleabane in winter fallow (Wu et al. 2008). Strategic use of preplant residual herbicides, such as sulfonylurea (chlorsulfuron) and triazine (atrazine) herbicides, also achieved effective control of flaxleaf fleabane in wheat or sorghum. Residual herbicides have also provided season-long control of horseweed (VanGessel et al. 2001; Wilson and Worsham 1988). Full-season control of horseweed was obtained with glyphosate in combination with residual herbicides in soybean (VanGessel et al. 2001).

Use of residual herbicides might restrict the choice of rotational crops. However, in this study, the amount of these residual herbicides in the soil was less than 0.05 mg/kg in the top 10 cm in soil cores collected from experimental sites 11 mo after the PP chlorsulfuron application, 7 mo after the EPOST application of metsulfuron–methyl, and 6 to 8 mo after the EPP application of atrazine. A glasshouse bioassay with the intact soil cores also showed no significant residual effects on cotton emergence and seedling growth when compared to nontreated controls.

Effective flaxleaf fleabane control can only be achieved by integrating chemical and nonchemical control tactics and by adopting a systems approach targeting all rotational components, including both fallow and crop rotations. Increasing wheat competition by adjusting seeding rates is an effective option in reducing flaxleaf fleabane populations. Targeting flaxleaf fleabane in fallow, such as the use of the sequential application of glyphosate plus 2,4-D amine fb a prepackaged herbicide mixture of paraquat plus diquat, was a prerequisite for cropping success in both winter wheat and summer sorghum.

Sources of Materials

[1] Prepackaged herbicide mixture, Spray.Seed® containing 135 g/L paraquat (present as paraquat dichloride) and 115 g/L diquat (present as diquat dibromide), Syngenta, Level 1, 2-4 Lyonpark Road, Macquarie Park, New South Wales 2113, Australia.

[2] Prepackaged mixture Tordon* 242 containing 420 g/L MCPA (present as the potassium salt) and 26 g/L picloram (present as the potassium salt), Dow Agrosciences, Locked Bag 502, Frenchs Forest, New South Wales 1640, Australia.

[3] Composite fertilizer, Granulock® Starter Z® fertilizer, Incitec Pivot Limited, 70 Southbank Boulevard, Southbank, Victoria 3006, Australia.

[4] Urea fertilizer, Incitec Pivot Limited, 70 Southbank Boulevard, Southbank, Victoria 3006, Australia.

[5] Turbo Teejet TT11001 flat spray nozzles, TeeJet® Technologies, 1801 Business Park Drive, Springfield, IL 62703.

[6] BS 1000 biodegradable surfactant, Crop Care Australasia Pty. Ltd., 77 Tingira Street, Pinkenba 4008, Australia.

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Literature Cited

Andersen, M. 1992. An analysis of variability in seed settling velocities of several wind- dispersed Asteraceae. Am. J. Bot. 79:1087–1091.

Bruce, J. A. and J. J. Kells. 1990. Horseweed (*Conyza canadensis*) control in no-tillage soybeans (*Glycine max*) with preplant and preemergence herbicides. Weed Technol. 4:642–647.

Felton, W. L., G. A. Wicks, and S. M. Welsby. 1994. A survey of fallow practices and weed floras in wheat stubble and grain sorghum in northern New South Wales. Aust. J. Exp. Agric. 34:229–236.

Keeling, J. W., C. G. Henniger, and J. R. Abernathy. 1989. Horseweed (*Conyza canadensis*) control in conservation tillage cotton (*Gossypium hirsutum*). Weed Technol. 3:399–401.

Kempen, H. M. and J. Graf. 1981. Weed seed production. Proc. West. Soc. Weed Sci. 34:78–81.

Martin, R. J., M. G. McMillan, and J. B. Cook. 1988. Survey of farm management practices of the northern wheat belt of New South Wales. Aust. J. Exp. Agric. 28:499–509.

Michael, P. W. 1977. Some weedy species of *Amaranthus* (amaranths) and *Conyza*/*Erigeron* (fleabanes) naturalised in the Asian-Pacific region. Pages 87–95. *in* Proceedings of the 6th Asian-Pacific Weed Science Society Conference, Indonesia.

Moseley, C. M. and E. S. Hagood Jr. 1990. Horseweed (*Conyza canadensis*) control in full-season no-till soyabeans (*Glycine max*). Weed Technol. 4:814–818.

Osten, V. A., S. R. Walker, A. Storrie, M. Widderick, P. Moylan, G. R. Robinson, and K. Galea. 2007. Survey of weed flora and management relative to cropping practices in the north-eastern grain region of Australia. Aust. J. Exp. Agric. 47:57–70.

Procopio, S. O., E. A. Ferreira, E.A.M. Silva, A. A. Silva, R.J.N. Rufino, and J. B. Santos. 2003. Leaf anatomical studies in weed species widely common in Brazil. III—*Galinsoga parviflora*, *Crotalaria incana*, *Conyza bonariensis* and *Ipomoea cairica*. Planta Daninha 21:1–9.

Urbano, J. M., A. Borrego, V. Torres, J. M. Leon, C. Jimenez, G. Dinelli, and J. Barnes. 2007. Glyphosate-resistant hairy fleabane (*Conyza Bonariensis*) in Spain. Weed Technol. 21:396–401.

VanGessel, M. J., A. O. Ayeni, and B. A. Majek. 2001. Glyphosate in full-season no-till glyphosate-resistant soybean: role of preplant applications and residual herbicides. Weed Technol. 15:714–724.

Walker, S., M. Widderick, and H. Wu. 2004. Proceedings of Weeds CRC and Cotton CRC workshop on fleabane, March 2004 Toowoomba, QLD, Australia. http://www.weedscrc.org.au/publications/wshop_proceedings.html. Accessed: March 7, 2010.

Walker, S. R., I. N. Taylor, G. Milne, V. A. Osten, Z. Hoque, and R. J. Farquharson. 2005. A survey of management and economic impact of weeds in dryland cotton cropping systems of sub-tropical Australia. Aust. J. Exp. Agric. 45:79–91.

Wicks, G. A., W. L. Felton, R. D. Murison, and R. J. Martin. 2000. Changes in fallow weed species in continuous wheat in northern New South Wales, 1981–90. Aust. J. Exp. Agric. 40:831–842.

Wiese, A. F., C. D. Salisbury, and B. W. Bean. 1995. Downy brome (*Bromus tectorum*), jointed goatgrass (*Aegilops cylindrica*) and horseweed (*Conyza canadensis*) control in fallow. Weed Technol. 9:249–254.

Wilson, J. S. and A. D. Worsham. 1988. Combinations of nonselective herbicides for difficult to control weeds in no-till corn, *Zea mays*, and soybeans, *Glycine max*. Weed Sci. 36:648–652.

Wu, H., S. Walker, and G. Robinson. 2008. Control of flaxleaf fleabane (*Conyza bonariensis* L. Cronq.) in winter fallows. Plant Prot. Q. 23:162–165.

Wu, H., S. Walker, M. J. Rollin, D.K.Y. Tan, and G. Werth. 2007. Germination, persistence and emergence of flaxleaf fleabane (*Conyza bonariensis* L. Cronq.). Weed Biol. Manag. 7:192–199.

Zinzolker, A., J. Kigel, and B. Rubin. 1985. Effects of environmental factors on the germination and flowering of *Conyza albida*, *C. bonariensis* and *C. canadensis*. Phytoparasitica 13:229–230.

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