Chemical control of flaxleaf fleabane (*Conyza bonariensis* (L.) Cronquist) in winter fallows

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Summary
Flaxleaf fleabane (*Conyza bonariensis* (L.) Cronquist) has recently become a problem weed in the northern grain region of Australia. Herbicide control of this weed has been variable. Experiments were conducted to identify effective herbicide control options for flaxleaf fleabane in winter fallows. Research showed that effective fleabane control in the fallow cannot be achieved with any single herbicide treatment, even with the knockdown herbicides such as glyphosate and paraquat + diquat. A combination of herbicides with different modes of action is needed to achieve effective control. The addition of a suitable mixing partner, especially auxins, such as 2,4-D and dicamba, to glyphosate improved control efficacy. A 'doubleknock' technique, sequential application of glyphosate followed by paraquat + diquat, also achieved 96% control. Three non-glyphosate mixtures, 2,4-D amine + metsulfuron methyl, Amitrole T® either mixed with 2,4-D ester or 2,4-D amine, also provided >94% control. Residual herbicides atrazine or mixture of atrazine + metolachlor at higher rates provided effective long-term (five to six months) control of flaxleaf fleabane in winter fallows. This preliminary study identified some post-emergence and residual herbicides that can provide effective control on flaxleaf fleabane, which will be useful for the development of an integrated weed management package for this weed.

Keywords: Flaxleaf fleabane, herbicides, fallow weed management.

Introduction

Flaxleaf fleabane (*Conyza bonariensis* (L.) Cronquist) has become one of the problem weeds in northern NSW and southern Queensland (Wu *et al.* 2007), coinciding with the wide adoption of no-till farming systems during the last 25 years (Felton *et al.* 1994). Similarly research has shown that a closely related *Conyza* species, Canadian fleabane (*Conyza canadansis* (L.) Cronquist) is also a major weed in no tillage production systems in North America (Keeling *et al.* 1989, Brown and Whitwell 1988, Weaver 2001). Wu *et al.* (2007) reported that flaxleaf fleabane predominantly emerges in autumn and early winter, forms a basal rosette stage over-winter and produces seeds in the following spring or summer.

Flaxleaf fleabane is a prolific seed producer, producing an average of 119 100 seeds per plant from samples collected from winter fallow paddocks across south east Queensland (Wu *et al.* 2007). Therefore the weed can rapidly build up numbers in seed banks.

The seeds of flaxleaf fleabane plants are enclosed singly in small hard achenes. The achenes are equipped with a tuft of bristles known as the pappus. The pappus enhances the seed dispersal distance by reducing the rate of gravitational settling (Andersen 1992). Flaxleaf fleabane seeds have an average settling velocity of 0.291 m sec^{-1} (SD = 0.0728) (Andersen 1992), which is lower than 0.323 m sec^{-1} (SD = 0.0687) reported for Canadian fleabane (Dauer *et al.* 2006). Simulation modelling based on a wind-tunnel research has estimated that *C. canadensis* seeds can travel between 65 to 740 m, depending on wind speed and the height of seeds being released (Dauer *et al*. 2006). The light-weighted seeds float on the surface of water, resulting in a long distance transport by surface run-off, and by water movement in irrigation channels and waterways.

Herbicides are the primary tool of weed control in no tillage farming systems due to the lack of soil disturbance by tillage. This system can lead to weed species shifts, where species that were poorly controlled by herbicides increase in relative abundance (Locke *et al.* 2002). Flaxleaf fleabane plants, especially at a mature growth stage, naturally tolerate high levels of glyphosate due to the leaf structures that protect against herbicide penetration, such as high trichome density, high cuticle thickness and low stomatal density in the adaxial side of the leaf (Procopio *et al.* 2003). This natural tolerance to herbicides partly explains the inconsistent and unsatisfactory herbicide control frequently reported by many growers. As fallow weed control costs have doubled due to this weed alone (Thorn 2004), alternative, low-cost chemicals are required.

Research on herbicide control of flaxleaf fleabane has been very fragmented. More than 180 treatments of herbicides or mixtures have been experimented in fallows in the northern grain region (Wu and Walker 2004). However, single application of these treatments achieved variable and inconsistent results, especially when mature weeds were targeted. The predominant emergence of flaxleaf fleabane in autumn and early winter suggests that for the effective management of this weed, an important strategy is to target it in winter fallows. The objective of this study was to identify effective herbicide control options of flaxleaf fleabane in winter fallows in the northern grain region.

Materials and methods

Two winter fallow experiments were conducted in a farm paddock (28°06'419S, 150°50'909E) in Western Darling Downs Queensland in 2003 on a light sandy soil with a natural flaxleaf fleabane density of about 90–100 plants m^{-2}. Research was focused on late applications due to the difficulties in achieving effective control of flaxleaf fleabane at a rosette stage >10 cm (diameter). The rainfall received during the experimental period was: February (90 mm), March (78 mm), April (71 mm), May (25 mm), June (42 mm), July (27 mm), August (12 mm), September (0 mm), October (28 mm), November (56 mm) and December (151 mm).

Post-emergence herbicide experiment

Seventeen non-selective post-emergence herbicides and herbicide mixtures were selected across five distinct herbicide modes of action group (Groups B, F, I, L and M). These treatments included 12 glyphosate-based mixtures and five non-glyphosate mixtures (Table 1). Three early treatments were applied to flaxleaf fleabane seedlings at a rosette stage (<8 cm in diameter) on 17th July 2003, and 13 late treatments at a rosette stage >10 cm on 7th August 2003. The plot size was 4 m × 14 m.

Residual herbicide experiment

Adjacent to the above post-emergence experiment, a second experiment was established to assess the effects of residual herbicides on flaxleaf fleabane control. Seven glyphosate-based treatments with residual herbicides across four distinct herbicide groups (Groups C, G, K and M) were evaluated (Table 2). All these treatments were applied to flaxleaf fleabane seedlings at a rosette stage of <8 cm in diameter on 17th July 2003. The plot size was 3 m × 20 m. The residual herbicide treatments were timely rain-incorporated after application.

Herbicide application and measurement
Treatments were applied with a tractor-mounted compressed-air-pressurized sprayer, which used Turbo Teejet TT11001 flat spray nozzles calibrated to deliver 70 or 100 L ha^{-1} (for the paraquat products) at 2 Kpa pressure. The surfactant BS 1000 at 0.1% was used in all herbicide treatments.

Flaxleaf fleabane control was assessed based on the control plots for comparison, using a scale from 0 = no visible plant injury to 100 = complete plant death. Flaxleaf fleabane density was measured by counting three random quadrats (0.5 × 1.0 m) in each plot. The visual rating and weed density measurements were conducted at three, six and nine weeks after the early treatments in both experiments. Two additional visual assessments were conducted at 17 and 21 weeks after the early treatments in the residual herbicide experiment. The 9-week assessment data are presented for the post-emergence, and the 9 and 21-week data for the residual herbicide experiment.

Design and statistical analysis
The experiments were arranged in a randomized complete block design with three replicates. Three untreated plots were included as controls within each replicate for the post-emergence herbicide experiment, and one untreated plot was included for the residual herbicide experiment. Research data from the post-emergence herbicide experiment was subjected to ANOVA analysis. REML analysis was carried out for the residual herbicide experiment by using Genstat 10. The weed density data were square-root transformed for normalization and initial weed densities were included as covariates.

Results and discussion

Control with post-emergence herbicides
Based on the weed density data, all the treated plots had significantly fewer weeds (2–38 plants per 10 m^2) than the untreated control plots (117 plants per 10 m^2). Similarly, flaxleaf fleabane control at the rosette stage had a visual rating of 47 to 99% depending on the treatments (Table 1). Fourteen of the 17 treatments achieved more than 88% control of the weed. The doubleknock technique (sequential application of glyphosate followed 20 days later by Spray.Seed®) achieved 96% control. This technique has been further evaluated to improve its control efficacy (Werth and Walker 2007). They found that Spray.Seed® applied as a follow-up earlier (seven days) achieved better control. This doubleknock technique was used to successfully control flaxleaf fleabane plants at various growth stages in a number of other field experiments (data not shown). It has been used to clean up the flaxleaf fleabane infested fields prior to the sowing of winter crops (wheat) or summer crops (sorghum).

Compared with the doubleknock technique, contact herbicides alone, such as paraquat + diquat or paraquat alone, was not effective in flaxleaf fleabane control (47–53%), even though they were applied early. There were no significant differences between the treatments of paraquat and paraquat + diquat, indicating that addition of diquat did not improve control. Regrowth after 2–3 weeks was common after these treatments. This re-growth problem after the application of the paraquat treatments has also been found in Canadian fleabane (Wilson and Worsham 1988). Regrowth also occurs after manual cutting (Davies 1999). Therefore, the prevention of regrowth largely depends on an improved herbicide translocation or sequential application.

Timeliness of herbicide application makes significant differences in control efficacy. It is critical to apply herbicides when the plant is small and actively growing. Herbicide efficacy decreased as the plants matured. Early application of glyphosate at a rosette stage of <8 cm in diameter gave 88% control (visual rating), while only 13% of control was achieved when applied to weed plants of more than 10 cm in diameter (the late application). Although there were no significant differences in weed density based on the transformed data between the early and late applications of glyphosate (19 and 38 plants per 10 m^2, respectively), the early application of glyphosate caused substantial reduction

Table 1. Effects of post-emergence treatments on flaxleaf fleabane (*Conyza bonariensis*) in winter fallow when assessed at nine weeks after treatments (2003).

Treatment	Rate (g a.e. or a.i. ha^{-1})	Weed density (10 m^{-2}) Original	Weed density (10 m^{-2}) Transformed[F]	Visual rating (%)
Paraquat + diquat	324 + 276	27	6.7	47
Paraquat[A]	325	33	7.2	53
Glyphosate[A]	675	19	6.0	88
Glyphosate	675	38	7.7	13
Glyphosate → (paraquat + diquat)[B]	675 → (324 +276)	7	4.0	96
Glyphosate + (amitrole + ammonium thiocyanate)[C]	675 + (625 + 550)	11	4.4	93
Glyphosate + metsulfuron methyl	675 + 4.2	5	5.4	90
Glyphosate + 2,4-D ester	675 + 560	6	5.0	94
Glyphosate + 2,4-D amine	675 + 1000	3	4.0	97
Glyphosate + Metsulfuron methyl + 2,4-D amine	675 + 4.2 + 500	19	6.3	93
Glyphosate + (2,4-D amine + picloram)[D]	675 + (300 + 75)	6	3.7	99
Glyphosate + (triclopyr + picloram)[E]	675 + (225 + 75)	6	4.3	98
Glyphosate + dicamba	675 + 140	5	4.6	96
Glyphosate + triclopyr + metsulfuron methyl	675 + 72 + 4.2	5	4.9	96
2,4-D ester + (amitrole + ammonium thiocyanate)[C]	560 + (625 + 550)	2	3.1	98
2,4-D amine + (amitrole + ammonium thiocyanate)[C]	1000 + (625 + 550)	18	6.0	94
2,4-D amine + metsulfuron methyl	1000 + 4.2	18	5.7	95
Untreated		117	11.6	0
LSD (P <0.05)			2.5	10.4

[A] Early treatments were applied to weeds at a rosette stage <8 cm in diameter; all others were late treatments applied at a rosette stage >10 cm, 20 days later. [B] Sequential application of glyphosate followed by Spray.Seed® (paraquat + diquat) within 20 days; [C] Amitrole T® (amitrole + ammonium thiocyanate); [D] Tordon 75D® (2,4-D amine + picloram); [E] Grazon DS® (triclopyr + picloram); [F] Square-root transformed data.

on weed growth, resulting in a better visual rating and potentially fewer weed seeds produced. Similarly, VanGessel *et al.* (2001) reported that herbicidal activity on Canadian fleabane was reduced if application was delayed. Herbicides at a higher rate were needed to control *C. canadensis* if applied at stem elongation stage compared with application at the rosette stage (Keeling *et al.* 1989). Moseley and Hagood (1990) also reported that early treatment with post-emergence herbicides (20–35 cm) controlled *C. canadensis* more effectively than late treatments (30–60 cm).

Successful management of flaxleaf fleabane depends on the use of appropriate herbicide mixtures. Glyphosate-based herbicide mixtures provided 90% or greater control based on the visual rating measurement. These glyphosate-based mixtures resulted in significantly fewer weed numbers (3–38 plants per 10 m^2), as compared to the untreated control. As well, addition of suitable mixing partners to glyphosate also significantly reduced weed density when compared with the glyphosate alone treatment, except for the addition of metsulfuron methyl and metsulfuron methyl + 2,4-D amine. Both weed density and visual rating data showed that the addition of auxin mixtures to glyphosate, such as Tordon 75D® (2,4-D amine + picloram) and Grazon DS® (triclopyr + picloram) did not further improve the control, when compared with the addition of a single auxin to glyphosate, such as 2,4-D ester, 2,4-D amine and dicamba. Similarly addition of metsulfuron methyl to the two-way mix of glyphosate + triclopyr or 2,4-D amine did not result in an improved control of flaxleaf fleabane. Three non-glyphosate mixtures, Amitrole T® either mixed with 2,4-D ester or 2,4-D amine, and 2,4-D amine + metsulfuron methyl also achieved 94% or greater control. In particular, the treatment of 2,4-D ester + Amitrole T® resulted in a weed density of only two plants per 10 m^2. Synthetic auxins, such as 2,4-D and dicamba, are often a good mixing partner to glyphosate and paraquat to improve control efficacy (Wilson and Worsham 1988, Keeling *et al.* 1989). Over the long-term, addition of 2,4-D based products to glyphosate appears to be a more viable option. 2,4-D is economical to use and provides effective control. Furthermore, no 2,4-D resistant biotypes of *Conyza* species have been documented to date (Heap 2007).

The re-sprouting characteristics and prolonged emergence patterns between autumn and spring suggest that sequential application techniques are important tactics for flaxleaf fleabane control. We have found that there were about 3–6 buds at the top of the taproot (near the soil surface) of the over-wintered flaxleaf fleabane plants. These buds sprouted easily after the removal of aboveground parts either due to frost, contact herbicide application or manual cutting.

A follow-up application provides an opportunity to control newly emerged or sprouted seedlings as well as those survivors missed in the first application due to numerous small weed seedlings being covered under large and dense flaxleaf fleabane plants and under crop stubbles. Sequential application is an important control tactic to minimize early weed competition and prevent seed-set of the over-wintered weeds that bolt rapidly in spring. Bruce and Kells (1990) reported that sequential application provided equal or greater *C. canadensis* control and resulted in equal or greater soybean yield than a single application. Preplant glyphosate application followed by postemergence herbicides enhanced *C. canadensis* control when compared to postemergence application alone (VanGessel *et al.* 2001). Although *C. canadensis* density was greater in no-tillage than conventional tillage plots, sequential application of paraquat (preplant) followed by preemergence application of metolachlor and early postemergence application of 2,4-D was effective on *C. canadensis* control, diminishing the differences between tillage systems on *C. canadensis* (Vencil and Banks 1994).

The prolific seed production of flaxleaf fleabane suggests that, if the weed is not effectively managed, seeds produced by only a small percentage of survivors in one single season are sufficient to maintain a high level of seedbank, which would result in severe infestations in subsequent crops. Our research has shown that Amitrole T® could be strategically used as a late treatment to target mature survivors. It targeted the elongated shoots and flowering heads, showing a typical bleaching symptom as a result of inhibition of carotenoid biosynthesis and resulting in the loss of seed production. It can greatly reduce the replenishment of new seeds into the soil although it does not completely kill the mature plant.

Control with residual herbicides

Residual herbicide treatments were rain-incorporated with 7 mm of rainfall received within seven days of application as well as with a follow-up 32 mm rainfall in late July and August. At nine weeks after application, the six residual herbicide treatments achieved significantly better control (90% or greater based on the visual rating) than the glyphosate alone treatment (85%) (Table 2). At 9 WAT, weed density in the herbicide treated plots ranged from 2 to 53 plants per 10 m^2, while it was 167 plants per 10 m^2 in the untreated control plots. As well, the higher rate of atrazine (2400 g a.i. ha^{-1}) and a mix of a lower rate of atrazine 1180 g a.i. ha^{-1} + S-metolachlor 928 g a.i. ha^{-1} as of Primextra® provided long term residual control, with 80% or greater control even at 21 weeks after treatments, although it was not significantly different to the glyphosate alone treatment. These two treatments at 21 WAT had a flaxleaf

Table 2. Effects of residual herbicide treatments on flaxleaf fleabane in winter fallow (2003). Herbicide treatments were applied to weeds at a rosette stage <8 cm in diameter. Original weed density data were square-root transformed.

Treatment	Rate (g a.e. or a.i. ha^{-1})	Weed density (10 m^{-2}) 9 WAT[A] Original	9 WAT[A] Transformed	21 WAT Original	21 WAT Transformed	Visual rating (%) 9 WAT	Visual rating (%) 21 WAT
Glyphosate + atrazine	650 + 1200	19	3.8	51	4.0	93	65
Glyphosate + atrazine	650 + 2400	2	2.2	15	3.5	96	81
Glyphosate + (atrazine + S-metolachlor)[B]	650 + (1180 + 928)	9	3.5	14	3.1	95	87
Glyphosate + S-metolachlor	650 + 1920	53	6.1	69	7.4	90	58
Glyphosate + Oxyfluorfen	650 + 60	28	5.8	45	5.7	93	51
Glyphosate + Diuron	650 + 1260	41	6.1	42	4.0	93	55
Glyphosate	650	49	6.7	55	6.0	85	65
Untreated		167	7.5	84	7.3	0	0
LSD (P <0.05)		na	3.8	na	3.7	3.9	27.6

[A] WAT refers to weeks after treatments; [B] Primextra® (atrazine + S-metolachlor).

fleabane density of 14–15 plants per 10 m^2 compared with 55 and 84 plants per 10 m^2 in the glyphosate-alone and the untreated plots, respectively.

The natural leaf barriers of this weed against herbicide penetration limit the success of any single herbicide application. The use of residual herbicides provides an alternative strategy to control flaxleaf fleabane via root uptake instead of foliar uptake. Strategic use of preplant residual herbicides, such as atrazine and Primextra® at a high rate, achieved effective long-term control of flaxleaf fleabane in winter fallows. Similarly, the role of residual herbicides in providing long-term control of *C. canadensis* has been reported by a number of researchers (Wilson and Worsham 1988, Moseley and Hagood 1990, VanGessel *et al.* 2001). Wilson and Worsham (1988) found that addition of residual herbicides increased the activity of foliar herbicides regardless of *C. canadensis* size. However, care should be taken when using residual herbicides, which might restrict the choice of rotational crops (Charles 2002).

Conclusions

Most of the herbicide options for flaxleaf fleabane assessed in this study are not currently registered for *C. bonariensis* control in Australia except for Spray.Seed® and Tordon 75-D. Addition of Group I or F herbicides, such as 2,4-D, dicamba, Tordon 75D (2,4-D amine and picloram), Grazon DS (triclopyr and picloram) and Amitrole (amitrole + ammonium thiocyanate), improved the control efficacy of glyphosate. The three non-glyphosate mixtures, 2,4-D amine + metsulfuron methyl, Amitrole T either mixed with 2,4-D ester or 2,4-D amine, also provided excellent control (>94%). Effective control of this weed relies on the timely application of postemergence herbicides in relation to weed size, soil moisture and growing conditions. The actions of all herbicides or mixtures tested, except paraquat treatments, were generally very slow on flaxleaf fleabane. It generally took about 35–45 days after herbicide application to develop herbicidal symptoms. We have found in other trials that if herbicides were applied to moisture-stressed plants as evident by changes in per cent control with time, they seem to remain inside the plant for an extended period (1–2 months). Herbicides were then activated after adequate rainfall, resulting in the appearance of long-awaited herbicidal effects. Residual herbicides also played a part in flaxleaf fleabane management. Atrazine or Primextra® (atrazine and S-metolachlor) applied at higher rates provided effective long-term control of flaxleaf fleabane in winter fallows. Other residual herbicides in combination with glyphosate also achieved excellent control, although with limited long-term residual effect.

Smart use of these herbicides is imperative due to the potential evolution of flaxleaf fleabane resistance to atrazine, diquat, and paraquat, as well as glyphosate (Heap 2007). Differential responses to glyphosate have also been found among flaxleaf fleabane populations in Australia. Populations collected from cropping paddocks were more tolerant than those collected from non-agricultural situations (Walker and Robinson 2007). The potential evolution of flaxleaf fleabane resistance to commercial herbicides, especially glyphosate, will impose great difficulties in designing effective control programs. An integrated approach, incorporating chemical and non-chemical control options should be adopted to manage this weed. Non-glyphosate alternatives should also be used to prevent the development of glyphosate resistance *of* flaxleaf fleabane in Australia.

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