A survey of weeds in dryland cotton cropping systems of sub-tropical Australia. 1. Management practices and effectiveness

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Abstract.

The main weeds and effectiveness of weed management practices used in dryland cotton cropping systems were identified using information collected in a postal and a field survey in southern Queensland and northern New South Wales. Forty-eight completed questionnaires were returned, and 32 paddocks were monitored in early and late summer for weed species and density. The main problem weeds were bladder ketmia (*Hibiscus trionum*), common sowthistle (*Sonchus oleraceus*), barnyard grasses (*Echinochloa* spp.), liverseed grass (*Urochloa panicoides*) and black bindweed (*Fallopia convolvulus*), but the relative importance of these differed with crops, fallows, and crop rotations. Pigweed (*Portulaca oleracea*), amaranths (*Amaranthus* spp.), caltrops (*Tribulus* spp.), and cowvine (*Ipomoea lonchophylla*) were common summer weeds but not considered by growers as difficult to control. The weed flora was diverse with 54 genera identified in the field survey. Control in rotational crops and fallows depended largely on herbicides, particularly glyphosate in fallow and atrazine in sorghum, although control was not consistently effective. Control in dryland cotton involved numerous combinations of selective herbicides, several non-selective herbicides, inter-row cultivation and some manual chipping. Despite this, seeding residual weeds were found in approximately three-quarters of the survey paddocks. Crops were normally sown in widely spaced rows, and few growers control weed survivors or late flushes in the rotational crops. The approach of managing weed populations across the whole cropping system needs wider adoption to reduce the weed pressure in dryland cotton and the economic impact of weeds in the long-term. Strategies that optimise herbicide performance and minimise return of weed

seed to the soil are needed. Information from the survey provides direction and priorities for research to improve weed management in this cropping system.

Introduction

Dryland (rain-grown) cotton has become an important rotational crop in the last two decades in broad-acre cropping region in southern Queensland and northern NSW. Dryland cotton can account for up to 20% of the total area sown to cotton in Australia, with the remaining area grown under irrigation (Shaw 2002). The cropping system with dryland cotton is complex, as it involves different rotational crops and variable length fallows, with the amount of stored soil moisture being the most critical factor influencing the decision whether to sow dryland cotton versus other crops (Marshall 2002). Dryland cotton is grown in the sub-tropic region that receives both summer and winter rainfall (Webb *et al.* 1997) that is characteristically variable, particularly during the critical growing season of summer crops (Hammer and Muchow 1990, Ford and Forrester 2002).

Weed management is thus also complex, and needs to be flexible to respond to changes in these farming systems (Charles 2002a). Weeds can be very competitive, as cotton seedlings are often slow to emerge and grow slowly in the cool spring conditions. As well, weeds emerge in the non-planted skip rows and utilise resources that would otherwise be available for cotton plants later in the season. Weeds can be hosts for cotton insects and diseases, and adversely affect harvesting and cotton lint quality. In general, weed management in dryland cotton involves controlling weeds in previous fallows and rotational crops, using selective herbicides, as well as inter-row cultivation, inter-row spraying of non-selective herbicides with a shielded sprayer, and manual chipping. However, little information is available on the effectiveness of these different management practices, the economic impact of weeds, or the important weed issues concerning this system. Charles (1991) reported of a weed survey conducted in irrigated cotton , which was grown mostly as mono-culture or in simple crop rotations. The weeds, management techniques and issues are likely to differ between the irrigated and dryland cropping systems.

Several previous surveys documented the weed flora and weed management practices in the grain cropping systems of sub-tropical Australia. Martin *et al.* (1988) surveyed the weeds and management practices used in wheat in northern NSW. Later, Felton *et al.* (1994) surveyed the impact of fallow practices on weed flora in summer fallow and sorghum in the

same region. Gavin *et al.* (1999) monitored changes in weed species, density and effectiveness of control practices in wheat paddocks of a wheat-sorghum rotation in northern NSW and southern Queensland over 2 years. Widderick *et al.* (1999) conducted a postal survey on distribution and management practices for control of common sowthistle (*Sonchus oleraceus* L.) across the sub-tropical grain region. These field and postal surveys were followed by an extensive postal survey on the distribution, density and economic impact of weeds in winter crops across Australia, which included northern NSW and southern Queensland (Alemseged *et al.* 2001, Jones *et al.* 2003). The authors validated the postal survey data by following it with a limited field survey (Jones *et al.* 2000).

This paper reports on the results from a postal and field survey of weeds, management practices and their effectiveness in rotations with dryland cotton. A second paper focuses on the economic impact of weeds in this system. The information is used to provide direction and priorities for research needed to improve weed management and thus reduce the impact of weeds in this important and relatively new component crop in an inherently complex farming system.

Materials and methods

Postal survey

A self-completion questionnaire was mailed to 286 growers of dryland cotton in southern Queensland and northern NSW in September 2001. The survey form asked growers to provide information on their crop rotations with dryland cotton, soil types, the use and frequency of nominated farming practices for weed control in each crop and fallow by selecting a category of 'often used', 'sometimes used', or 'rarely or not used'. For each crop and fallow, growers were asked to list the five main weeds, herbicides used, control normally achieved by selecting a category of 'very good', 'acceptable', or 'variable'. As well, they were asked for information on their average crop yields, and losses from uncontrolled weeds and contamination penalties. Information from each completed survey was entered into a Microsoft Access database, from which queries were undertaken to collate and present results in this paper. Data are presented as percentages of responses compared with the total number of responses for each part of the questionnaire.

Grower interview and field survey

Ten of the postal survey respondents were chosen at random for interviewing and monitoring weeds in their rotations with dryland cotton. Seven of the farms were in the Darling Downs region of southern Queensland, and three were in northern New South Wales between Goondiwindi and Narrabri.

The growers were asked individually for more information on their crop agronomy and weed management strategies. Then, 32 paddocks on these 10 farms were monitored for weed diversity and density. The paddocks were either in fallow (19), cotton (9) or sorghum (4), and weeds were rated in December 2001 to give an indication of the weeds initially infesting the crop or fallow, and in May 2002 to give an indication of the surviving residual weeds.

Weeds were monitored in 20 transects, each 10m x 1m, in each paddock, which was divided into 4 sections where 5 transects were made at random across each section. The presence and density of each species were noted in each transect. The density of each species was rated using the scale of 0 to 3, where 0 = no plants/10m^2, 1 = 1-9 plants/10m^2, 2 = 10-100 plants/10m^2, 3 = >100 plants/10m^2.

Results

Postal survey response

Forty-eight completed responses were received, representing a response rate of 17%. Thirty-two respondents were from the Darling Downs region, and 16 were from the Goondiwindi to Narrabri region. This distribution corresponds well with the portion of dryland cotton growers in these 2 regions (Dowling 2000, 2001, 2002).

Crop rotations and soils

Twenty-eight crop and fallow sequences with dryland cotton were listed by the growers. The most common rotation was cotton with winter cereal (Table 1). Cotton was rotated with either one wheat crop (28%), two wheat crops (17%), wheat followed by barley (5%), or three wheat crops (1%). The other common rotation was cotton with summer and winter cereals. In this rotation, cotton was rotated with one wheat crop and one sorghum crop (11%), or with wheat, barley and sorghum (4%). Other rotations were dryland cotton only, or had various combinations of sorghum, maize, chickpea, mung bean, and peanut. Cotton was

normally preceded by a fallow of approximately 12-18 months, and was followed with either a winter crop after a very short or 12-month fallow, or a summer crop after an approximate 6-month fallow. Consequently, cotton was grown once every 2-4 years in these rotations. Most interviewed growers decided on their crop rotation based on optimising soil water conservation (90%) and for better weed control (70%).

Practically all of this cropping system was grown on vertisol soils, which have high clay content (40-80%) with a high capacity to store plant-available water (Webb *et al.* 1997).

Table 1. Categories of crop rotations nominated by dryland cotton growers in the postal survey, with data presented at % of the 79 listed rotations, which had 28 different sequences of crops and fallows. Most growers nominated more than 1 rotation.

Rotation category	Crops grown with dryland cotton	%
Winter cereal only	Wheat, barley	51
Summer cereal + winter cereal	Wheat, barley, sorghum	15
Winter cereal + pulse	Wheat, barley, chickpea, mung bean, peanut	8
Summer cereal only	Sorghum, maize	8
Long fallow only	None	8
Summer cereal + winter cereal + pulse	Sorghum, maize, wheat, barley, chickpea, mung bean	8
Pulse only	Chickpea, mung bean	2

Crop agronomy

The interviewed growers sowed dryland cotton in 1m rows either as a solid plant, single skip (every third row was not planted), or double skip (every third and forth row were not planted). Sowing rate of cotton varied from 4.5 to 11 kg/ha depending on row spacing. The survey was conducted prior to the commercial release of Roundup Ready® cotton. Sorghum was normally sown in 1m rows either solid planting or single skip at 3-5 kg/ha. Winter cereals were normally sown in 25 to 38cm rows at 40 kg/ha or less.

Fallow weeds

Growers were highly reliant on knockdown herbicides for fallow weed control, with 89% using these herbicides regularly in both summer and winter fallows (Table 2). Cultivation was used by 23-28% of growers on a regular basis and another 34-51% on a less regular basis. Spot spraying was used by more than half of the growers at times in summer fallows, whereas residual herbicides and grazing were not commonly used.

Table 2. Management practices used for weed control in summer and winter fallows as indicated by growers in the postal survey. Data presented as % of the respondents, which were 48 for summer fallow, winter fallow, and cotton, 31 for sorghum, 39 for wheat, and 11 for chickpea. Several growers did not complete all questions on management practices. The late herbicide application was termed 'Late selective herbicide application to control escapes or late flushes'.

Management practice	Often used	Sometimes used	Rarely or not used	Often used	Sometimes used	Rarely or not used
		Summer fallow			*Winter fallow*	
Knockdown herbicides	89	11	0	89	9	0
Cultivation	28	34	36	23	51	21
Residual herbicides	11	28	51	11	17	60
Spot spraying	6	47	28	6	30	40
Grazing	0	11	62	0	11	62
		Dryland cotton			*Sorghum*	
Pre-emergent herbicides	76	15	9	68	19	13
Higher seeding rates	7	7	70	10	16	65
Post-emergent herbicides	61	28	11	45	39	16
Late herbicide application	20	28	35	16	29	45
Inter-row cultivation	52	26	20	26	23	48
Shielded spraying	72	15	7	13	35	42
Chipping	28	52	20	0	13	71
Pre-harvest desiccation	61	22	11	39	39	16
		Wheat			*Chickpea*	
Pre-emergent herbicides	18	26	54	73	18	9
Higher seeding rates	13	28	46	0	36	64
Post-emergent herbicides	56	28	15	36	36	27
Late herbicide application	15	23	54	18	9	73
Inter-row cultivation	3	0	74	9	18	73
Shielded spraying	3	0	69	0	45	55
Chipping	0	15	64	9	27	55
Pre-harvest desiccation	5	3	72	55	27	9

Glyphosate alone and glyphosate mixes accounted for the large majority (92-94%) of the herbicide treatments applied to weeds in fallows (Table 3). The most common mix in both fallows was glyphosate with 2, 4-D (17%). Also in summer fallows, glyphosate was mixed with fluroxypyr, metsulfuron-methyl, atrazine, and to a lesser extent triclopyr, tribenuron-methyl, MCPA, and dicamba, whereas it was mixed with metsulfuron-methyl, dicamba, tribenuron-methyl, and to a lesser extent MCPA and oxyflurofen in winter fallows. Several herbicides, which were not mixed with glyphosate, were applied infrequently, such as metsulfuron-methyl, fluroxypyr, paraquat + diquat, and dicamba in summer fallows, and 2, 4-D, dicamba, and picloram + 2, 4-D in winter fallows.

Table 3. Herbicides used in fallows and main crops, as indicated by the postal survey respondents, which were 48 for summer fallow, winter fallow, and cotton, 31 for sorghum, 39 for wheat, and 11 for chickpea. Data presented as % of the total number of herbicide treatments listed, which was 177, 168, 146, 104, 121, and 34 for summer fallows, winter fallows, cotton, sorghum, wheat and chickpea respectively.

Fallow or crop	Herbicide	%
Summer fallow	Glyphosate	55
	Glyphosate + 2,4-D	17
	Glyphosate + fluroxypyr	8
	Glyphosate + metsulfuron-methyl	3
	Glyphosate + atrazine	2
	Other mixes with glyphosate	9
	Other herbicides	6
Winter fallow	Glyphosate	54
	Glyphosate + 2,4-D	17
	Glyphosate + metsulfuron-methyl	8
	Glyphosate + dicamba	6
	Glyphosate + tribenuron-methyl	3
	Other mixes with glyphosate	4
	2,4-D amine	4
	Other herbicides	4
Cotton	Glyphosate (shielded sprayer)	26
	Fluometuron + prometryn	17
	Fluometuron + prometryn + pendimethalin	8
	Fluometuron + prometryn + glyphosate	6
	Fluometuron + prometryn + diuron	3
	Fluometuron + prometryn + diuron + pendimethalin	3
	Fluometuron + prometryn + trifluralin	3
	Pendimethalin	4
	Pyrithiobac	3
	Diuron + prometryn	3
	Diuron	3
	Glyphosate + metolachlor	3
	Glyphosate + fluroxypyr	3
	Other mixes with glyphosate	2
	Other herbicides	13
Sorghum	Atrazine	37
	Atrazine + fluroxypyr	24
	Atrazine + metolachlor	14
	Atrazine + picloram + 2,4-D	4
	Fluroxypyr	8
	Metolachlor	7
	Metolachlor + fluroxypyr	4
	Picloram + 2,4-D	2
Wheat	Metsulfuron-methyl + MCPA	18
	Metsulfuron-methyl	10
	Metsulfuron-methyl + thifensulfuron	7
	Metsulfuron-methyl + MCPA + Picloram	4
	MCPA + picloram	14
	MCPA	9
	MCPA + fluroxypyr	7
	Clodinafop	12
	Fenoxaprop	6
	2,4-D	5
	Dicamba	3
	Other herbicides	5
Chickpea	Haloxyfop	24
	Simazine	15
	Simazine + isoxaflutole	12
	Simazine + prometryn + isoxaflutole	12
	Simazine + imazethapyr	9
	Glyphosate with shielded sprayer	12
	Other herbicides	16

The most common weeds in summer fallows, as nominated by growers, were grasses, bladder ketmia (*Hibiscus trionum* L.), common sowthistle, caltrop (*Tribulus* spp.), liverseed grass (*Urochloa panicoides* P.Beauv.), burrs (*Xanthium* spp.) and barnyard grass (*Echinochloa* spp.), as well as thornapples (*Datura* spp.), cowvine (*Ipomoea lonchophylla* J.M.Black) and pigweed (*Portulaca oleracea* L.) (Table 4). Many growers did not specify the names of their summer grasses, but it is likely that most were referring to barnyard and/or liverseed grass. These grasses were by far the most common weeds of summer fallows with 82% of growers listing them as their main weeds. Minor weeds of summer fallows were amaranths (*Amaranthus* spp.), bellvine (*Ipomoea plebia* R.Br.), black bindweed (*Fallopia convolvulus* A.Love), castor oil weed (*Ricinus communis* L.), caustic weed (*Chamaesyce drummondii* D.C.Hassall), devil's claw (*Martynia annua* L.), fleabanes (*Conyza* spp.), hairy wandering Jew (*Commelina benghalensis* L.), Johnson grass (*Sorghum halepense* Pers.), melons (*Cucumis* spp. and *Citrullus* spp.), mintweed (*Salvia reflexa* Hornem.), polymeria (*Polymeria pusilla* R.Br.), potato weed (*Galinsoga parviflora* Cav.), rhynchosia (*Rhynchosia minima* DC.), sesbania pea (*Sesbania cannabina* Pers.), small-flowered mallow (*Malva parviflora* L.), thistles (possibly *Silybum marianum* Gaertn. and/or *Cirsium vulgare* Ten.), turnip weed (*Rapistrum rugosum* All.), wild oats (*Avena* spp.), wild gooseberry (*Physalis minima* L.), and yabila grass (*Panicum queenslandicum* Domin).

In winter fallows, wild oats, common sowthistle, black bindweed and turnip weed were by far the most common weeds, with half or more of the growers nominating these weeds (Table 4). Paradoxa grass (*Phalaris paradoxa* L.), wireweed (*Polygonum aviculare* L.), thistles and mustards (*Sisymbrium* spp.) were also common but to a lesser extent. Minor weeds of winter fallows were African turnip weed (*Sisymbrium thellungii* O.E.Schulz), bladder ketmia, caltrop, cowvine, deadnettle (*Lamium amplexicaule* L.), fleabane, melons, New Zealand spinach (*Tetragonia tetragonioides* Kintze), potato weed, prickly lettuce (*Lactuca serriola* L.), ryegrass (*Lolium rigidum* L.), small-flowered mallow, vetches (*Vicia* spp.), and wild radish (*Raphanus raphanistrum* L.).

The majority of growers believed that they achieved very good control of wild oats and paradoxa grass in winter fallow, but less achieved equivalent control for liverseed and barnyard grass in summer fallow (Table 4). The broadleaved weeds, not controlled well by many growers were bladder ketmia, black bindweed, and common sowthistle in both fallows.

Table 4. The most common weeds infesting fallows and main crops, together with the overall control of these weeds achieved with herbicides. Data presented as % of the growers recording each weed as one their five main weeds, and % of these growers nominating one of three control category. 48 growers nominated weeds for summer fallow, winter fallow, and cotton, 31 for sorghum, 39 for wheat, and 11 for chickpea. Several growers listed weeds but did not nominate a control category.

Fallow or crop	Weed species	Growers	Control category (%)		
		(%)	Very good	Acceptable	Variable
Summer	Grasses	38	83	0	6
	Bladder ketmia (*Hibiscus trionum*)	35	35	29	24
	Common sowthistle (*Sonchus oleraceus*)	31	53	20	0
	Caltrops (*Tribulus* spp.)	25	75	17	0
	Liverseed grass (*Urochloa panicoides*)	23	55	36	0
	Burrs (*Xanthium* spp.)	23	73	9	0
	Barnyard grasses (*Echinochloa* spp.)	21	60	20	10
	Thornapples (*Datura* spp.)	19	67	22	0
	Cow vine (*Ipomoea lonchophylla*)	17	75	13	0
	Pigweed (*Portulaca oleracea*)	15	71	29	0
Winter	Wild oats (*Avena* spp.)	71	88	6	3
	Common sowthistle (*Sonchus oleraceus*)	65	58	23	13
	Black bindweed (*Fallopia convolvulus*)	52	40	24	24
	Turnip weed (*Rapistrum rugosum*)	48	74	9	4
	Paradoxa grass (*Phalaris paradoxa*)	21	100	0	0
	Wireweed (*Polygonum aviculare*)	17	75	0	13
	Thistles	17	63	25	13
	Mustard or wild turnip	15	100	0	0
Cotton	Bladder ketmia (*Hibiscus trionum*)	46	27	27	30
	Caltrops (*Tribulus* spp.)	33	38	25	31
	Burrs (*Xanthium* spp.)	27	38	23	23
	Grasses	23	55	9	18
	Liverseed grass (*Urochloa panicoides*)	21	30	20	20
	Amaranths (*Amaranthus* spp.)	21	70	10	0
	Barnyard grasses (*Echinochloa* spp.)	17	38	25	13
	Common sowthistle (*Sonchus oleraceus*)	15	43	43	14
	Thornapples (*Datura* spp.)	10	40	40	0
	Cowvine (*Ipomoea lonchophylla*)	10	60	10	10
	Pigweed (*Portulaca oleracea*)	10	60	0	10
Sorghum	Bladder ketmia (*Hibiscus trionum*)	45	50	21	14
	Caltrops (*Tribulus* spp.)	35	45	36	9
	Grasses	29	22	78	0
	Thornapples (*Datura* spp.)	23	71	14	0
	Liverseed grass (*Urochloa panicoides*)	23	43	14	29
	Amaranths (*Amaranthus* spp.)	19	86	0	0
	Barnyard grasses (*Echinochloa* spp.)	16	0	40	20
	Cowvine (*Ipomoea lonchophylla*)	13	100	0	0
	Burrs (*Xanthium* spp.)	13	50	25	0
	Pigweed (*Portulaca oleracea*)	13	75	0	25
Wheat	Turnip weed (*Rapistrum rugosum*)	79	84	6	3
	Common sowthistle (*Sonchus oleraceus*)	59	57	30	4
	Black bindweed (*Fallopia convolvulus*)	62	33	38	21
	Wild oats (*Avena* spp.)	44	71	12	12
	Paradoxa grass (*Phalaris paradoxa*)	28	55	27	9
	Wireweed (*Polygonum aviculare*)	28	64	18	18
	Mustards (*Sisymbrium* spp.)	13	60	0	0
	NZ spinach (*Tetragonia tetragonioides*)	10	75	0	0
Chickpea	Wild oats (*Avena* spp.)	82	67	22	11
	Turnip weed (*Rapistrum rugosum*)	55	50	17	17
	Common sowthistle (*Sonchus oleraceus*)	55	33	50	0
	Black bindweed (*Fallopia convolvulus*)	36	25	50	0
	Paradoxa grass (*Phalaris paradoxa*)	27	100	0	0

Weeds in dryland cotton and sorghum

The majority of dryland cotton growers used a mix of weed control practices, such as pre- and post-emergent herbicides, non-selective herbicides applied with a shielded sprayer between the rows, pre-harvest desiccation, inter-row cultivation, and to a lesser extent chipping (Table 2). Very few growers sowed cotton at higher than district average seeding rates. In sorghum, they used less inter-row cultivation, shielded spraying and chipping.

The most common herbicides used in dryland cotton (Table 3) were glyphosate applied with a shielded sprayer (26%) and fluometuron + prometryn applied alone or mixed with pendimethalin, glyphosate, or diuron (40%). The other herbicide treatments listed were diquat + paraquat, diuron, fluazifop, fluroxypyr, haloxyfop, metolachlor, oxyflurofen, pendimethalin, pyrithiobac, trifluralin, triclopyr, and various mixes of these herbicides.

Atrazine, alone or mixed, accounted for 79% of the herbicides used in sorghum (Table 3). Fluroxypyr, metolachlor and picloram + 2, 4-D were the other herbicides nominated.

The weed spectrum was very similar in cotton and sorghum (Table 4). The most common weeds were bladder ketmia, caltrop, unspecified grasses, liverseed grass and barnyard grass. The burrs were less common in sorghum than cotton, and thornapple was more common in sorghum than cotton. Other weeds that were listed to a lesser extent were bellvine, black bindweed, black pigweed (*Trianthema portulacastrum* L.), castor oil weed, devil's claw, fleabanes, Johnson grass, melons, mintweed, mustards, paradoxa grass, potato weed, rhynchosia, sesbania pea, summer grass (*Digitaria ciliaris* Koeler), turnip weed, vetches and wild gooseberry.

The majority of growers did not achieve very good control of many common weeds of both crops, particularly for bladder ketmia in cotton, and liverseed and barnyard grass in both crops (Table 4). However, amaranths, cowvine and pigweed were controlled generally better than the other common weeds.

Weeds in wheat and chickpea

Weed control in wheat relied mostly on post-emergent herbicides, with other chemical and non-chemical options used either irregularly or rarely by many growers (Table 2). In comparison, chickpea growers used more pre-emergent herbicides and pre-harvest desiccation, but tended to use less post-emergent herbicides.

The majority of wheat growers (69%) applied metsulfuron-methyl, MCPA or mixes with MCPA and/or metsulfuron-methyl (Table 3). Eighteen precent used the graminicides, clodinafop or fenoxaprop. Other herbicides were 2,4-D, dicamba, and mixes with picloram, thifensulfuron, fluroxypyr, and chlorsulfuron. Chickpea growers used mainly the graminicide haloxypyr (24%), simazine or mixes with simazine (48%). Others applied glyphosate between rows with a shielded sprayer.

The weed flora in wheat and chickpea was very similar, with both crops infested mainly with turnip weed, common sowthistle, black bindweed and wild oats (Table 4). Other weeds included paradoxa grass, wireweed, mustards and New Zealand spinach, and to a lesser extent Mexican poppies (*Argemone* spp.), prickly lettuce, shepherd's purse (*Capsella bursa-pastoris* Medik.), thistles, and wild radish. The least well-controlled weeds with herbicides were black bindweed in both crops and common sowthistle in chickpea.

Field survey

In general, the field survey supported the findings of the postal survey in relation to the main weeds and level of control achieved for weeds in the summer components of the rotations.

Sixty-one weed species of 54 genera (Table 5), as well as 5 crops, volunteer barley, cotton, sorghum, sunflower and wheat, were identified in the surveyed paddocks. Most species were recorded in the initial survey, whereas 37 weed species were recorded at the end of the season, which were classed as residual weeds. The most common weed was bladder ketmia, which infested 72% of the paddocks. Other common weeds were pigweed, common sowthistle, dwarf amaranth (*Amaranthus macrocarpus* Benth.), barnyard grass (*Echinochloa crus-galli* P.Beauv.), caltrop (*Tribulus terrestris*), cowvine, and liverseed grass, which were found in 31-47% of the paddocks. Fleabane, which was not nominated as a main weed by most growers, was found in 19% of the paddocks.

Bladder ketmia had the highest mean density rating of 0.81, when averaged across the infested paddocks (Table 6). Barnyard grass and pigweed also had high mean densities, which were 0.74 and 0.71 respectively. Some individual paddocks had very high ratings of 1.7-2.1 for these and other common weeds. The majority of the initially infested paddocks had residual weeds at the end of the crop or fallow. For individual species, densities of the residual weeds were generally 25-50% of the initially recorded levels, although some paddocks had similar or higher densities, particularly common sowthistle (data not presented). For the weed flora, density ratings of all residual weeds were 0.1-1 in 60% of the paddocks, and 2-5 in 20% of the paddocks (data not presented).

Table 5. Weeds found in the field survey of 32 paddocks, 19 as summer fallow, 9 with dryland cotton, 4 with sorghum. Fields were survey early in fallow or crop (infested) and late in the season prior to crop harvest (residual). Data presented as number of paddocks in which each weed was detected in 20 x 10m^2 quadrats, as well as total number of paddocks initially infested as % of all paddocks.

Weed species	Fallow		Cotton		Sorghum		Total
	Infested	Residual	Infested	Residual	Infested	Residual	(% infested)
Bladder ketmia (*Hibiscus trionum*)	12	7	8	6	3	3	72
Pigweed (*Portulaca oleracea*)	8	6	6	5	1		47
Common sowthistle (*Sonchus oleraceus*)	9	9	5	6	1	1	47
Dwarf amaranths (*Amaranthus macrocarpus*)	7	2	4	2	2	3	41
Barnyard grass (*Echinochloa crus-galli*)	8	4	3	3	2	2	41
Caltrop (*Tribulus terrestris*)	8	3	3	3	1	2	38
Cow vine (*Ipomoea lonchophylla*)	6	3	4	5	1	1	34
Liverseed grass (*Urochloa panicoides*)	6	1	2		2	1	31
Caustic weed (*Chamaesyce drummondii*)	7	3	2	3			28
Boggabri weed (*Amaranthus mitchelli*)	5	2	2	1			22
Australian bindweed (*Convolvulus erubescens*)		4	4		2	1	19
Fleabane (*Conyza bonariensis*)	3	3	2	1	1	1	19
Burr gherkin (*Cucumis anguria*)	6	1					19
Malvastrum (*Malvastrum americanum*)	5	3	1				19
Yabila grass (*Panicum queenslandicum*)	2	1	2	1	2	2	19
Wild gooseberry (*Physalis minima*)	5	3	1	1		1	19
Emu foot (*Cullen tenax*)	1	1	3	3	1		16
Native sensitive weed (*Neptunia gracilis*)	2	2	1	1	2	2	16
African turnip weed (*Sisymbrium thellungii*)	4		1				16
Redshank (*Amaranthus cruentus*)	1	3	3	1			13
Black bindweed (*Fallopia convolvulus*)	3	1	1				13
Burr medic (*Medicago polymorpha*)	1	1	3				13
Polymeria (*Polymeria pusilla*)	2	2	1		1		13
Mintweed (*Salvia reflexa*)	3	2	1	2			13
Green amaranthus (*Amaranthus viridis*)	3						9
Wild oats (*Avena* spp.)	3	1					9
Spear thistle (*Cirsium vulgare*)	1		1		1		9
Cudweed (*Gamochaeta pensylvanica*)	2				1	1	9
Panicums (*Panicum* spp.)	2				1		9
Swamp grass (*Paspalidium* spp.)	1		2				9
Turnip weed (*Rapistrum rugosum*)	2		1				9
Rhynchosia (*Rhynchosia minima*)	2	2	1				9
Vigna (*Vigna lanceolata*)	2		1				9
Feathertop Rhodes grass (*Chloris gayana*)	1	1			1		6
Thornapple (*Datura ferox*)	2	1		1			6
Stink grass (*Eragrostis cilianensis*)	1	1			1		6
Red flinders grass (*Iseilema vaginiflorum*)	1				1		6
Devil's claw (*Martynia annua*)			2	2			6
Wireweed (*Polygonum aviculare*)	2						6
Sesbania (*Sesbania cannabina)*			2				6
Cobbler's pegs (*Bidens pilosa*)	1						3
Chenopodiums (*Chenopodium spp.*)	1	1		1			3
Slender celery (*Ciclospermum leptophyllum*)	1						3
Button grass (*Dactyloctenium radulans*)	1	1		1			3
Digitaria (*Digitaria* spp.)			1				3
Weeping lovegrass (*Eragrostis parviflora*)	1						3
Prickly lettuce (*Lactuca serriola*)	1	1					3
Deadnettle (*Lamium amplexicaule*)			1				3
Small flowered mallow (*Malva parviflora*)	1						3
Tree pear (*Opuntia monacantha*)			1				3
Guinea grass (*Panicum maximum*)			1				3
Paradoxa grass (*Phalaris paradoxa*)	1						3
Docks (*Rumex* spp.)	1						3
New Zealand spinach (*Tetragonia tetragonioides*)			1				3
Black pigweed (*Trianthema portulacastrum*)			1	1			3
Caltrop (spineless) (*Tribulus micrococcus*)	1						3
Blue bells (*Wahlenbergia* spp.)	1						3
Noogoora burr (*Xanthium occidentale*)	1						3

Table 6. Density ratings of 6 common weeds recorded in a field survey of 19 fallow, 9 dryland cotton, and 4 sorghum paddocks. Data are mean rating scores (20 quadrats per paddock) for each weed species, where 1 = <1 weed/m^2, 2 = 1-10 weeds/m^2, 3 = >10 weeds/m^2. Weed densities were rated in the first 1-2 months of the fallow or crop.

Paddock	Bladder ketmia	Pigweed	Common sowthistle	Amaranths	Barnyard grass	Caltrop
Fallow after cotton						
1	1.70	0.70		1.00	0.05	0.45
2	0.55		0.30	0.15		0.05
3	1.65			0.75		
4	1.30					0.10
5	1.45			0.15		0.40
6	0.70					
7		1.25	0.10	0.05	0.40	
8	1.70	0.75				
Fallow after wheat						
9	1.45			0.85		0.10
10	0.30					
11		0.25	0.25		0.60	0.05
12		0.90		0.10	1.45	0.05
13	1.90	1.30	0.05	0.40	2.10	0.55
14			0.05			
15						
16			0.10		0.45	
17	0.15	0.90	0.10	0.50	0.10	0.05
18		0.45	0.75	0.25	1.70	
Fallow after sorghum						
19	0.35		0.15			
Cotton after long fallow						
20	0.55	0.03	1.15	0.15		0.05
21	0.55		0.30	0.15		0.05
22	0.90		0.05	0.80		
23	0.25	0.55				
Cotton after sorghum						
24	0.25	0.05		0.80		
25	0.20					0.30
Cotton after wheat						
26		0.10	0.10		0.25	
27	0.55	0.55		0.15	0.20	
28	0.05	0.90	0.15	0.10	0.05	
Sorghum						
29	1.00			0.55		
30	0.20					
31	0.95	2.00			1.10	0.10
32			0.05	0.05	1.15	
Mean	*0.81*	*0.71*	*0.24*	*0.39*	*0.74*	*0.18*

The initial densities of some weed species appeared to differ substantially between paddocks with different cropping background. Bladder ketmia was more prevalent in fallow paddocks following cotton than in fallow paddocks following wheat (Table 6). All paddocks that had none or very low densities (rating <0.2) of bladder ketmia were in rotations that included two wheat crops or two winter cereal crops plus a sorghum crop for each cotton crop. Common sowthistle was found least in sorghum, cotton following sorghum, and fallow after cotton, whereas barnyard grass was found most in sorghum, cotton following wheat, and fallow following wheat. In contrast, amaranths were present in paddocks irrespective of the previous cropping background.

Discussion

Growers nominated 42 different genera as the main weeds of their fallows and crops grown in rotations involving dryland cotton, which consisted of 28 different crop and fallow sequences, indicating the complexity of weed management in this system. Also, we identified 54 different genera in fallows, dryland cotton and sorghum during summer 2001/02. The more common weeds identified in the field survey were very similar to those listed as main weeds by the growers, apart from a few weeds such as fleabane. The main problem weeds in the summer components of the rotations were bladder ketmia, common sowthistle, barnyard grass, and liverseed grass. Common summer weeds that were not considered by growers as difficult to control included pigweed, amaranths, cowvine and caltrop. Black bindweed and common sowthistle were the main problem winter weeds.

Many growers used a range of selective and non-selective herbicides, non-chemical tools and crop rotation to control these weeds in dryland cotton, which indicates that they are implementing integrated weed management principles, at least in the short-term. However, this strategy was not applied across the farming system, as most growers relied heavily on a limited number of herbicides for weed control in the rotational crops. This is in contrast with the findings of Streit (1996), who found that the majority of grain growers of the Darling Downs practiced integrated weed management, although this was in the intensive double cropping region of the inner Darling Downs with rotations of winter and summer cereals and pulses but not dryland cotton.

The variation in the level of weed management inputs for dryland cotton compared with other crops is shown in the differences in expenditure on weed control. Hoque *et al.* (2003) calculated using the data from the postal survey that growers spend on average $220/ha for weed control in dryland cotton compared with $60/ha for sorghum, $39/ha for chickpea and $20/ha of wheat. They also spend $35/ha on controlling weeds in each 6-month fallow. Very few growers attempted to control weed survivors or late flushes in the rotational crops. Despite this large expenditure, weeds continue to flourish in this cropping system. This is evident by the number of residual weeds in the field survey and the low number of growers achieving effective herbicidal control of their main weeds in the postal survey.

The approach to weed control needs to change from treating infestations to the concept of managing weed populations across the whole cropping system, with the aim of reducing the weed pressure in dryland cotton and thus reducing the economic impact of weeds

in the long-term. Jones and Medd (1997, 2000) predicted that strategies minimizing return of weed seed to the soil maximise profits. Apart from optimising herbicide performance, other tools need to be incorporated into the management strategy, such as greater crop competition, and seed kill techniques to minimise seeding of weed survivors and replenishment of the seed-bank. Walker *et al.* (2001, 2002) showed that control of wild oats and paradoxa grass can be improved substantially with increased competition of winter cereals, and this needs to be explored for sorghum in this environment. Medd *et al.* (1995) and Cook *et al.* (1999) developed selective spray-topping technology for seed kill of wild oats, and similar techniques may be applicable to surviving summer weeds. As well, the reasons for certain rotations and crop or fallow situations that favour the prevalence of some weed species and not others need to be understood, and possibly exploited.

Herbicide resistance is a major issue for Australian agriculture, although no resistant weeds have been identified in cotton (Charles 2002b). Several weeds however, such as wild oats, common sowthistle, black bindweed, turnip weed and liverseed grass have developed resistance in wheat and sorghum in the same cropping region (Adkins *et al.* 1997). Weed management plans in farming systems involving dryland cotton need to take the potential for herbicide resistance into account, particularly with the recent introduction of Roundup Ready® cotton into those systems.

Residual herbicides are often cost-effective weed control options. However, the need to maintain flexibility in the cropping system restricts the use of some potentially useful residual herbicides, particularly in fallows and rotational crops (Charles 2002a).

The main problem weeds in dryland cotton differed to those identified by Charles (1991) in irrigated cotton. Bladder ketmia was the greatest problem weed identified in our survey, whereas it was ranked as number six in the irrigated cotton survey. Liverseed grass, common sowthistle and amaranths were problems in dryland but not in irrigated cotton, whereas perennial weeds, such as *Cyperus* spp., raspweed (*Haloragis glauca* Lindl.) and polymeria (*Polymeria longifolia* Lindl.), were major weeds of irrigated cotton but were not identified in our survey.

The weed flora and their relative importance in summer fallow and sorghum in our cropping system were similar to that recorded by Felton *et al.* (1994) in the wheat-sorghum cropping system of northern New South Wales. The main exceptions were the lesser

importance of bladder ketmia and the absence of cowvine in the survey by Felton *et al.* (1994).

The main weeds in wheat were similar to those recorded in other surveys during the last two decades (Martin *et al.* 1988, Gavin *et al.* 1999, Alemseged *et al.* 2001). All found wild oats, paradoxa grass, one or more Brassicaceae weeds, wireweed, and most had common sowthistle and black bindweed. The main differences were the increasing importance of common sowthistle over time, as found by Widderick *et al.* (1999), and the absence of annual ryegrass (*Lolium* spp.) in our survey compared to it being an important weed in the survey by Alemseged *et al.* (2001). Also, the relative importance of the Brassicaceae weeds differed between the surveys. An example is wild turnip (*Brassica tournefortii* Gouan.), which was ranked as number two in the survey by Alemseged *et al.* (2001), but was not mentioned as a main weed in the others. This may be due to incorrect weed identification, as many of the Brassicaceae weeds are commonly referred to as turnip weed or wild turnip.

Response rate to the postal survey was similar to that of other surveys (Alemseged *et al.* 2001). The questionnaire requested detailed information on many aspects of weed management, and this may have contributed to the reduced response rate. However, sufficient information was obtained from the postal and field surveys to benchmark the weed situation in dryland cotton cropping system, and to identify and prioritise research needs for improved weed management.

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