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Survey of weed flora and management relative to cropping practices in the north-eastern grain region of Australia

V. A. Osten[A,E], *S. R. Walker*[B], *A. Storrie*[C], *M. Widderick*[B], *P. Moylan*[C], *G. R. Robinson*[B] *and K. Galea*[D]

[A]Department of Primary Industries and Fisheries, LMB 6, Emerald, Qld 4720, Australia.
[B]Department of Primary Industries and Fisheries, PO Box 2282, Toowoomba, Qld 4350, Australia.
[C]NSW Department of Primary Industries, 4 Marsden Park Road, Tamworth, NSW 2340, Australia.
[D]3 Wendy Court, Toowoomba, Qld 4350, Australia.
[E]Corresponding author. Email: vikki.osten@dpi.qld.gov.au

Abstract. The main weeds and weed management practices undertaken in broad acre dryland cropping areas of north-eastern Australia have been identified. The information was collected in a comprehensive postal survey of both growers and agronomists from Dubbo in New South Wales (NSW) through to Clermont in central Queensland, where 237 surveys were returned. A very diverse weed flora of 105 weeds from 91 genera was identified for the three cropping zones within the region (central Queensland, southern Queensland and northern NSW). Twenty-three weeds were common to all cropping zones. The major common weeds were *Sonchus oleraceus*, *Rapistrum rugosum*, *Echinochloa* spp. and *Urochloa panicoides*. The main weeds were identified for both summer and winter fallows, and sorghum, wheat and chickpea crops for each of the zones, with some commonality as well as floral uniqueness recorded. More genera were recorded in the fallows than in crops, and those in summer fallows exceeded the number in winter. Across the region, weed management relied heavily on herbicides. In fallows, glyphosate and mixes with glyphosate were very common, although the importance of the glyphosate mix partner differed among the cropping zones. Use and importance of pre-emergence herbicides in-crop varied considerably among the zones. In wheat, more graminicides were used in northern NSW than in southern Queensland, and virtually none were used in central Queensland, reflecting the differences in winter grass weed flora across the region. Atrazine was the major herbicide used in sorghum, although metolachlor was also used predominantly in northern NSW. Fallow and inter-row cultivation were used more often in the southern areas of the region. Grazing of fallows was more prominent in northern NSW. High crop seeding rates were not commonly recorded indicating that growers are not using crop competition as a tool for weed management. Although many management practices were recorded overall, few growers were using integrated weed management, and herbicide resistance has been and continues to be an issue for the region.

Introduction

Weeds are important and costly constraints to Australian agricultural production (Medd 1997). The impact and cost of weed management have increased across Australia including the north-eastern grain region (Adkins *et al*. 1997) with the recent development of herbicide resistance (Matthews 1994; Preston 2000).

Weed management is an integral part of cropping, and several surveys have documented the weed situation in several cropping systems for parts, but not the whole of the north-eastern grain region. Martin *et al*. (1988) recorded over 50 weed species in winter crops from a mail survey of growers in northern New South Wales (NSW), whereas Felton *et al*. (1994) recorded over 100 weed species in a field survey of summer fallows for the same locality. Charles (1991) identified 34 weed genera in irrigated cotton in northern NSW, and more recently, Walker *et al*. (2005) reported on weeds in dryland cotton farming systems in southern Queensland and northern NSW, where they identified 54 weed genera infesting summer crops and fallows. Jones *et al*. (2000) conducted a more comprehensive mail and field survey of winter crop weeds across Australian grain production regions, with the exception of central Queensland.

The grain region of north-eastern Australia comprises about 4 300 000 ha of cropping, made up of three main cropping areas, central and southern Queensland and northern NSW. The region spans about 1600 km from Dubbo (32.3°S) in NSW to Clermont (22.7°S) in Queensland, and is between 100 and 400 km west of the coast (Webb *et al*. 1997). The cropping areas of central Queensland are in the Fitzroy and southern part of the Burdekin river catchments; the southern Queensland cropping zone is in the Condamine–Balonne–Maranoa river catchments; and the northern NSW cropping area consists of the Macintyre, Gwydir, Namoi, Castlereagh and Macquarie catchments.

The climate is mostly subtropical (Webb *et al*. 1997). Daily maximum temperatures range from 27–33°C in summer to 12–20°C in winter, and minima from 12–20°C in summer to 0–9°C in winter, with mean temperatures generally higher in the northern part of the region. The median annual rainfall of

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600–800 mm is transitional between winter dominant in the south and summer dominant in the north. Moderate to high rainfall variability is a strong characteristic with more variability in central Queensland than further south. The annual evaporative demand (1600–2000 mm) is at least double the annual rainfall.

The main grain cropping soils of this region are Vertosols and Sodosols, and to a lesser extent Kandosols and Dermosols (Webb *et al*. 1997). Most soils have high plant available water capacity, owing to their high clay content, which allows for accumulating soil water during fallows.

The farming systems are diverse, reflecting the different soils and climates across the region with a general trend of summer crops being grown more in the north and winter crops grown more in the south (Webb *et al*. 1997). Overall, the main crops based on area grown are wheat and sorghum, and to a lesser extent, barley, oats, canola, maize, sunflower, chickpea, mungbean and dryland cotton with relative importance varying across the region (Australian Bureau of Statistics 2001). In central Queensland, farming systems are generally mixed enterprises with cattle and opportunistic cropping (Spackman and Garside 1995). In southern Queensland and northern NSW, farming systems are mostly a mix of summer and winter crops, but with a trend of increased winter cropping and some grazing in the more southern and drier western parts (Tow and Schultz 1991). Fallows vary in timing and duration for the different farming systems across the region.

This paper describes the results of a unique survey on the diverse weed flora and range of weed management practices used across the whole grain region of north-eastern Australia. It highlights the differences in weed floras and the weed management practices used in the three cropping zones of the region, and these differences are explained in terms of climate and farming systems. These data were used to assess the risk for further development of herbicide resistance in this region (Walker *et al*. 2002*a*, 2004), which is discussed further here with recommendations to minimise the risk.

Materials and methods

Postal survey

A questionnaire was mailed to 535 growers and about 850 agronomists throughout the subtropical grain region of north-eastern Australia between September and November 2001. The package included the questionnaire, a covering letter plus a prepaid envelope. It was sent to 275 growers in central Queensland who received a Department of Primary Industries & Fisheries newsletter, to 260 growers in southern Queensland and northern NSW who received the Conservation Farmers newsletter, and to 1700 recipients of a Grains Research and Development Corporation Northern Update newsletter of which about half were agronomists working in the north-eastern grain region (J. Cameron, pers. comm.). Growers were requested to base their responses on cropping and weed management used on their farm, whereas agronomists were asked to base their responses on the overall cropping and weed management used by their clients in their nominated shire.

An abbreviated version of the questionnaire is presented in Appendix 1, along with some typical responses in italics. Growers and agronomists were requested to list the main crops grown and their frequency over 5 years; the use frequency of pre- and post-emergence herbicides, higher seeding rates and inter-row cultivation in these main crops; and the frequency of the use of knockdown and residual herbicides, cultivation and grazing in winter and summer fallows. Frequency categories listed on the questionnaire were rarely, sometimes (used in some years but not others) and regularly (used once or more per crop or fallow). Growers and agronomists were also asked to list the main weeds for each crop and fallow, and to specify the main herbicides used for each weed. The survey was field tested with several selected growers and agronomists, and modified accordingly before distribution (White *et al*. 2005). Some additional information was requested on levels of infestation for each nominated main weed, frequency of herbicide use in a paddock over 5 years, and level of weed control normally achieved for each herbicide, which was used for a risk assessment for weeds developing herbicide resistance (data not presented in this paper).

Each returned survey was assigned a code, and the information, including the shire of the farm or consultancy, was entered into a Microsoft Access® database. If there were any ambiguity in any answers, the respondents were contacted by phone for clarification before their data were entered into the database. The survey was designed for comparing weed flora and management practices among the three main cropping zones of central Queensland, southern Queensland, and northern NSW, based on the shire of the respondents. The main cropping shires in these zones, as well as the cropping area, are listed in Table 1 (Australian Bureau of Statistics 2001). Queries were generated to extract data on cropping systems, weed flora, main weeds infesting each crop and fallow, and general weed management practices and herbicides used in each crop and fallow in the three zones.

Table 1. Number of surveys returned by agronomists and growers in the main cropping zones of the north-eastern grain region
Cropping area is based on the 1997 census (Australian Bureau of Statistics 2001)

Shires in each zone	Cropping area (× 1000 ha)	Number of respondents	
		Agronomists	Growers
Central Queensland: Banana, Bauhinia, Duaringa, Emerald, Peak Downs, Belyando, Broadsound	519	7	68
Southern Queensland: Cambooya, Clifton, Chinchilla, Inglewood, Jondaryan, Millmerran, Murilla, Pittsworth, Rosalie, Tara, Waggamba, Wambo, Warwick, Balonne, Bendemere, Bungil, Waroo, Gayndah, Kingaroy, Mundubbera, Wondai	1314	25	69
Northern NSW: Inverell, Gunnedah, Parry, Quirindi, Yallaroi, Moree Plains, Narrabri, Bogan, Coonamble, Walgett, Warren, Coolah, Coonabarabran, Dubbo, Gilgandra, Merriwa, Mudgee, Narromine, Wellington	2506	40	32

Data analysis

Data for each general weed management practice used in wheat, chickpea, sorghum, and winter and summer fallows were analysed separately using logistic regression with logit-transformation on the number of regular use responses. The dispersion parameter was estimated for the data as it was often over-dispersed. The analysis assessed differences in the total number of responses among the three zones and compared the two information sources (agronomists and growers). If significant ($P < 0.05$), pair-wise testing was done for the predicted percentage responses for the three zones. As information provided by agronomists and growers did not differ for 90% of data analysed (see Table 6), data were combined for both sources in the other tables except where noted.

Results

Response to the survey

Seventy-two agronomists and 169 growers responded to the survey, with a total of 72 from northern NSW, 75 from central Queensland, and 94 from southern Queensland (Table 1). In general, more growers responded from southern and central Queensland, each with 29% of the respondents, than northern NSW (13%), whereas more agronomists responded from northern NSW (16%) and southern Queensland (10%) than central Queensland (3%). Response rate per area of cropping was greatest in central Queensland and least in northern NSW.

Cropping systems

The main crops across the region were wheat and sorghum, with 96–100% of respondents nominating wheat and 66–91% nominating sorghum, depending on the cropping zone (Table 2). Chickpea was also common with 48–60% of respondents nominating this crop. Wheat was grown mostly between 2 and 5 times over 5 years across the region, whereas sorghum was grown mostly 2–5 times in central Queensland but generally 1–3 times in southern Queensland and northern NSW. As well, chickpea tended to be grown more frequently in central Queensland than the other cropping zones. Other important crops were barley, canola, cotton, maize, mungbean and sunflower, although the relative importance of many of these crops tended to differ across the region. Barley, and to a lesser extent cotton, was grown mostly in southern Queensland and northern NSW. Canola was predominantly grown in northern NSW, but only limited areas of sunflower and maize were grown in that part of the region. Central Queensland tended to have more sunflower and mungbean grown than further south. The minor crops were oats, triticale, canary seed, faba bean, field pea, lupins, millet, navy bean, peanut, sesame and soybean, as well as pastures, such as lucerne, butterfly pea, guar bean, laboratory laboratory and forage sorghum. Generally, these crops and pastures were grown by less than 10% of the respondents, apart from lupins and faba beans, which were nominated by 12 and 16% of respondents in northern NSW, respectively (data not shown).

Weed flora

The diversity of weeds across the north-eastern grain region is highlighted with 91 genera nominated by growers and agronomists as their main weeds in the various farming systems (Table 3). Of the 105 weeds listed, only 23 weeds were listed as common in all cropping zones. The most common weeds across the region were *Sonchus oleraceus* with 52–80% of respondents listing it as a main weed, as well as *Avena* spp., *Echinochloa* spp., *Rapistrum rugosum*, *Urochloa panicoides* and *Fallopia convolvulus*. The relative importance of many of these 23 weeds differed substantially among the three zones, particularly for *Argemone* spp., *Avena* spp., *Fallopia convolvulus* and *Sisymbrium thellungii.*

Thirteen weeds were nominated as main weeds only in central Queensland, with *Brachiaria eruciformis*, *Corchorus trilocularis* and *Parthenium hysterophorus* listed as the most common (Table 3). In addition, another 17 weeds were nominated as main weeds of both central and southern Queensland, but not northern NSW, with *Sesbania cannabina*, *Ipomoea lonchophylla*, *Trianthema portulacastrum* and *I. plebeia* the most common weeds in these two cropping zones.

Eighteen weeds were nominated as main weeds in southern Queensland and northern NSW, but not in central Queensland, with *Polygonum aviculare*, *Phalaris paradoxa*, *Lolium rigidum*, *Raphanus raphanistrum*, *Conyza* spp. and *Digitaria ciliaris* nominated by more than 30% of the respondents (Table 3). In addition, another 14 weeds were nominated as main weeds only in southern Queensland, although these were listed only by 1–4% of the respondents particularly growers. As well, 16 weeds were nominated as main weeds only in northern NSW

Table 2. Percentage of respondents who listed whether their main crops were sown once, 2–3 or 4–5 times in a paddock over a typical 5-year period for the main cropping zones of the north-eastern grain region
All respondents completed this question and data are combined for growers and agronomists

Crop	Central Queensland			Southern Queensland			Northern NSW		
	1	2–3	4–5	1	2–3	4–5	1	2–3	4–5
Barley	1	5	1	19	18	5	38	22	5
Canola	0	0	0	1	2	0	22	13	1
Chickpea	21	30	10	31	17	1	35	13	0
Cotton	7	7	5	15	29	5	7	16	10
Maize	12	7	2	6	10	2	1	1	1
Mungbean	21	22	12	17	15	1	12	1	1
Sorghum	5	42	44	24	40	8	37	25	4
Sunflower	21	28	12	9	2	1	9	1	0
Wheat	9	51	36	14	55	27	0	75	25

Table 3. Weed flora in the main cropping zones in the north-eastern grain region

Data are presented as the percentage of respondents that listed them as a main weed in any crop or fallow. All respondents completed this question and data are combined for growers and agronomists

Botanical name (common names used by growers and agronomists)	Central Queensland	Southern Queensland	Northern NSW
All cropping zones			
Sonchus oleraceus L (sowthistle, milkthistle)	52	80	63
Avena spp. (wild oats, black oats)	3	65	84
Echinochloa spp. (barnyard grasses)	25	65	26
Rapistrum rugosum (L) All (turnip weed)	21	53	34
Urochloa panicoides P Beauv (liverseed grass, urochloa)	28	63	13
Fallopia convolvulus (L) A Love (black bindweed, climbing buckwheat)	1[A]	44	54
Argemone spp. (Mexican poppy, poppy)	47	5[A]	6
Tribulus spp. (caltrop, yellow vine, bull head)	13[A]	26	13
Hibiscus trionum L (bladder ketmia, wild cotton)	13	29	6
Sisymbrium thellungii OE Schulz (African turnip weed, African radish)	35	7	1[B]
Cucumis spp. (burr gherkin, wild cucumber, cucumber)	7[A]	14	21
Portulaca oleracea L (pigweed, red pigweed)	12[A]	27	3[A]
Datura spp. (datura, thornapple, castor oil, stramonium, fierce thornapple, ferox)	8[A]	21	9
Xanthium occidentale Bertol (noogoora burr)	4[A]	15	12
Cyperus rotundus L (nutgrass)	5[A]	9	7
Physalis spp. (annual ground cherry, wild gooseberry, gooseberry)	11[A]	6	1[A]
Tetragonia tetragonioides (Pall) Kuntze (New Zealand spinach)	7[A]	10[A]	1[B]
Amaranthus spp. (amaranths)	3[A]	13	1[B]
Salvia reflexa Hornem (mintweed)	3[A]	12	1[A]
Solanum nigrum L (blackberry nightshade, nightshade)	4[A]	4[A]	3[B]
Sorghum halepense (L) Pers (Johnson grass)	1[A]	6	3[A]
Eragrostis cilianensis (All) Vignolo ex Janch (lovegrass, stinkgrass)	4[A]	3[A]	1[B]
Haloragis spp. (raspweed, haloragis)	1[A]	2	1[B]
Only in central Queensland			
Brachiaria eruciformis (Sm) Griseb (sweet summer grass, summer grass in CQ)	48	—	—
Parthenium hysterophorus L (parthenium weed)	33	—	—
Corchorus trilocularis L (native jute, jute)	28	—	—
Verbesina encelioides (Cav) A Gray (crownbeard, wild sunflower)	16	—	—
Amaranthus mitchellii Benth (boggabri weed, water weed)	12[A]	—	—
Sorghum almum Parodi (sorghum almum, almum)	12[A]	—	—
Abelmoschus ficulneus (L) Wight&Arn ex Wight (native rosella)	7	—	—
Chamaesyce hirta (L) Millsp (asthma plant)	3[A]	—	—
Chloris gayana Kunth (Rhodes grass)	3[A]	—	—
Cynodon aethiopicus Claytoon & JR Harlan (African star grass, star grass)	3[A]	—	—
Senecio brigalowensis I Thomps (fireweed)	3[A]	—	—
Alstonia constricta F Muell (bitter bark)	1[A]	—	—
Zaleya galericulata (Melville) H Eichler (hogweed)	1[A]	—	—
Only in southern Queensland			
Dactyloctenium radulans (RBr) P Beauv (button grass)	—	4	—
Cirsium vulgare (Savi) Ten (spear thistle)	—	3[A]	—
Commelina benghalensis L (wandering Jew)	—	3	—
Cenchrus ciliaris L (buffel grass)	—	2	—
Galinsoga parviflora Cav (potato weed)	—	2	—
Amaranthus hybridus L (redshank)	—	1[A]	—
Bidens pilosa L (cobbler's pegs, farmer's friend)	—	1[A]	—
Boerhavia dominii Meikle & Hewson (tarvine)	—	1[A]	—
Centaurea solstitialis L (St Barnaby's thistle)	—	1[A]	—
Euphorbia davidii Subils (euphorbia, milk weed)	—	1[A]	—
Gaura parviflora Douglas (clockweed)	—	1[A]	—
Ibicella lutea (Lindl) Van Eselt (devil's claw)	—	1[A]	—
Stachys arvensis (L) L (stagger weed)	—	1[B]	—
Urtica spp. (nettles, stinging nettles)	—	1[B]	—
Only in northern NSW			
Polymeria longifolia Lindl (Peak Downs Curse)	—	—	12
Silybum marianum (L) Gaertn (variegated thistle)	—	—	12

Continued next page

Table 3. continued

Botanical name (common names used by growers and agronomists)	Central Queensland	Southern Queensland	Northern NSW
Arctotheca calendula L Levyns (capeweed)	—	—	6[B]
Sinapis arvensis L (charlock)	—	—	4
Ammi majus L (bishop's weed)	—	—	3
Buglossoides arvensis (L) IM Johnst (corn gromwell)	—	—	3
Echium plantagineum L (Paterson's curse)	—	—	3
Medicago spp. (medics, clover)	—	—	3
Vulpia spp. (fescue, vulpia)	—	—	3
Amsinckia spp. (yellow burrweed)	—	—	1[A]
Capsella bursa-pastoris ((L) Medik (shepherd's purse)	—	—	1[B]
Chondrilla juncea L (skeleton weed)	—	—	1[B]
Cyperus esculentus L (yellow nutgrass)	—	—	1[B]
Fumaria officinalis L (fumitory)	—	—	1[A]
Lactuca saligna L (willow lettuce)	—	—	1[B]
Lepidium spp. (peppercress)	—	—	1[B]
Both central and southern Queensland			
Sesbania cannabina (Retz) Pers (sesbania pea, horse bean)	36	9	—
Ipomoea lonchophylla JM Black (cowvine, peachvine)	21	19	—
Trianthema portulacastrum L (black pigweed, giant pigweed)	33	1[A]	—
Ipomoea plebeia R Br (bellvine)	13	14	—
Atriplex muelleri Benth (annual saltbush, saltbush, saltine)	3[A]	13	—
Rhynchosia minima (rhyncho, rhynchosia)	12	4	—
Cynodon dactylon (L) Pers (couch)	11[A]	3	—
Cenchrus echinatus L (Mossman river grass, Mossman river burr grass)	1[A]	4[A]	—
Convolvulus spp. (field bindweed, European bindweed, bindweed, convolvulus)	1[A]	4[A]	—
Malvastrum americanum (L) Torr (spiked malvastrum, malvastrum)	1[A]	4	—
Flaveria australasica Hook (speedy weed)	1[A]	3[A]	—
Acanthospermum hispidum DC (starburr)	1[A]	2[A]	—
Chamaesyce drummondii (Boiss) DC Hassall (caustic weed, caustic creeper)	1[A]	2[A]	—
Crotalaria spp. (rattle pod, crotalaria)	1[A]	2[A]	—
Polymeria pusilla (polymeria)	1[A]	2[A]	—
Panicum spp. (panic grasses)	1[A]	1[A]	—
Salsola kali (soft rolypoly)	1[A]	1[A]	—
Both southern Queensland and northern NSW			
Polygonum aviculare L (wireweed)	—	17	32
Phalaris paradoxa L (paradoxa grass, wild canary, phalaris)	—	14	34
Lolium rigidum Gaudin (ryegrass, annual ryegrass, Wimmera ryegrass)	—	2[A]	38
Raphanus raphanistrum L (wild radish, radish)	—	14	21
Conyza spp. (fleabane)	—	15	18
Digitaria ciliaris (Retz) Koeler (summer grass)	—	6	24
Sisymbrium spp. (mustards)	—	18	7[B]
Carthamus lanatus L (saffron thistle)	—	3[A]	18
Xanthium spinosum L (Bathurst burr)	—	9	7
Lamium amplexicaule L (deadnettle)	—	7	6
Malva parviflora L (marshmallow, small flowered mallow, mallow)	—	4[A]	7
Emex australis Steinh (spiny emex)	—	7[A]	1[B]
Eleusine indica (L) Gaertn (crowsfoot grass, crabgrass)	—	5	1[A]
Heliotropium spp. (blue heliotrope, common heliotrope, heliotrope)	—	1[A]	4
Lactuca serriola L (prickly lettuce)	—	3[A]	1[B]
Anoda cristata L Schltdl (anoda weed)	—	1[B]	1[B]
Centaurea melitensis L (Maltese cockspur)	—	1[A]	1[B]
Hordeum spp. (barley grasses)	—	1[A]	1[B]
Both central Queensland and northern NSW			
Brassica tournefortii Gouan (wild turnip)	13	—	7
Citrullus lanatus (Thunb) Matsum & Nakai (camel, paddy, wild, and pie melons)	1[A]	—	19
Sida spp. (sida, sida retusa)	4[A]	—	3[B]
Eragrostis spp. (Eragrostis)	1[B]	—	1[B]

[A]Weeds were recorded only by growers.

[B]Weeds were recorded only by agronomists.

Table 4. The main weeds infesting winter and summer fallow, wheat, chickpea and sorghum for the main cropping zones of the north-eastern grain region

Weeds that were nominated by at least 5% of growers and agronomists are listed by order of importance, with total number of weed genera listed for each crop and fallow in each zone

Central Queensland	Southern Queensland	Northern NSW
	Winter fallow	
Sonchus oleraceus	*Sonchus oleraceus*	*Avena* spp.
Sisymbrium thellungii	*Avena* spp.	*Sonchus oleraceus*
Argemone spp.	*Rapistrum rugosum*	*Fallopia convolvulus*
Parthenium hysterophorus	*Fallopia convolvulus*	*Polygonum aviculare*
Rapistrum rugosum	*Polygonum aviculare*	*Lolium rigidum*
Brachiaria eruciformis[B]		*Carthamus lanatus*
		Rapistrum rugosum
(38 genera)	(36 genera)	(25 genera)
	Summer fallow	
Brachiaria eruciformis	*Echinochloa* spp.	*Sonchus oleraceus*
Ipomoea spp.	*Sonchus oleraceus*	*Fallopia convolvulus*
Parthenium hysterophorus	*Urochloa panicoides*	*Echinochloa* spp.
Sonchus oleraceus	*Ipomoea spp*	*Polygonum aviculare*
Urochloa panicoides	*Hibiscus trionum*	*Digitaria ciliaris*
Trianthema portulacastrum		*Cucumis* spp.
Corchorus trilocularis		*Citrullus lanatus*
Sesbania cannabina		*Carthamus lanatus*
Echinochloa spp.		*Conyza* spp.
(44 genera)	(51 genera)	(38 genera)
	Wheat	
Argemone spp.	*Sonchus oleraceus*	*Avena* spp.
Sonchus oleraceus	*Rapistrum rugosum*	*Fallopia convolvulus*
Sisymbrium thellungii	*Avena* spp.	*Lolium rigidum*
Rapistrum rugosum	*Fallopia convolvulus*	*Sonchus oleraceus*
Parthenium hysterophorus	*Sisymbrium* spp.	*Phalaris paradoxa*
	Polygonum aviculare	*Polygonum aviculare*
		Rapistrum rugosum
(22 genera)	(23 genera)	(28 genera)
	Chickpea	
Sonchus oleraceus	*Avena* spp.	*Avena* spp.
Argemone spp.	*Sonchus oleraceus*	*Phalaris paradoxa*
Rapistrum rugosum	*Fallopia convolvulus*	*Fallopia convolvulus*
Sisymbrium thellungii	*Rapistrum rugosum*	*Rapistrum rugosum*
Parthenium hysterophorus	*Phalaris paradoxa*	*Sonchus oleraceus*
Brassica tournefortii	*Sisymbrium* spp.	*Polygonum aviculare*
Verbesina encelioides		*Lolium rigidum*[B]
(14 genera)	(20 genera)	(14 genera)
	Sorghum	
Sesbania cannabina	*Echinochloa* spp.	*Echinochloa* spp.
Trianthema portulacastrum	*Urochloa panicoides*	*Urochloa panicoides*
Brachiaria eruciformis	*Ipomoea* spp.	*Digitaria ciliaris*
Ipomoea spp.	*Hibiscus trionum*	*Xanthium* spp.
Corchorus trilocularis	*Tribulus* spp.	*Fallopia convolvulus*
Parthenium hysterophorus	*Sonchus oleraceus*	*Datura* spp.
Echinochloa spp.	*Xanthium* spp.	*Sonchus oleraceus*[B]
Verbesina encelioides	*Portulaca oleracea*	
(34 genera)	(34 genera)	(17 genera)

[A]Weeds were recorded only by growers.

[B]Weeds were recorded only by agronomists.

by 1–12% of the respondents with *Polymeria longifolia* and *Silybum marianum* the most common in this cropping zone.

Mostly, growers and agronomists recorded their main weeds using their local common names and these have been listed in Table 3. The authors identified most of these weeds with their botanical name, although 22 weeds could only be identified at the genus level, as the common names were applicable to two or more species within a genus.

The most common weed in the region, *Sonchus oleraceus*, grew in both summer and winter, and was one of the most common weeds in wheat, chickpea, winter fallow and summer fallow in each of the three cropping zones, as well as sorghum in two cropping zones (Table 4). Several other weeds were common in both summer and winter situations, although these were specific to the different cropping zones such as *Parthenium hysterophorus*, *Brachiaria eruciformis* and *Urochloa panicoides* in central Queensland. *Fallopia convolvulus* was ranked in the top five most common weeds irrespective of the cropping or fallow situation in northern NSW. Of the other main weeds common across the whole region, *Avena* spp. and *Rapistrum rugosum* were common in wheat, chickpea and winter fallow in southern Queensland and northern NSW, whereas *Echinochloa* spp. and *Urochloa panicoides* were found in summer fallow and sorghum in most zones.

Overall, more weed genera were recorded as common weeds of fallows than crops, and more in summer fallow compared with winter fallow (Table 4). In fallows, 38–51 and 25–38 genera were listed in summer and winter fallow, respectively, compared with 17–34, 14–20 and 22–28 genera in sorghum, chickpea and wheat, respectively.

Weed management practices

The majority of growers regularly used knockdown herbicides (76–93%) with the remainder using them sometimes. Less than a third regularly used residual herbicides (8–29%) in winter and summer fallows irrespective of cropping zone (Table 5). About a third cultivated regularly for weed control in fallows (20–41%) regardless of cropping zone, whereas use of grazing in summer fallows differed ($P < 0.05$) among the zones with greater use in northern NSW (mean 26%) than southern Queensland (mean 8%).

Similar herbicides were used in both winter and summer fallows in southern Queensland and northern NSW, with 100% using glyphosate alone and 31–63% using glyphosate mixed with either 2,4-D or metsulfuron methyl (Table 6). The main differences in fallow herbicides between these two cropping zones were the relative importance of minor glyphosate mixes, and greater use of ester formulations of 2,4-D and paraquat +

Table 5. The use of herbicides and non-chemical practices for weed control in fallows and main crops for the main cropping zones of the north-eastern grain region

Data are the percentages of the respondents that nominated whether each tactic was used regularly, which was defined as used once or more per crop and fallow. The numbers of respondents are indicated in parentheses. Tests of significance in responses between regions and information source (agronomists and growers) were performed using regression analysis with levels of Chi probability given for each weed control practice for each fallow and crop

Weed control practice	Central Queensland		Southern Queensland		Northern NSW		Chi probability	
	Agronomists	Growers	Agronomists	Growers	Agronomists	Growers	Zone	Information source
			Winter fallow					
Knockdown herbicides	100 (7)	80 (65)	96 (24)	76 (62)	82 (33)	89 (27)	0.837	0.105
Residual herbicides	29 (7)	8 (64)	13 (24)	10 (62)	11 (27)	16 (19)	0.859	0.497
Cultivation	43 (7)	23 (65)	33 (24)	28 (64)	31 (29)	35 (26)	0.622	0.553
Grazing	43 (7)	16 (63)	8 (24)	12 (58)	30 (27)	13 (15)	0.157	0.213
			Summer fallow					
Knockdown herbicides	100 (7)	86 (64)	100 (24)	81 (63)	92 (36)	93 (30)	0.441	0.034
Residual herbicides	14 (7)	14 (64)	8 (24)	15 (62)	18 (28)	29 (24)	0.267	0.250
Cultivation	43 (7)	20 (64)	33 (24)	30 (64)	27 (33)	41 (27)	0.339	0.984
Grazing	29 (7)	19 (64)	4 (24)	12 (58)	27 (30)	25 (16)	0.044	0.796
			Wheat					
Pre-emergence herbicides	0 (6)	11 (63)	13 (24)	19 (57)	27 (37)	31 (32)	0.006	0.466
Post-emergence herbicides	100 (6)	69 (64)	83 (24)	70 (57)	54 (39)	88 (32)	0.579	0.355
Inter-row cultivation	0 (6)	0 (63)	0 (24)	0 (57)	3 (29)	0 (9)	0.845	0.507
Higher seeding rate	0 (6)	17 (63)	17 (24)	18 (57)	11 (36)	20 (30)	0.905	0.238
			Chickpea					
Pre-emergence herbicides	25 (4)	42 (31)	81 (16)	73 (26)	60 (15)	91 (11)	0.004	0.249
Post-emergence herbicides	0 (4)	20 (30)	56 (16)	42 (26)	47 (15)	82 (11)	0.003	0.298
Inter-row cultivation	0 (4)	3 (29)	0 (16)	8 (26)	0 (15)	0 (5)	0.895	0.934
Higher seeding rate	0 (4)	0 (30)	6 (16)	8 (26)	0 (15)	0 (9)	0.948	0.763
			Sorghum					
Pre-emergence herbicides	43 (7)	34 (62)	65 (23)	70 (43)	41 (22)	95 (20)	0.001	0.028
Post-emergence herbicides	57 (7)	44 (62)	48 (23)	43 (42)	32 (22)	22 (18)	0.139	0.343
Inter-row cultivation	0 (7)	3 (62)	17 (23)	14 (43)	9 (22)	14 (14)	0.032	0.939
Higher seeding rate	0 (7)	6 (62)	9 (23)	5 (43)	5 (21)	11 (9)	0.986	0.874

Table 6. Herbicides and their frequency of use by the respondents (%) in winter and summer fallow, wheat, chickpea and sorghum for the main cropping zones of the north-eastern grain region

Minor herbicides, used by less than 5% of respondents, are grouped as 'Other'. Data are combined for growers and agronomists. The numbers of respondents are indicated in parentheses for each herbicide and total number of responses (*n*) is listed for each crop and fallow in each zone (central Queensland, southern Queensland and northern NSW, respectively)

Central Queensland	Southern Queensland	Northern NSW
	Winter fallow (n = 71, 80, 72)	
Glyphosate + 2,4-D amine (65)	Glyphosate (100)	Glyphosate (100)
Glyphosate (52)	Glyphosate + 2,4-D amine (51)	Glyphosate + 2,4-D amine or ester (51)
Glyphosate + metsulfuron methyl (44)	Glyphosate + metsulfuron methyl (31)	Glyphosate + metsulfuron methyl (31)
2,4-D amine (13)	Glyphosate + dicamba (15)	Glyphosate + dicamba (16)
Metsulfuron methyl (6)	Other (30)	Paraquat + diquat (10)
Other (9)		Glyphosate + fluroxypyr (8)
		Glyphosate + oxyfluorfen (7)
		Other (31)
	Summer fallow (n = 69, 85, 72)	
Glyphosate + 2,4-D amine (97)	Glyphosate (100)	Glyphosate (100)
Glyphosate (93)	Glyphosate + 2,4-D amine (48)	Glyphosate + 2,4-D amine or ester (63)
Glyphosate + metsulfuron methyl (51)	Glyphosate + metsulfuron methyl (38)	Glyphosate + metsulfuron methyl (36)
2,4-D amine (14)	Glyphosate + dicamba (7)	Glyphosate + triclopyr (21)
Other (22)	2,4-D amine (5)	Glyphosate + dicamba (15)
	Glyphosate + triclopyr (5)	Glyphosate + oxyfluorfen (11)
	Triclopyr (5)	Glyphosate + fluroxypyr (8)
	Other (39)	Paraquat + diquat (6)
		Other (42)
	Wheat (n = 62, 81, 69)	
Metsulfuron methyl (53) + mix (8)	Metsulfuron methyl + MCPA (40)	Chlorsulfuron (54) + mix (4)
2,4-D amine (37)	Clodinafop-propargyl (37)	Clodinafop-propargyl (54) + mix (4)
Metsulfuron methyl + MCPA (32)	Picloram + MCPA (25) + mix (8)	Metsulfuron methyl + MCPA (48)
MCPA amine (15)	Metsulfuron methyl (22) + mix (2)	MCPA amine or LVE (32) + mix (12)
Other (10)	2,4-D amine (17)	Fenoxaprop-p-ethyl (28)
	Fenoxaprop-p-ethyl (16)	Diclofop methyl (28) + mix (12)
	Thifensulfuron+metsulfuron (12) + mix (1)	Picloram + MCPA (25)
	Fluroxypyr (10) + mix (5)	2,4-D amine or ester (22) + mix (4)
	Chlorsulfuron (10) + mix (2)	Metsulfuron methyl (17)
	MCPA amine or LVE (10)	Tralkoxydim (13)
	Other (28)	Dicamba (4) + mix (12)
		Other (65)
	Chickpea (n = 21, 37, 23)	
Simazine (76)	Haloxyfop-R (38) + mix (2)	Haloxyfop-R (91)
Flumetsulam (14)	Simazine + prometryn (36)	Simazine (61)
Haloxyfop-R (10)	Simazine (30) + mix (6)	Simazine + prometryn (22)
Metsulfuron methyl (10)	Simazine + imazethapyr (14)	Simazine + isoxaflutole (19)
Isoxaflutole (5)	Glyphosate (11) + mix (2)	Trifluralin (13) + mix (9)
Other (0)	Quizalofop (11)	Isoxaflutole (9)
	Isoxaflutole (11) + mix (6)	Fluazifop (5) + mix (9)
	Clodinafop-propargyl (8)	Other (30)
	Other (41)	
	Sorghum (n = 59, 62, 26)	
Atrazine (80) + mix (7)	Atrazine (73) + mix (9)	Atrazine (65) + mix (4)
Atrazine + fluroxypyr (22)	Atrazine + fluroxypyr (23)	Metolachlor (46)
Fluroxypyr (15)	Atrazine + metolachlor (21)	Fluroxypyr (31)
2,4-D amine (10)	Metolachlor (19)	Atrazine + metolachlor (27)
Glyphosate (5) + mix (3)	Glyphosate (15)	Atrazine + fluroxypyr (19)
Other (2)	Fluroxypyr (13) + mix (2)	Other (12)
	Other (7)	

diquat in northern NSW than in southern Queensland. Fallow weed control in central Queensland relied predominantly on glyphosate, metsulfuron methyl and 2,4-D amine, and tended to rely on glyphosate mixtures with 2,4-D amine or metsulfuron methyl more than further south.

The majority of growers used post-emergence herbicides in wheat (69–88%), and pre-emergence herbicides were used significantly more in northern NSW (mean 31%) than in southern Queensland (mean 17%) and central Queensland (mean 10%) (Table 5). Post-emergence herbicides in wheat were mostly graminicides, sulfonylureas and phenoxys in southern Queensland and northern NSW (Table 6). Northern NSW tended to use a greater range and more graminicides than southern Queensland. Combinations of metsulfuron methyl, 2,4-D amine and MCPA represented 90% of the herbicides used in wheat in central Queensland. The pre-emergence herbicide chlorsulfuron was used more in northern NSW than in southern and central Queensland. According to growers, the crop was not commonly sown at higher seeding rates, and no inter-row cultivation was used in wheat.

The extent of herbicide use in chickpea differed ($P < 0.01$) among the regions (Table 5), with more pre- and post-emergence herbicides used in southern Queensland (mean 76 and 48%, respectively) and northern NSW (mean 68 and 56%, respectively) than in central Queensland (mean 40 and 18%, respectively). Inter-row cultivation and higher seeding rates were not used regularly.

Chickpea post-emergence graminicides such as haloxyfop-R were used more in northern NSW than in central Queensland (Table 6). Similarly, the pre-emergence herbicide simazine tended to be used less in central Queensland chickpea crops than further south.

Sorghum pre-emergence herbicides were used more ($P < 0.001$) in southern Queensland (mean 68%) and northern NSW (mean 67%) than in central Queensland (mean 35%) according to the grower responses ($P < 0.05$; Table 5). These herbicides were predominantly atrazine and metolachlor, with a trend of greater use of metolachlor in northern NSW than in southern Queensland (Table 6). Less than half of the growers across the region regularly used post-emergence herbicides (22–44%), which were mostly atrazine and fluroxypyr. Sorghum was inter-row cultivated more ($P < 0.05$) in southern Queensland (mean 15%) than in central Queensland (mean 3%), and only a few crops were seeded at higher sowing rates.

Overall, the views of agronomists correlated very well with what was practiced by growers (Table 5). The only significant differences were slightly higher estimation of use of knockdown herbicides in winter and summer fallows, and underestimation of use of pre-emergence herbicides in sorghum particularly for northern NSW.

The herbicides listed in Table 6 represent 85–100% of all herbicide treatments nominated by growers and agronomists. Overall, a greater range of herbicide treatments was used in southern Queensland and northern NSW than in central Queensland, where in the latter weed control relied mostly on only seven herbicides for the main crops and fallows.

Discussion

Weed flora

The weed flora of the north-eastern Australian grain region is certainly diverse with 105 species being recorded as main weeds in crops and fallows in this postal survey. By no means is this list fully inclusive of all known broad-acre cropping weeds of the region. In comparison, Rew *et al*. (2005) physically recorded 138 species in a limited area of this cropping region. No other weed management survey has been conducted that covers the entire north-eastern grain region of Australia. Unlike past weed related surveys within this region (Jones *et al*. 2000; Rew *et al*. 2005), data from this survey were not validated by actual paddock sampling as the sheer size of this survey area would require enormous resources and time for representative field sampling. A reasonable level of confidence can be placed on this survey data based on results of a similar field validated postal survey conducted in the dryland cotton industry within this same region (Walker *et al*. 2005). That survey showed a good correlation between the weeds growers nominated and the actual weeds recorded in a follow up respondent subsample paddock survey. Hence, the chances of misidentification or omission of species are slight. There is sufficient knowledge and experience among the authors to qualify the data generated here. Past limited survey coverage makes it difficult to compare changes in weeds and weed management practices over time for the whole region. Smaller subregional and particular cropping industry surveys provide some comparisons, except for central Queensland, which has not been surveyed previously. Consequently, this paper is unique in that it includes data and comparisons for central Queensland.

The four most frequently nominated main weeds across all zones include two summer grasses (*Echinochloa* spp. and *Urochloa panicoides*), a non-seasonal broadleaf species (*Sonchus oleraceus*) and a winter dominant broadleaf (*Rapistrum rugosum*). These four weeds could be deemed as the major weeds of the region. This seasonal species range is a direct reflection of the climate and cropping systems of the north-east grain region. Prevalent summer and sufficient winter rains (Webb *et al*. 1997) and fallowing allow for both summer and winter cropping compared with the temperate regions where the climate and soils confine cropping and, thus, most weeds to the cooler months. These climate data indicate the wide favourable window for weed emergence and cropping opportunities in the region, although it varies within the different cropping zones.

The weed floras within the three main cropping zones of the region have many similarities but also many differences. *Sonchus oleraceus* was by far the most common across all cropping zones. Past regional surveys have assigned varying levels of importance to this weed. The northern NSW wheat belt survey of Martin *et al*. (1988) did not rank *S. oleraceus* within the top 10 troublesome species for either summer or winter. Felton *et al*. (1994) had *S. oleraceus* within the top eight weeds based on density for wheat and sorghum paddocks in the same area. The 10-year continuous survey by Wicks *et al*. (2000), again in the northern NSW cropping region, indicated that *S. oleraceus* had become a problem fallow weed as well as one of the worst in-crop weeds. Its importance increased

dramatically during the 1980s particularly in no-tillage fallows as predicted by Martin (1983). Jones *et al*. (2000) recorded this weed in the top five major weeds for the northern grain region. Walker *et al*. (2005) ranked *S. oleraceus* within the top four major problem weeds of the summer components of dryland cotton farming systems in subtropical Australia. Niknam *et al*. (2002) recorded it as the third main weed infesting lentil paddocks in the Wimmera and Mallee regions of Victoria. The distribution and prevalence of *S. oleraceus* across the north-eastern region can be attributed to its germination preferences for light, wide range of temperature and soil water potentials (Widderick 2002*a*), and its emergence preference for nil or low soil disturbance situations (Widderick *et al*. 2002) such as zero and minimum tillage systems. Effectively, it is able to germinate all year round provided moisture is available (Widderick 2002*b*). Herbicide efficacy limitations to commonly used herbicides and development of herbicide resistance (Adkins *et al*. 1997) may also be adding to the dominance of this weed.

The importance of the summer grass weeds, *Echinochloa* spp. and *Urochloa panicoides*, as main weeds for this region has been described in several past surveys. Martin *et al*. (1988) indicated *Echinochloa* spp. were the third and *U. panicoides* (liverseed grass) was the fifth most important summer weed species during 1984–85 in northern NSW cropping. A later survey in the same cropping zone by Felton *et al*. (1994) indicated that these weeds had increased in importance. Wicks *et al*. (2000) indicated that *Echinochloa colona* and *U. panicoides* were among several species in northern NSW summer fallows that displayed tolerance to recommended field rates of glyphosate and, hence, adequate weed control was not being achieved. The recent survey by Walker *et al*. (2005) listed both of these grasses in the top five weeds infesting the summer components of dryland cotton farming systems in southern Queensland and northern NSW.

The winter broadleaf *Rapistrum rugosum*, although common to all zones, was more prevalent in northern NSW and southern Queensland. It was not recorded in the surveys of Felton *et al*. (1994) or Jones *et al*. (2000) and this could be a reflection of the difficulties and ambiguities in identification and use of common name nomenclature in brassica weeds (Rew *et al*. 2005; Walker *et al*. 2005). Medd *et al*. (1995) listed *R. rugosum* as a major problem in wheat and chickpea and a minor problem in fallow in northern NSW, whereas Walker *et al*. (2005) listed it as a major weed in the winter components of dryland cotton farming systems in southern Queensland and northern NSW. Both Martin *et al*. (1988) and Wicks *et al*. (2000) nominated *R. rugosum* as an important or major weed in grain production areas of northern NSW. Rew *et al*. (2005) recorded *R. rugosum* on 56% of their crop field survey sites between the Liverpool Plains of northern NSW and Kingaroy in southern Queensland. Like *Sonchus oleraceus*, some populations of *R. rugosum* within the region have developed herbicide resistance (Adkins *et al*. 1997; Preston 2000) and this may be adding to its dominance.

With respect to differences in weed flora among cropping zones, it is interesting to note that four weeds were specific to northern NSW and central Queensland but were not listed for southern Queensland. More than likely this is an anomaly of the survey, as it would be unusual to find species only capable of surviving the extremes of a climatic zone and not in between. However, according to Wilson *et al*. (1995), *Sida* spp. and *Citrullus lanatus* are only very minor weeds in southern Queensland. The unique weeds for central Queensland were predominantly summer species, whereas those of southern Queensland were a seasonal mix, and the winter species dominated in northern NSW. The authors believe that overall this reflects the main weed flora in the different zones.

Some of the weeds listed only for central Queensland have not been listed as weeds in past surveys for any areas within the north-eastern grain region. These include *Parthenium hysterophorus*, *Senecio brigalowensis* and *Corchorus trilocularis*. The first is an introduced species and one where proactive containment has probably been responsible for halting its spread. The latter two are native species possibly endemic to central Queensland, although *S. brigalowensis* has been indicated as occurring widely in southern Queensland on fertile soils sometimes in association with brigalow scrub (T. Bean, pers. comm.). A few of the other species, although listed in this survey for central Queensland only, have been recorded elsewhere, for example, *Abelmoschus ficulneus* in northern NSW and *Trianthema portulacastrum* in southern Queensland, both at very low abundance levels (Rew *et al*. 2005).

For the most common weeds of northern NSW and southern Queensland, the incidences were often higher for northern NSW. All were winter species reflecting the cooler conditions and increased winter cropping opportunities in the more southern parts of the region. Jones *et al*. (2000) identified *Avena* spp. and *R. raphanistrum* as major weeds of both the southern and western Australian grain production regions, and listed *F. convolvulus*, *P. paradoxa* and *P. aviculare* as major weeds within the southern region. In the postal survey component of the same study, Alemseged *et al*. (2001) listed *Avena* spp. and *R. raphanistrum* as two of the top three most nationally widespread and abundant weeds of winter grain production. Many of these common weeds of northern NSW and southern Queensland have been recorded in past surveys for the same areas. All five weeds listed above have been recorded as moderate to major weeds in the surveys of Jones *et al*. (2000) and Rew *et al*. (2005). All except *R. raphanistrum* have been recorded in the surveys of Martin *et al*. (1988), Wicks *et al*. (2000) and Walker *et al*. (2005). However, although the survey of Felton *et al*. (1994) listed all five weeds, they reported *R. raphanistrum* and *P. paradoxa* as minor compared with the other three weeds. It is evident that populations of *R. raphanistrum* are increasing in the north-eastern grain region. Further, all of these weeds, with the exception of *P. aviculare*, have populations within the region that have developed herbicide resistance within the past 10 years (O'Donnell *et al*. 2002).

Across the region, the number of summer weed genera was greater than for winter weeds. There were also more summer genera in the two Queensland zones compared with northern NSW, although the number of genera in winter crops was similar for all zones. Some of this may reflect the timing of the survey, when prevalent weeds in paddocks at the time would have been summer germinating. Also, these differences are potentially a reflection of the climate, with summer weeds dominating where the majority of the annual rainfall is received

during summer and conditions are warmer. In addition, more weed genera were recorded for fallows than in crops. This may be due to weeds being more visible during fallow, and that crops offer competition, hence restricting the presence of some less competitive weed species.

The seasonal range and wide diversity of weeds present in the north-eastern grain region show that many growers in this region have a large suite of weeds to deal with, both within and across seasons. Coupled with the diversity in cropping options and systems technology, such as differences in tillage systems, good weed management planning is complicated and critical to business success. A single weed management practice is generally not sufficient to provide effective broad spectrum control, and north-eastern grain growers need to be armed with a range of management options to cover the suite of weeds they are likely to encounter.

Weed management

A range of weed management practices was used across the region. Herbicides played a vital role in all cropping systems and the use of knock-downs and post-emergence type products was generally greater than the use of residual and pre-emergence based products. Forty-nine herbicides and mixes were recorded as commonly used treatments. Non-chemical methods, such as grazing, tillage and crop competition were also utilised, but the degree of use and, therefore, importance of each practice varied across the region and within components of the cropping system. Irrespective of importance, a range of practices and options within the practices is needed to manage the diverse weed flora.

Knock-down and post-emergence herbicides were the most commonly used weed control tools in fallows and wheat crops, whereas pre-emergence herbicides were more important in chickpea and sorghum crops. Growers were also more likely to use tillage in fallow rather than residual herbicides, and tillage was most likely used for escapes and hard to control species. The reluctance to use residuals during the fallow was possibly owing to growers wishing to maintain re-cropping flexibility.

The data showed that about a third of growers in the region regularly practised conventional tillage. A zonal trend existed for the use of zero or minimum tillage, with more growers in central Queensland tending to operate under reduced tillage systems, which reflects the fragility and vulnerability of the soils when exposed to short but intense summer storms often experienced in that part of the region. Stubble retention through minimum tillage helps protect the soil and assists by increasing water capture and reducing run-off and erosion. Thomas *et al*. (1997) predicted that the use of conservation tillage and the replacement of tillage with herbicides would increase in the north-eastern grain region. Our data suggests that there has been little increase in the use of reduced tillage since then. It is possible that reduced tillage practices have not increased in part owing to the development or threat of herbicide resistance, with some growers continuing to utilise cultivation in lieu of some herbicides to control weed survivors.

The use of grazing on fallows was limited and confined to the more southern and most northern areas of the region, where livestock, sheep and cattle in the south or cattle in the north are a major component of farming systems. The lack of grazing reported for southern Queensland could possibly reflect the value of prime cropping land and that livestock enterprises are probably kept separate to cropping.

Few growers across the region were adopting crop competition as a tool for weed management. The only evidence of the utilisation of crop competition existed in wheat, where 17–20% of growers used high seeding rates, which has been shown to improve weed control in this region (Walker *et al*. 2001, 2002*b*). In contrast, no chickpea growers utilised crop competition, probably because it is not a competitive crop (Whish *et al*. 2002), and only 5–11% of sorghum growers planted at higher than average seeding rates. Although the survey did not question crop row spacing, this attribute is still important. As practices within the region move towards wider row cropping systems, the value of crop competition for weed management purposes could be lost.

In both summer and winter fallows, there was a very high reliance on glyphosate, applied either alone or in mixes, with some differences in mix partners evident among the zones. In central Queensland, the glyphosate mix partners were restricted to 2,4-D amine and metsulfuron methyl, whereas dicamba, triclopyr, fluroxypyr, oxyfluorfen, atrazine and tribenuron were used as well as 2,4-D and metsulfuron methyl in southern Queensland and northern NSW. These differences are likely owing to differences in the fallow flora and economics. For example, the more difficult to control species such as *Cucumis* spp. and *Citrullus lanatus* were found more in the southern areas than in central Queensland. As well, the zonal differences in glyphosate mix partners may reflect the willingness to use residual herbicides and to use more expensive herbicides in areas with more reliable cropping and rotations. Some growers used non-glyphosate fallow treatments such as metsulfuron methyl, 2,4-D amine and triclopyr possibly for paddocks that had only broadleaf weeds. A few growers in northern NSW also used paraquat alone or in mixes with diquat as an alternative to glyphosate, which is likely owing to the presence of glyphosate resistant *Lolium rigidum* populations in that area (Storrie and Cook 2002).

In wheat, the most widely grown crop in the region, significantly more pre-emergence herbicides were used in northern NSW compared with central and southern Queensland. This reflects the greater use of chlorsulfuron in northern NSW, where crop rotations with summer crops were less likely, so re-cropping restrictions were less of an issue. Similarly, more graminicides were used in northern NSW than southern Queensland, and none were used in central Queensland, which was a direct reflection of the incidence of winter grass species. There were no winter grasses in central Queensland, and northern NSW had more winter grass species than southern Queensland.

In chickpeas, graminicides were not used in central Queensland. Again more graminicides were used in this crop in northern NSW compared with southern Queensland, reflecting the level of importance of the winter grass weeds in the southern areas. Less pre-emergence herbicide (simazine) was used in central Queensland compared with the areas further south. The more southern areas were less likely to double crop or rotate to summer crop, so residues were not an issue. The inclusion of

metsulfuron methyl in central Queensland chickpea crops reflected a pre-harvest desiccation use.

Differences in weed management in sorghum were also noted across the region. Like chickpea, more pre-emergence herbicides, mainly atrazine, were used in the southern areas compared with central Queensland. This could be due to the greater importance of summer grasses in the southern systems. Although *Brachiaria eruciformis* was a common weed of sorghum in central Queensland, it was less important relative to the broadleaf weeds. Further, many central Queensland growers will not apply herbicides in sorghum until weeds emerge, and, therefore, atrazine is generally applied as a post-emergence treatment. Metolachlor was also used in the southern Queensland and northern NSW for improved residual control of summer grasses. Inter-row cultivation for weed control was used less in central Queensland, and again this is likely a reflection of the greater degree of minimum or zero tillage being undertaken in the north due to vulnerability of soils under intense storm activity.

Implications for herbicide resistance

Despite the great diversity of weeds and cropping systems, and the large range of weed management tools used, herbicide resistance to several herbicides has been recorded in 10 weed species in southern Queensland and northern NSW (Adkins *et al*. 1997; O'Donnell *et al*. 2002; Storrie and Cook 2002; Storrie and Walker 1999). Six broadleaf weeds, *Rapistrum rugosum*, *Fallopia convolvulus*, *Sisymbrium thellungii*, *Sonchus oleraceus*, *Sisymbrium orientale* and *Sinapsis arvensis* developed resistance to sulfonylurea herbicides in areas that grew predominantly wheat and used chlorsulfuron extensively and repeatedly from the mid 1980s to the mid 1990s. Since then, the use of chlorsulfuron appears to have reduced, although metsulfuron methyl is used widely but often mixed with herbicides with a different mode of action. In the grasses, populations of *Avena* spp. and to a lesser extent *Phalaris paradoxa* were resistant to aryloxyphenoxy propanate (fop) and in some cases, cyclohexanedione (dim) herbicides. These weeds developed resistance in paddocks that grew predominantly wheat and winter pulses, and relied greatly on these herbicides. A few populations of *Urochloa panicoides* developed resistance to atrazine in paddocks that grew predominantly sorghum, and some *Lolium rigidum* populations in northern NSW have developed resistance to glyphosate that was repeatedly applied during the winter fallow.

Herbicide resistance has not been recorded as yet in central Queensland. Chlorsulfuron was not used extensively or repeatedly in the majority of this cropping zone, and fop or dim herbicides were rarely used. Although atrazine was used widely, it was generally applied as a post-emergence option and often under hot and dry conditions. Thus, herbicide efficacy was frequently compromised particularly for grasses in this environment, hence reducing the selection pressure for development of atrazine resistance.

The extent of herbicide resistance and number of resistant weed species are likely to increase in the north-eastern grain region (Walker *et al*. 2002*a*, 2004). Even with the many management options and herbicides used, some weeds are still exposed to a strong selection pressure for resistance to some important herbicides. The main ones are winter grasses to the Group A (inhibitors of acetyl coenzyme A carboxylase) herbicides such as clodinafop and fenoxaprop in southern Queensland and northern NSW; a variety of broadleaf weeds to Group B (inhibitors of acetolactate synthase) herbicides, particularly for metsulfuron methyl, which was frequently applied in winter crops and fallows in central Queensland; and summer and winter grasses to Group M (inhibitors of 5-enolpyruvylshikimate-3-phosphate synthase) herbicides, particularly for glyphosate, across all cropping zones. Some growers have adapted their management practices to avoid herbicide resistance, such as use of tillage and rotation of herbicides with different modes of action. This is possibly why a greater diversity of weed management tools was used in southern Queensland and northern NSW, the area with current resistance problems and risks for further development in both area and number of weed species.

Conclusions and recommendations

Grain growers in north-eastern Australia grow a range of crops during both summer and winter and thus have to contend with multi-suites of weeds at any given time. The diverse weed flora tends to change from predominantly summer species in the northern parts of the region to mostly winter species, reflecting the climate change from subtropical to temperate. Cropping systems also change, reflecting the differences in climate with summer cropping under zero or reduced till more dominant in the north and winter cropping more dominant in the south.

Herbicides are, and are likely to continue to be, the mainstay for weed management, although some other tools are also being used to a limited extent. More weed management practices are utilised in the middle to southern zones of the region, whereas the northern zone relies nearly solely on herbicide, which is likely to reflect the current extent of herbicide resistance across the region. However, it is evident from this survey that an integrated weed management approach is not being implemented across the whole cropping system. Thus, herbicide resistance is likely to continue to develop in more weeds and increase in area.

Growers need to review their management practices to maximise weed control efficacy for the multi-suites of weeds present, and not just the few dominant species. As well as optimising herbicide performance and rotating between herbicides with different modes of action, management strategies need to include tactics to limit the replenishment of the weed seed-bank, such as use of tillage in fallow and wide row crops, growing all crops more competitively, and use follow-up herbicides to kill survivors. This is particularly important to conserve the weed susceptibility to glyphosate, which plays a major role in fallow weed control in conservation farming systems.

Although growers in the north-eastern grain region have much to contend with in respect to weed management, they cannot afford to become complacent, particularly those in central Queensland who are yet to experience herbicide resistance. Monitoring of weed control efficacy, managing weed populations across the whole cropping systems, and the ability to modify and focus management in response to changes in

weed dynamics and to herbicide resistance threats are the keys to successful weed management.

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References

Adkins SW, Wills D, Boersma M, Walker SR, Robinson G, McLeod RJ, Einam JP (1997) Weeds resistant to chlorsulfuron and atrazine from the north-east grain region of Australia. *Weed Research* **37**, 343–349. doi:10.1046/j.1365-3180.1997.d01-56.x

Alemseged Y, Jones RE, Medd RW (2001) A farmer survey of weed management and herbicide resistance problems of winter crops in Australia. *Plant Protection Quarterly* **16**, 21–25.

Australian Bureau of Statistics (2001) IRDB (Integrated Regional Database, Australia). [CD-ROM] Product Number 1353.0 (Australian Bureau of Statistics: Canberra)

Charles GW (1991) A grower survey of weeds and herbicide use in the New South Wales cotton industry. *Australian Journal of Experimental Agriculture* **31**, 387–392. doi:10.1071/EA9910387

Felton WL, Wicks GA, Welsby SM (1994) A survey of fallow practices and weed floras in wheat stubble and grain sorghum in northern New South Wales. *Australian Journal of Experimental Agriculture* **34**, 229–236. doi:10.1071/EA9940229

Jones R, Alemseged Y, Medd R, Vere D (2000) The distribution, density and economic impact of weeds in the Australian annual winter cropping system. CRC for Weed Management Systems, Technical Series No. 4, Adelaide.

Martin RJ (1983) Population dynamics of weeds in cropping systems in northern New South Wales. In 'No-tillage crop production in northern NSW – Proceedings of the project team meeting, Agricultural Research Centre, Tamworth 4 May 1983'. (Eds RJ Martin, WL Felton) pp. 90–99. (Department of Agriculture NSW: Tamworth)

Martin RJ, McMillan MG, Cook JB (1988) Survey of farm management practices of the northern wheat belt of New South Wales. *Australian Journal of Experimental Agriculture* **28**, 499–509. doi:10.1071/EA9880499

Matthews JM (1994) Management of herbicide resistant weed populations. In 'Herbicide resistance in plants – biology and biochemistry'. (Eds SB Powles, JAM Holtum) pp. 317–335. (CRC Press: Boca Raton, FL)

Medd RW (1997) Biological change: weeds. In 'Sustainable crop production in the sub-tropics – an Australian perspective'. (Eds AL Clarke, PB Wylie) pp. 131–149. (Queensland Department of Primary Industries: Brisbane)

Medd RW, Martin RJ, Felton WL (1995) Herbicide tolerant crops: opportunities and concerns for the summer rainfall grain belt in Australia. In 'Herbicide resistant crops and pastures in Australian farming systems'. (Eds GD McLean, G Evans) pp. 139–158. (Bureau of Resource Sciences, DPIE: Canberra)

Niknam SR, Moerkerk M, Cousens R (2002) Weed seed contamination in cereal and pulse crops. In 'Proceedings of the 13th Australian weeds conference'. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 59–62. (Plant Protection Society of WA: Perth)

O'Donnell CC, Adkins SW, Walker SR (2002) Herbicide resistance in the northern grain region of Australia: developments in research from 1993 to present. In 'Proceedings of the 13th Australian weeds conference'. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 617–619. (Plant Protection Society of WA: Perth)

Preston C (2000) Herbicide mode of action and herbicide resistance. In 'Australian weed management systems'. (Ed. BM Sindel) pp. 209–225. (RG and FJ Richardson: Melbourne)

Rew LJ, Medd RW, Van der Ven R, Gavin JJ, Robinson GR, Tuite M, Barnes J, Walker S (2005) Weed diversity and abundance on farms in the sub-tropical grain region of Australia. *Australian Journal of Experimental Agriculture* **45**, 711–723. doi:10.1071/EA03273

Spackman GB, Garside AL (1995) Major factors affecting crop production in central Queensland and their implications for sustainable grain farming systems. Grains Research and Development Corporation, Canberra.

Storrie A, Cook T (2002) Glyphosate resistance in northern New South Wales – a growing concern. In 'Proceedings of the 13th Australian weeds conference'. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 601–604. (Plant Protection Society of WA: Perth)

Storrie A, Walker S (1999) Coping with the threat of herbicide resistance in weeds. In 'Proceedings of the 2nd national conservation farming and minimum tillage conference'. (Ed. M Burgis) pp. 39–42. (Conservation Farmers Inc.: Toowoomba, Qld)

Thomas GA, Felton WL, Radford BJ (1997) Tillage and crop residue management. In 'Sustainable crop production in the sub-tropics – an Australian perspective'. (Eds AL Clarke, PB Wylie) pp. 195–213. (Queensland Department of Primary Industries: Brisbane)

Tow PG, Schultz JE (1991) Crop and pasture sequences. In 'Dryland farming – a systems approach: an analysis of dryland agriculture in Australia'. (Eds V Squires, P Tow) pp. 55–75. (Sydney University Press: Sydney)

Walker SR, Robinson GR, Medd RW (2001) Management of *Avena ludoviciana* and *Phalaris paradoxa* with barley and less herbicide in subtropical Australia. *Australian Journal of Experimental Agriculture* **41**, 1179–1185. doi:10.1071/EA01002

Walker S, Osten V, Storrie A, Robinson G, Cook T, Galea K (2002*a*) Weeds at risk of developing herbicide resistance in the different cropping systems of the northern region. In 'Proceedings of the 13th Australian weeds conference'. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 620–621. (Plant Protection Society of WA: Perth)

Walker SR, Medd RW, Robinson GR, Cullis BR (2002*b*) Improved management of *Avena ludoviciana* and *Phalaris paradoxa* with more densely sown wheat and less herbicide. *Weed Research* **42**, 257–270. doi:10.1046/j.1365-3180.2002.00283.x

Walker S, Widderick M, Storrie A, Osten V (2004) Preventing glyphosate resistance in weeds of the northern grain region. In 'Proceedings of the 14th Australian weeds conference'. (Eds B Sindel, S Johnson) pp. 428–431. (Weed Society of NSW: Wagga Wagga)

Walker SR, Taylor IN, Milne G, Osten VA, Hoque Z, Farquharson RJ (2005) A survey of management and economic impact of weeds in dryland cotton cropping systems of subtropical Australia. *Australian Journal of Experimental Agriculture* **45**, 79–91. doi:10.1071/EA03189

Webb AA, Grundy MJ, Powell B, Littleboy M (1997) The Australian sub-tropical cereal belt: soils, climate and agriculture. In 'Sustainable crop production in the sub-tropics – an Australian perspective'. (Eds AL Clarke, PB Wylie) pp. 8–23. (Queensland Department of Primary Industries: Brisbane)

Whish JPM, Sindel BM, Jessop RS, Felton WL (2002) The effect of row spacing and weed density on yield loss of chickpea. *Australian Journal of Agricultural Research* **53**, 1335–1340. doi:10.1071/AR01168

White PCL, Jennings NV, Renwick AR, Barker NHL (2005) Questionnaires in ecology: a review of past use and recommendations for best practice. *Journal of Applied Ecology* **42**, 421–430. doi:10.1111/j.1365-2664.2005.01032.x

Wicks GA, Felton WL, Murison RD, Martin RJ (2000) Changes in fallow weed species in continuous wheat in northern New South Wales, 1981–1990. *Australian Journal of Experimental Agriculture* **40**, 831–842. doi:10.1071/EA99105

Widderick M (2002*a*) Common sowthistle – understanding its ecology is the key to better management. Queensland Department of Primary Industries, Crop Link Weed Update Information Series, Q102046, Agdex No. 642 2002, Brisbane

Widderick M (2002*b*) Ecology and management of the weed common sowthistle (*Sonchus oleraceus*). PhD thesis, University of New England, Armidale, Australia.

Widderick M, Sindel B, Walker S (2002) Emergence of *Sonchus oleraceus* (common sowthistle) is favoured under zero tillage farming systems. In 'Proceedings of the 13th Australian weeds conference'. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 91–92. (Plant Protection Society of WA: Perth)

Wilson BJ, Hawton D, Duff AA (1995) 'Crop weeds of northern Australia.' (Queensland Department of Primary Industries: Brisbane)

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Appendix 1. An abbreviated version of the questionnaire sent to growers with some typical responses in italics

Other information was also sought but not presented in this paper. Agronomists were sent a similar questionnaire requesting information relating to a typical farm in their nominated shire

Q1. What are the crops grown on your farm? How often is each crop likely to be grown on a paddock over a typical 5-year period?

Crop	Years grown over 5 years
Wheat	*4*
Barley	*1*
Chickpea	*0*

Q2. Please indicate how often each of the following farming practices are likely to be used in your main crops. Please use the following numbers: 0 = rarely; 0–1 = sometimes but not regularly; 1 = regularly (once per crop).

Farming practice	Crop 1: *Wheat*	Crop 2: *Barley*	Crop 3: *Chickpea*
Pre-emergent herbicides	*0–1*	*0–1*	*1*
Post-emergent herbicides	*1*	*0–1*	*0–1*
Sowing rates higher than district average	*0–1*	*0*	*0*
Inter-row cultivation	*0*	*0*	*1*

Q3. Please complete the following table for your main weeds growing in those crops that you listed in Q2.

Main weeds	Crop	Main herbicides and mixtures used for each weed and crop (list in order of importance)
Wild oats	*Wheat*	*Topik*
Turnip weed	*Wheat*	*Mataven*
	Barley	*Achieve*
	Chickpea	*Verdict*
	Wheat	*Tordon242*

Q4. Please indicate how often each of the following farming practices are likely to be used in your fallows. Please use the following numbers: 0 = rarely; 0–1 = sometimes but not regularly; 1 = regularly; 1+ = more than once per fallow.

Farming practice	Summer fallow	Winter fallow
Residual herbicides (e.g. Flame, atrazine)	*0*	*0–1*
Knockdown herbicides (e.g. glyphosate, 24D)	*1*	*1*
Cultivation	*0*	*0*
Grazing	*0*	*0*

Q5. Please complete the following table for your main weeds in each fallow.

Main weeds (or group of weeds sprayed with same herbicide or mixrure	Fallow		Main herbicides and mixtures normally used for each weed and fallow (list in order of importance)
	Summer	Winter	
Sowthistle	√	√	*GlyphosateCT + Ally*
Barnyard grass	√		*GlyphosateCT alone*