Weed species richness, density and relative abundance on farms in the subtropical grain region of Australia


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Abstract. Weed management is one of the most important economic and agronomic issues facing farmers in Australia’s grain regions. Weed species occurrence and abundance was monitored between 1997 and 2000 on 46 paddocks (sites) across 18 commercial farms located in the Northern Grain Region. The sites generally fell within 4 disjunct regions, from south to north: Liverpool Plains, Moree, Goondiwindi and Kingaroy. While high species richness was found (139 species or species groups), only 8 species occurred in all 4 regions and many (56 species) only occurred at 1 site or region. No species were observed at every site but 7 species (Sonchus spp., Avena spp., Conyza spp., Echinochloa spp., Convolvulus erubescens, Phalaris spp. and Lactuca serriola) were recorded on more than 70% of sites. The average number of species observed within crops after treatment and before harvest was less than 13. Species richness tended to be higher in winter pulse crops, cotton and in fallows, but overall was similar at the different sampling seasons (summer v. winter). Separate species assemblages associated with the Goondiwindi and Kingaroy regions were identified by correspondence analysis but these appeared to form no logical functional group. The species richness and density was generally low, demonstrating that farmers are managing weed populations effectively in both summer and winter cropping phases. Despite the apparent adoption of conservation tillage, an increase in opportunity cropping and the diversity of crops grown (13) there was no obvious effect of management practices on weed species richness or relative abundance. Avena spp. and Sonchus spp. were 2 of the most dominant weeds, particularly in central and southern latitudes of the region; Amaranthus spp. and Raphanus raphanistrum were the most abundant species in the northern part of the region. The ubiquity of these and other species shows that continued vigilance is required to suppress weeds as a management issue.

Introduction

Weeds have been identified by farmers in all 3 major grain-growing regions of Australia as their single most important land management issue (Alemseged et al. 2001). One of these regions, the Northern Grain Region (NGR), covers the subtropical cropping areas of northern NSW, north of 32°S latitude, and Queensland. It has summer-dominant but variable rainfall, a hot climate and naturally fertile soils. The rainfall pattern provides the basis for both summer and winter crops to be grown in rotations (Webb et al. 1997). The environment favours an extensive weed flora with over 50 species listed as being a problem by farmers (Martin et al. 1988), while Felton et al. (1994) recorded over 100 species in a summer survey of commercial paddocks, and Wicks et al. (2000) recorded 80 weed species on 4 sites when comparing fallow management treatments.

Historically, growers in the NGR have predominantly used a bread wheat (Triticum aestivum)–sorghum (Sorghum bicolor) rotation, producing 2 crops in 3 years, with fallow periods varying from 6 to 18 months between crops. While this approach has provided reliable disease and weed control, it can result in wasteful water management (Hayman et al. 1996). Opportunity cropping, which involves sowing a crop whenever soil water reserves are adequate, has been suggested as a better alternative (e.g. Hayman et al. 1996). Consequently, farming systems in the region have diversified considerably with an increase in the range of summer and winter crops grown (Cooper 1999). Nevertheless, bread
The reported work had the objective of monitoring weeds in the NGR concentrated on fallow weeds and did not require future research. Previously, many weed studies associated control problems is needed to identify areas under the realisation that a better understanding of the weed species and assemblages and increasing complexity of weed management in cropping programs and the timing of operations.

Furthermore, the growth and maturation of weeds under the subtropical conditions is rapid. Many species have staggered recruitment patterns and this in conjunction with short life cycles increases the chances of weeds surviving to maturity and producing seeds. Limiting seed production of weed escapes is now recognised as a key goal of weed management programs (Jones and Medd 2000; Medd 1997), and adds emphasis to the planning of weed management programs and the timing of operations.

The study reported here arose from concerns about the increasing complexity of weed management in cropping systems in the NGR, and the realisation that a better understanding of the weed species and assemblages and associated control problems is needed to identify areas requiring future research. Previously, many weed studies in the NGR concentrated on fallow weeds and did not fully reflect the complexity of on-farm weed problems. The reported work had the objective of monitoring weeds on commercial paddocks in the NGR, through winter and summer cropping as well as fallow cycles for over 3 years, to obtain a better understanding of the weed species spectrum and abundance.

Materials and methods

Location of sites

Paddocks on 18 farms were monitored in 4 disjunct regions of the NGR, 8 on the Liverpool Plains (L); 3 south of Moree (M), 4 north of Goondiwindi (G) and 3 south of Kingaroy (K), from May 1997 until July 2000. These 4 disjunct regions of the NGR are referred to as regions hereafter. A total of 3 paddocks were sampled on each of the collaborating L and M properties, with 1 paddock in each part of the notional wheat–sorghum and long fallow rotation. The exception was 1 M farm where 4 paddocks were sampled. In the G region participating farmers followed a more continuous winter cereal regime, whereas a more opportunistic and multiple cropping regime was monitored on the participating K farms. A total of 2 paddocks per farm were sampled in the G region and on 1 of the K farms. At the 2 remaining K farms, only 1 paddock per farm was assessed. There was a total of 46 paddocks (sites) sampled overall. The L, M and G sites were located on predominately deep heavy grey vertisols (cracking clays) and the K sites on strongly structured red krasnozem or euchrozem soils.

Sampling scheme

At each site, parallel transects located 20 m apart were established. Each transect was 100 m long, with 4 permanent quadrats (10 x 1 m) placed at 20-m intervals along each transect. At the L and M sites 4 such transects were used (providing 16 quadrats), while only 3 transects were established at the G and K sites, giving 12 quadrats. To ensure accurate and easy repositioning of transects, distances from static landmarks (e.g. fence posts, trees) were generally recorded, along with grid coordinate readings from differential global positioning systems (DGPS, Magellan GPS Systems, Australia).

Weeds were identified and individual species densities assessed within each 10 m² quadrat using a scoring system involving 8 categories (Table 1). This involved visually estimating the density of each species within a quadrat and assigning it a score. A more detailed description of the scoring system and its validation is given by Rew et al. (2000). Species nomenclature follows the Flora of NSW (Harden 1990, 2002), and several handbooks were consulted to aid identification in the field.

Quadrats at all sites were assessed 2–3 times during the cropping phase, within 6–8 weeks of sowing (post-sowing) and again 1–3 weeks before harvest (pre-harvest). If post-emergence herbicides were applied to the crop, an assessment was made 4 weeks after application of herbicides.

<table>
<thead>
<tr>
<th>Score category</th>
<th>Range (plants/10 m²)</th>
<th>Mid-range density (plants/10 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>1–6</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>7–20</td>
<td>14.5</td>
</tr>
<tr>
<td>3</td>
<td>21–60</td>
<td>40.5</td>
</tr>
<tr>
<td>4</td>
<td>61–190</td>
<td>125.5</td>
</tr>
<tr>
<td>5</td>
<td>191–600</td>
<td>400.5</td>
</tr>
<tr>
<td>6</td>
<td>601–6000</td>
<td>3300.0</td>
</tr>
<tr>
<td>7</td>
<td>&gt;6000</td>
<td>10000.0</td>
</tr>
</tbody>
</table>

Table 1. Scoring system used for estimating weed density of species observed within 10 m² quadrats and the assigned mid-range density value used in data analysis.
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Table 2. Number of sites sown to different crops and sampled for weeds during May 1997–July 2000

<table>
<thead>
<tr>
<th>Crop</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bread wheat</td>
<td>18</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Barley</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Faba bean</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Chickpea</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Canola</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Oats</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Summer crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>8</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Mungbean</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Soybean</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maize</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Cotton</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Nary bean</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Values in parentheses are sites sown to crops but not sampled for weeds in that year. Year represents the year in which the crop was sown but not necessarily harvested.

Results

Overall, 13 different crops were grown in the 46 sites spanning the 4-regions, though many were sown infrequently and not all were sampled (Table 2). Bread wheat was the most frequently sown winter crop followed by durum wheat. Sorghum was the most frequently sown summer crop.

At least 157 taxa were recorded across all the sites. Some species were grouped at a generic level due to difficulties in determining specific identification at the seedling stage. These are reported as genus followed by spp. for: *Avena fatua* and *A. ludoviciana*; *Echinocloa crus-galli* and *E. colona*; *Epilobium hoopesianum* subsp. *cinerium* and *E. hirtigerum*; undetermined *Euphorbia* species and *Chaenomys drammondii*; undetermined *Echithontium/Gamochaeta* species; *Lepidium species* and *L. bonariense; Medicago* minima and *M. polymorpha var. vulgaris* and undetermined *Medicago* species; *Polygonum aviculae* and *P. patulam; Sonchus asper* and *S. oleraceus*; *Sisymbrium officinale, S. orientale* and *S. thellungi*; and undetermined *Veronica* species and *V. peregrine*. Thirteen volunteer crops were recorded and included in the weed list, namely barley, chickepea, cotton, faba bean, maize, mungbean, nary bean, oats, sorghum, soybean, sunflower, bread wheat and durum wheat — the last 2 crops being grouped since they were difficult to distinguish. Including the unknown category, the resulting condensed list of 139 species or generic groups (Appendix 1), are hereafter referred to as species.

Species richness

Weed species diversity/richness for the entire study period was highest in L with 111 species, whilst 71 species were recorded at M, 62 in G and the least diverse was K with 27 species. In all regions the richness consisted of species that were recorded only in a region (56 species) or species that occurred in 2 (43 species), 3 (32 species) or all 4 regions (8 species) namely: *Amaranthus spp., Avena spp., Lamium amplexicaule, Raphanus raphanistrum, Rapistrum rugosum, Sonchus spp., Urochloa paniculodes* and volunteer wheat (durum and winter wheat were grouped) (Table 3).
Table 3. Species richness (number of species) recorded in each region (L, Liverpool Plains; M, Moree; G, Goondiwindi; K, Kingaroy) during May 1997–July 2000

The number of species occurring in a region is indicated in italics; where a species occurred in 2 or more regions it is included in each cell.

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>M</th>
<th>G</th>
<th>K</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of species recorded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>only in a single region</td>
<td>33</td>
<td>4</td>
<td>12</td>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td>to 2 regions</td>
<td>24</td>
<td>24</td>
<td>11</td>
<td>11</td>
<td>56</td>
</tr>
<tr>
<td>to 3 regions</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>to 4 regions</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Ubiquitous species</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>32</td>
</tr>
<tr>
<td>Total</td>
<td>111</td>
<td>70</td>
<td>62</td>
<td>27</td>
<td>139</td>
</tr>
</tbody>
</table>

The mean number of species in any region for a site at any time was less than 10 and declined, as did variability, from south (L) to north (K), when averaged across sampling times (Fig. 1a). Species richness tended to be greater in winter pulse crops, cotton and fallows than other crops (Fig. 1b), and the richness of the weed floras recorded in winter was marginally greater and more diverse than that recorded in summer periods (Fig. 1c).

Similarly, species density was highly skewed and mostly below 17 plants/m² in L, M and G regions and mostly below 10 plants/m² in all crops (Fig. 1d and e). Mean density was <10 plants/m² in the M region, slightly higher in the L (14) and G (16) regions and about 52 plants/m² in the K region because of high densities in some bread wheat crops. Sorghum, cotton and the summer pulse crops tended to have lower weed densities than the other crops (Fig. 1e). Thus mean weed densities observed during the winter seasons were slightly higher than those recorded during summer (Fig. 1f).

Correspondence analysis — site and species separation

Eigenvalues of λ₁ = 0.458, λ₂ = 0.345, λ₃ = 0.208, λ₄ = 0.189 and λ₅ = 0.176 were calculated for the first 5 ordination axes of the CA, with the remaining eigenvalues declining slowly. Plots of the site scores for the first 2 axes of the CA clearly show separation of the regions into 3 distinct groups, LP/M, G and K (Fig. 2). The strong separation on these 2 axes into 3 regional groupings can be attributed in part to those species that are unique to a region or that occur infrequently. The corresponding plot of the species scores (Fig. 3) demonstrates this point: with species affiliated with the regional groupings, and with a number of species strongly affiliated to the K region and others to the G region over the LP/M region and vice versa.

However, ordination of species is not as clear as for the sites (Fig. 2 v. Fig. 3). Among those separated to the far right of the first ordination axis, 5 species were recorded only in the K region, but other species were recorded in a mixture of regions. The second axis separates some species into the bottom left corner, and 11 of those species were recorded solely in the G region. Another 11 species, which could be considered part of the same cluster, were recorded in a mixture of regions, which always included G, and 2 species that were recorded only in L region. The majority of species for the L and M regions show no separation on a species basis using correspondence analysis, indicating that there is a level of overlap in species occurrence and these species are mainly observed near the origin of the axes (Fig. 3). However, the tabular data reveals that 4 species were recorded only in M and 33 only in the L region (Table 3; Appendix 1).

When species that were unique to a region were excluded from the analysis, as well as species that occurred at fewer than 5 sites (leaving only 65 of the original 139 species), the first 2 axes of the restricted CA still separated the regions in the same way as the full dataset (data not shown). An examination was also undertaken of the next few CA axes, but these revealed no further clear separation of sites and/or species (data not shown), reflecting the magnitude of the corresponding eigenvalues and their slow decline. These results indicate that after accounting for regional differences, there are no dominant gradients accounting for site differences within regions; i.e. there was not dominant effects of tillage, crop rotation, weed management etc.

Relative abundance of species

Due to the regional trends identified in the correspondence analysis, rₐb values were calculated on a regional basis using sites at each sampling time as the sampling unit. Within all regions relative abundance was highly skewed with 75% or more of species having values lower than the mean (Fig. 4). Thus a few species contributed most to rₐb, as indicated by the 10 species with the highest values in each region (Table 4). When combined into 1 group, these 10 most abundant species within each region gave relative abundance scores of 0.48, 0.53, 0.63 and 0.73 for regions L, M, G and K, respectively (Table 4).

Of the 8 species found in all 4 regions, 6 also featured among the highest rₐb values in one or more of the regions. *Avena* spp. and *Sonchus* spp. were in the top 10 highest rₐb values in L, M and G regions, *Lamium amplexicaule* in L and K regions, *Raphanus raphanistrum*, *Coronopus didymus* and...
Amaranthus spp. in the K region, and *Rapistrum rugosum* in the M region (Table 4). Other species with high $r_{ab}$ values in a number of regions included, *Convolulus erubescens* in L, M and K, and *Echinochloa* spp. in L, M and G, *Polygonum* spp. in L and M, and *Phalaris paradoxa* in M and G. Conversely, a few species which were recorded only in one region were also calculated to have high $r_{ab}$ values including, volunteer soybean and *Stachys arvensis* in K, and *Crassula* spp. in L (Table 4), suggesting regional if not local high abundance. Volunteer sorghum and faba bean crop species also had among the 10 highest $r_{ab}$ values in the M region.

The 8 species observed in all regions were also widespread across sites. *Sonchus* spp. were recorded at 94% of sites (Table 5), with $r_{ab}$ values of 0.061, 0.093, 0.172, 0.014 in L, M, G and K, respectively, *Avena* spp. were recorded on 91% of sites with $r_{ab}$ values of 0.069, 0.242, 0.153 and 0.007, for L, M, G and K, respectively (Appendix 1). In all, 33 species occurred in 3 regions, and of these *Echinochloa* spp. were present at 78% of the sites with $r_{ab}$ values of 0.083, 0.039 and 0.144 and *Phalaris paradoxa* on 76% of sites with $r_{ab}$ values of 0.019, 0.068 and 0.065 for L, M and G, respectively. *C. erubescens* was found at 76% of sites ($r_{ab}$ values of 0.024, 0.043 and 0.041 for L, M and K regions), and wind-dispersed species *Conyza* spp., *Lactuca serriola* and *Euchiton/Gamochaeta* species, occurred on 83, 74 and 70% of sites, respectively (G, L and M) but had low $r_{ab}$ values (Appendix 1). A total of 42 species occurred in 2 regions.

**Discussion**

The diverse weed flora identified by this study in the NGR exceeded 139 species. Whilst there was no indication of weed species assemblages due to temporal or management influences, there was an indication of spatial influences. Separate assemblages of a small number of species were identified in the Kingaroy and Goondiwindi regions which both differed from the majority of species that occurred in the Moree and Liverpool Plains regions. Despite this high
species richness, generally only a few species dominated at any 1 site at any single point in time. The main species observed, if not their ubiquity, were similar to those reported from a mail and paddock surveys conducted at wheat harvest by Martin et al. (1988), paddock surveys conducted in the summer by Felton et al. (1994), and mail and field surveys conducted by Alemseged et al. (2001). Alemseged et al. (2001) reported on grain growers’ views of
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Relative abundance/10 m² (log scale)

0.0001 0.001 0.01 0.1

L'pool Plains

Moree

Goondiwindi

Kingaroy

Figure 4. Box plot of species relative abundance within regions (excluding species not recorded in a region, see Appendix 1). The line within each box is the median, the heavy solid line is the mean, the box demarcates the 25th and 75th percentiles, error bars indicate 10th and 90th percentiles and dots are ‘outliers’. Note log scale. L’pool Plains, Liverpool Plains region.

Table 4. Relative abundance (r_ab) ranking of the top 10 species in each region and their combined value over the whole study period, May 1997–July 2000

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Liverpool Plains</th>
<th>Moree</th>
<th>Goondiwindi</th>
<th>Kingaroy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Species</td>
<td>r_ab</td>
<td>r_ab</td>
<td>r_ab</td>
<td>r_ab</td>
</tr>
<tr>
<td>Lamium amplexicaule</td>
<td>0.231</td>
<td>Avena spp.</td>
<td>0.242</td>
<td>Sonchus spp.</td>
<td>0.172</td>
</tr>
<tr>
<td>Echinochloa spp.</td>
<td>0.083</td>
<td>Sonchus spp.</td>
<td>0.093</td>
<td>Avena spp.</td>
<td>0.153</td>
</tr>
<tr>
<td>Avena spp.</td>
<td>0.069</td>
<td>Phalaris paradoxa</td>
<td>0.068</td>
<td>Echinochloa spp.</td>
<td>0.144</td>
</tr>
<tr>
<td>Sonchus spp.</td>
<td>0.061</td>
<td>Medicago spp.</td>
<td>0.048</td>
<td>Sisymbrium spp.</td>
<td>0.130</td>
</tr>
<tr>
<td>Fallopia convolvulus</td>
<td>0.044</td>
<td>Convolvulus erubescens</td>
<td>0.043</td>
<td>Phalaris paradoxa</td>
<td>0.065</td>
</tr>
<tr>
<td>Crassula spp.</td>
<td>0.035</td>
<td>Raphanus raphanistrum</td>
<td>0.042</td>
<td>Cirsium vulgare</td>
<td>0.036</td>
</tr>
<tr>
<td>Convolvulus erubescens</td>
<td>0.024</td>
<td>Echinochloa spp.</td>
<td>0.039</td>
<td>Euphorbia spp.</td>
<td>0.027</td>
</tr>
<tr>
<td>Lactuca serriola</td>
<td>0.023</td>
<td>Sorghum bicolor</td>
<td>0.035</td>
<td>Echimon adiannus</td>
<td>0.024</td>
</tr>
<tr>
<td>Conyza spp.</td>
<td>0.020</td>
<td>Vicia faba</td>
<td>0.034</td>
<td>Solanum nigrum</td>
<td>0.023</td>
</tr>
<tr>
<td>Polygonum spp.</td>
<td>0.020</td>
<td>Polygonum spp.</td>
<td>0.028</td>
<td>Tetragonia tetragonoides</td>
<td>0.019</td>
</tr>
<tr>
<td>Combined r_ab</td>
<td>0.475</td>
<td>0.528</td>
<td>0.623</td>
<td>0.730</td>
<td></td>
</tr>
</tbody>
</table>

the most difficult to control weeds in the NGR which included, Avena spp., Brassica tournefortii, P. patodosa, Sonchus spp., Polygonum aviculare, Lolium rigidum, Fallopia convolvulus, R. raphanistrum, Argemone mexicana and Arctotheca calendula. An earlier mail survey to growers by Martin et al. (1988) had resulted in a similar but not identical list of troublesome weeds, Avena spp., R. rugosum, P. aviculare, P. patodosa, F. convolvulus, Silbum marianum, Carthamus lanatus, Sisymbrium orientale and Lolium spp. Some of the species perceived as the worse problems were reflected in our site ubiquity and relative abundance values for each region, for example Avena spp., P. patodosa, Sonchus spp., P. aviculare, F. convolvulus and R. raphanistrum but others were neither found very frequently nor at high abundance. We observed only L. rigidum, B. tournefortii, C. lanatus and A. ochroleuca at the Liverpool Plains sites, Arctotheca calendula was not recorded at any sites, although it was only ranked as an important weed by 6% of growers (Alemseged et al. 2001). Identification of the different Brassicaceae weeds was found to be poor in a separate survey (L. J. Rew, A. Storrie unpublished data) and is further confused by the use of common names. Because of these anomalies in identification, comparison of the relative importance of these species between the surveys is pointless. In our sampling R. raphanistrum and Sisymbrium species had similar relative
Table 5. Percentage of sites (n = 46) on which particular species occurred during May 1997–July 2000

<table>
<thead>
<tr>
<th>Species</th>
<th>Proportion of sites (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonchus spp.</td>
<td>93.5</td>
</tr>
<tr>
<td>Avena spp.</td>
<td>91.3</td>
</tr>
<tr>
<td>Conyza spp.</td>
<td>82.6</td>
</tr>
<tr>
<td>Echinochloa spp.</td>
<td>78.3</td>
</tr>
<tr>
<td>Crotalaria erubescens</td>
<td>76.1</td>
</tr>
<tr>
<td>Phleum pratense</td>
<td>76.1</td>
</tr>
<tr>
<td>Lactuca serriola</td>
<td>73.9</td>
</tr>
<tr>
<td>Echisten and Gayoehoeota spp.</td>
<td>69.6</td>
</tr>
<tr>
<td>Citron valgate</td>
<td>69.6</td>
</tr>
<tr>
<td>Medicago spp.</td>
<td>67.4</td>
</tr>
<tr>
<td>Raphanus raphanistrum</td>
<td>65.2</td>
</tr>
<tr>
<td>Rupancheira indica</td>
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</tr>
<tr>
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<tr>
<td>Sorghum bicolor</td>
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</tr>
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<td>Fallopia comosulata</td>
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</tr>
<tr>
<td>Urochloa panicoides</td>
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</tr>
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</table>

Only species which occurred on 50% or more sites are listed.

There is no indication in our study of any species shifts having occurred from either the adoption of conservation tillage or opportunity cropping. The correspondence analysis highlighted some regional trends in weed associations but as no further separation of species was readily apparent it can be inferred that particular practices, for example tillage, crop rotation or agrochemical input had no identifiable bearing on the weed flora. Nevertheless, weed assemblages observed in any paddock are purported to result from management practices (tillage, crop rotation, sowing time, row spacing, weed management practices, Buhler 2002). Climate or the introduction of seeds from areas outside the paddock (e.g. as crop seed contamination, on machinery, wind-dispersal) may also influence assemblages. Upon examination, there is nothing especially remarkable about the species assemblages separated by the correspondence analysis. Both the Goondiwindi and Kingaroy groups involved a range of annual and perennials as well as broadleaved and grass species and there appeared to be no

in what ostensibly had been nominated by the participating farmers as sites in a wheat–sorghum rotation. The fact that many farmers appear to be following a more opportunity cropping approach by incorporating information on available soil moisture and market values endorses the work of Hayman et al. (1996) and others, the extension service and decision support models such as ‘Wheatman’ (Woodruff 1992) even though adoption of such models been poor (Hayman and Easdown 2002).

All 13 crop species grown on sites involved in the study were observed as volunteer weeds which is characteristic of the subtropical region. Soybean attained the fifth highest relative abundance value in the Kingaroy region, and sorghum and faba bean were eight and ninth highest in the Moree region. Other than Roundup Ready cotton, which was first grown commercially in the region in 2000 after this study was completed, canola is the only other herbicide tolerant crop presently grown commercially in Australia. Only 1 site in 1 year sowed trazine resistant canola. Should herbicide tolerant crops be more widely adopted in the future, the high abundance of many of the crops as volunteers suggests that they would become a major weed issue in the NGR. Glyphosate resistant varieties would be of particular concern since glyphosate is the main chemical used during the fallow period. This supports the views and reservations about such varieties put forwards by Medd et al. (1995). Already a biotype of L. rigidum resistant to glyphosate has been selected for in the region (Storie and Cook 2002), signalling the problem of over reliance on this herbicide for fallow management.

There is a perception by farmers and researchers that the increased adoption of conservation tillage practices has led to an associated change in the weed spectrum. ‘Shifts in weed flora are part of the folklore of weed science and indeed have taken place throughout agricultural history’ (Medd 1987). There is no indication in our study of any species shifts having occurred from either the adoption of conservation tillage or opportunity cropping. The correspondence analysis highlighted some regional trends in weed associations but as no further separation of species was readily apparent it can be inferred that particular practices, for example tillage, crop rotation or agrochemical input had no identifiable bearing on the weed flora. Nevertheless, weed assemblages observed in any paddock are purported to result from management practices (tillage, crop rotation, sowing time, row spacing, weed management practices, Buhler 2002). Climate or the introduction of seeds from areas outside the paddock (e.g. as crop seed contamination, on machinery, wind-dispersal) may also influence assemblages. Upon examination, there is nothing especially remarkable about the species assemblages separated by the correspondence analysis. Both the Goondiwindi and Kingaroy groups involved a range of annual and perennials as well as broadleaved and grass species and there appeared to be no

abundance overall, R. ragosum was lower and B. tournefortii the lowest.

Felton et al. (1994) surveyed 65 uncultivated fallow and 25 sorghum paddocks during the summer of 1989 and observed 87 and 51 different species, respectively. In their study, C. erubescens, E. crus-galli, U. panicoides, Panicum decompositum, Conyza spp. and S. oleraceus were the most ubiquitous, observed in more than 50% of fallow paddocks; C. erubescens, E. crus-galli, U. panicoides, P. decompositum, Hibiscus trionum, Portulaca oleracea, P. aviculare, Tribulus spp., Xanthium spinosum, Avena spp. and Eragrostis cilianensis were most ubiquitous (more than 50%) in sorghum paddocks. All of these species were observed at more than 50% of the sites.

About 2 decades ago almost half of farmers in the southern part of the NGR followed a continuous wheat rotation, one third a wheat–sorghum rotation and about one-fifth a wheat–legume rotation (Medd et al. 1995 based on Martin et al. 1988). The general perception in the mid to late 1990s was that more farmers in the NGR region were aiming for a wheat–sorghum and long fallow rotation, growing 2 crops over 3 years. However, adhering to any rotation is often thwarted by climatic and economic volatility (Martin et al. 1988), as found in our study. A change towards more opportunity cropping and/or diverse cropping sequences is apparent given the 7 winter crops and 6 summer crops grown
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functional relationship within the species groups in terms of their seasonality.

Felton et al. (1994) found that weed density and species richness was generally lower in fallow paddocks that had been treated with herbicide (glyphosate and/or atrazine) compared with fallows where tillage was practiced. While we found no evidence of cultural influences on the fallow flora, there was an indication of higher species diversity in fallows. Canadian experience has shown that weed spectrum changes cannot be related to tillage practices alone (Derksen et al. 1993). Subsequently Leeson et al. (2000) found that cropping history had the largest influence on weed communities from a survey of 28 farms and about 300 commercial fields sampled in Saskatchewan; herbicide had the second largest impact on weed species assemblages. Thus, numerous site-specific factors need to be considered before the weed assemblages or changes to assemblages can be fully explained.

Despite the diversity of management practices underlying our study the average number of species observed in a site over the study period was about 6 at any sampling time, varying slightly among regions and crops; and the median number of species observed at any sampling time was between 4 and 8 depending on the crop and sampling period. Most sites had some form of crop rotation that involved both summer and winter crops; farms in the Goondiwindi region were the exception in tending to grow wheat repeatedly. Doucet et al. (1999) asserted that crop rotation is generally perceived to reduce weed density and maintain species richness, thus preventing dominance of a few weeds, which is a possible explanation for the high species richness and generally low weed abundance observed in this study. In the NGR rainfall can occur all year around but much falls in summer storms and most rain events result in flushes of weeds. Separating the data into summer or winter crops, to differentiate species which germinate in fallows. Canadian experience has shown that weed flora, there was an indication of higher species diversity or cultural/management practices adopted, some species will have potential to benefit and become dominant in different crops and seasons.

Acknowledgments

Many thanks to all of the farmers who collaborated with this project and to John Hosking and Andrew Storrie at Tamworth Agricultural Institute for help with plant identification. The project was funded by the Grains Research and Development Corporation with support from NSW Agriculture. Constructive comments from 2 anonymous referees helped to improve this manuscript, particularly regarding the use of correspondence analysis.

References


Appendix 1. Relative abundance of species, listed alphabetically by scientific name, recorded in the Liverpool Plains (L), Moree (M), Goondiwindi (G) and Kingaroy (K) regions within the subtropical grain region of Australia

Values are means for the total study period of May 1997 to July 2000 Species nomenclature follows the Flora of New South Wales (Harden 1990, 2002)

<table>
<thead>
<tr>
<th>Index</th>
<th>Species</th>
<th>Common name</th>
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<th>M</th>
<th>G</th>
<th>K</th>
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<td>Abelmoschus ficulneus</td>
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<td>—</td>
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<td>—</td>
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<td>Avena spp. (A. fatua and A. ludoviciana)</td>
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<td>0.2415</td>
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<td>Bidens pilosa</td>
<td>Bidens pillow</td>
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<td>Boerhavia malvinae</td>
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<td>0.0024</td>
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<td>0.0012</td>
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<td>Cynodon dactylon</td>
<td>Eje lights</td>
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<td>Echinochloa spp. (E. colona, E. can-gallii)</td>
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<td>0.0395</td>
<td>0.1457</td>
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<td>0.0395</td>
<td>0.1457</td>
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<td>51</td>
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<td>Barnyard grass</td>
<td>0.0827</td>
<td>0.0395</td>
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## Appendix 1. Continued

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<th>M</th>
<th>G</th>
<th>K</th>
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<td><em>Elytrigia repens</em></td>
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<td><em>Epilobium hirtigerum</em> and</td>
<td>Hoary willowherb</td>
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<td><em>Eriochloa pseudoacrotricha</em></td>
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<td><em>Filipendula rubra</em></td>
<td>Yellow twin-stem/speedy weed</td>
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<td><em>Galium aparine</em></td>
<td>Cleavers</td>
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<td><em>Geranium molle</em></td>
<td>Dove's-foot cranesbill</td>
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<td>Australian cranesbill</td>
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## Appendix 1. Continued

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