Research reports

Control of *Carex appressa* R.Br. using herbicides and surface sown pasture species

M.H. Campbell[A], D.W. Burbidge[B] and H.I. Nicol[A]
[A]NSW Agriculture, Agricultural Research and Veterinary Centre, Forest Road, Orange, New South Wales 2800, Australia.
[B]'Burnafahes', Bigga, New South Wales 2583, Australia.

Summary
The effect of type, rate and time of herbicide application, drainage, slashing and sowing improved pasture species on the control of *Carex appressa* was determined at Bigga and Orange, New South Wales between 1990 and 1996. Results showed it was necessary to drain the area prior to treatment so that improved species, particularly legumes, could establish and survive. Glyphosate proved the most effective herbicide in killing vigorously growing *C. appressa* when applied at 0.9 kg a.i. ha^{-1} in January or February. Slashing with a forage harvester in early summer removed *C. appressa* foliage and allowed pasture species to establish when sown late in the following winter. A two-spray treatment was necessary: glyphosate in January/February to kill *C. appressa* and glyphosate again in late winter to kill volunteer weeds. Sowing pasture species in late winter avoided periods of waterlogging that occurred earlier in winter. *Lotus pedunculatus*, *Trifolium repens*, *Festuca arundinacea* and *Phalaris aquatica* were the most successful species for tolerating short periods of waterlogging and competing with seedling regeneration of *C. appressa*.

Introduction
In some regions of New South Wales (NSW) and Victoria *Carex appressa* R.Br. (tussock sedge), a native perennial, has spread from swamps and waterways and replaced native and improved pastures on creek flats and adjacent hill country (Figure 1). As infestations increase in density, natural drainage is blocked, extending water logged areas, thus facilitating the spread of the weed. A heavy infestation can substantially reduce animal production because the weed physically dominates the pasture, is unpalatable to sheep and cattle and of low feed value (green leaves have 7% crude protein, 47% acid detergent fibre and 48% dry matter digestibility). Traditional methods used to control pasture weeds have seldom proved satisfactory with *C. appressa* (Shovelton *et al.* 1985). Repeated slashing and burning are ineffective. Cultivation is the best method of control but is difficult to implement because of the generally water logged soil and the difficulty in ploughing out and breaking down the fibrous leaves and large leaf bases of the plant. It has been shown that glyphosate will kill the weed (Shovelton *et al.* 1985, Campbell and Burbidge 1993) but there has been no detailed research into time and rate of application. Spraying alone can be effective for removing isolated plants but infestations regenerate from seed in the soil. Thus a program of spraying and sowing is necessary to permanently replace the weed. In our study five experiments were set down between 1990 and 1996 to ascertain the most effective time, rate and type of herbicide for killing the weed and the best method of establishing improved species to replace it.

Material and methods
Sites
Experiments 1, 3 and 5 were conducted at Orange NSW and Experiments 2 and 4 at Bigga NSW. At both sites *C. appressa* grew in waterways which had water flowing over the soil surface in winter and other wet periods. The respective soils were derived from basalt and granite and had pHs ($CaCl_2$) of 4.2 and 4.4 and exchangeable phosphorous levels of 3.7 and 13.9 µg g^{-1} (Bray No. 1). Although the plants at both sites were identified by the National Herbarium of NSW as *C. appressa* there were obvious visual differences. For example, the *C. appressa* plants from Bigga had thin leaves (4.2 mm when flattened) and leaf bases in large trunks that occupied up to 40% ground cover and remained for up to five years after the plants died. The *C. appressa* at Orange had broad leaves (7 mm) with sharp toothed edges that readily cut unprotected flesh, no well defined leaf base trunks but it commonly occupied 70% ground cover. *C. appressa* is reported to be 'widespread and variable' by the National Herbarium of NSW.

Experiments
Herbicides were applied to 4 × 5 m plots in 500 to 625 L water per hectare from a hand held pneumatic sprayer with a single nozzle. A non-ionic surfactant (Turbo®) was added to all herbicides at 0.5 L per hectare. Results were recorded by visually estimating ground cover of *C. appressa* at spraying, at various periods during and at the end of each experiment and are presented as the percentage reduction in ground cover over the term of the experiment.

Figure 1. *Carex appressa* invading hill country pastures (foreground and background) adjacent to an infested waterway (in valley) near Bigga NSW.

Table 1. Effect of type and rate of herbicide on reduction in ground cover of *C. appressa* between spraying on 1 April 1993 and measurement on 24 February 1994.

Herbicide and rate (kg a.i ha^{-1})	Reduction in ground cover (%)
Glyphosate	
1.8	91 a
1.35	87 ab
0.9	75 bc
2,2-DPA	
22.4	85 ab
11.2	73 c
Imazapyr	
0.5	81 abc
0.3	39 d
Flupropanate	
3.0	31 d
1.5	14 e
Sethoxydim	
0.6	5 fg
0.2	13 ef
Clethodim	
0.5	5 fg
0.2	0 g
Fluazifop	
0.4	2 g
0.2	0 g
Quizalofop	
0.2	0 g
0.1	0 g
Control	0 g

Means followed by a common letter do not differ significantly at P=0.05.

In Experiments 4 and 5 where pasture species were sown after spraying, seed and fertilizer were hand broadcast on the soil surface. All seed was treated with permethrin to reduce losses due to ants (Campbell and Gilmour 1979) and legume seed was inoculated and lime pelleted. For the first two years of each sown experiment superphosphate with 0.02% molybdenum trioxide was applied at 200 kg ha^{-1} and for each following year single superphosphate was applied at 100 kg ha^{-1}.

Experiment 1. Two rates of flupropanate, 2,2-DPA, quizalofop, fluazifop, clethodim, sethoxydim and imazapyr and three rates of glyphosate (Table 1) were applied to *C. appressa* at Orange on 1 April 1993. An unsprayed control was also included. At spraying, the leaves of *C. appressa* had not been damaged by frost and plants were growing vigorously in response to 91 mm of rain in the preceding four weeks. Results were recorded by visual estimates of the percentage ground cover of *C. appressa* at spraying on 1 April 1993 and at the end of the experiment on 24 February 1994. The experiment had a randomized block design with four replications.

Experiment 2. Glyphosate was applied at four rates (Table 2) to *C. appressa* in each season of the year, i.e. on 22 November 1990, and 29 January, 24 April and 18 June 1991 at Bigga. An unsprayed control was also included. *C. appressa* was growing vigorously at each time of spraying except January 1991 when it was 85% browned out due to three dry months before spraying in which only 64 mm of rain was received. Results were recorded by visual estimates of percentage ground cover of *C. appressa* at spraying and at the end of the experiment on 23 June 1992. The experiment had a randomized block design blocked for time of spraying with four replications.

Experiment 3. Glyphosate was applied at three rates (Table 3) to *C. appressa* at Orange on 12 November and 10 December 1993 and 18 January, 18 February and 14 March 1994. An unsprayed control was also included. *C. appressa* was growing vigorously at each time of spraying due to 139 mm of rain in October 1993 and 85, 34, 11, 138 and 137 mm in the following five months. Results were recorded by visual estimates of percentage reduction in ground cover of *C. appressa* between spraying and final measurement on 23 February 1996. The experiment had a randomized block design with four replications.

Experiment 4. Glyphosate at various rates and timings was applied to *C. appressa* prior to surface-sowing pasture species at Bigga in 1990. A two-spray treatment consisted of glyphosate application on 13 March 1990 at 0.9, 1.35 and 1.8 kg a.i. ha^{-1} followed by another application on 8 May 1990 at 0.7 kg a.i. ha^{-1}. In a one-spray treatment glyphosate was applied at 0.9, 1.35 and 1.8 kg a.i. ha^{-1} on 8 May 1990. An unsprayed control was also included. All treatments were surface-sown with seed of *Trifolium subterraneum* cv. Karridale, *Trifolium repens* cv. Haifa, *Dactylis glomerata* cv. Currie and *Phalaris aquatica* cvs. Australian commercial and Sirosa at, respectively 3, 0.3, 1.0, 1.5 and 1.5 kg ha^{-1} on 14 May 1990. The establishment of pasture species was measured on 24 September 1990 and control of *C. appressa* and ground cover of pasture species recorded on 15 September 1994 (Tables 4 and 5). The experiment had a randomized block design, blocked for spray treatment with four replications.

Experiment 5. The effects of three slashing treatments (nil, summer [15 December 1994], autumn [13 April 1995]) × four herbicide treatments (nil, summer [7 February 1995], winter [22 August 1995] and summer and winter [7 February and 22 August 1995]) were recorded on the establishment of surface-sown pasture species and control of *C. appressa* at Orange between 1994 and 1996. The slashing treatments were applied with a forage harvester to remove large amounts of *C. appressa* foliage from the plots and provide bare ground for pasture establishment. The summer herbicide treatment was applied to kill *C. appressa* and the winter treatment to kill volunteer weeds

Table 2. Effect of applying glyphosate in each season of the year on reduction in ground cover (%) of *C. appressa* between spraying and measurement on 23 June 1992.

Rate of glyphosate (kg a.i. ha^{-1})	Time of spraying			
	November 1990 (Spring)	January 1991 (Summer)	April 1991 (Autumn)	June 1991 (Winter)
1.35	98 a	36 fg	69 bc	59 cd
1.01	97 a	48 def	56 cd	42 efg
0.67	92 a	34 fg	53 de	26 g
0.34	76 b	32 g	46 def	22 g
0	0 h	0 h	0 h	0 h

Means followed by a common letter do not differ significantly at P=0.05.

Table 3. Percentage reduction in ground cover of *C. appressa* due to application of glyphosate between late spring 1993 and early autumn 1994 and percentage increase in ground cover on the control. Results recorded on 23 February 1996.

Glyphosate (kg a.i. ha^{-1})	Reduction in ground cover (%) from spraying				
	Nov 1993	Dec 1993	Jan 1994	Feb 1994	Mar 1994
1.80	79 bc	78 bc	94 a	96 a	93 a
1.35	61 def	71 cd	96 a	92 a	92 a
0.90	54 ef	57 ef	92 a	89 ab	67 cde
Control	+14 g				

Means followed by a common letter do not differ significantly at P=0.05.

(mainly *Holcus lanatus* L. and *Anthoxanthum odoratum* L.). Glyphosate was applied at 1.8 kg a.i. ha^{-1} where treatments were sprayed once and at 1.8 and 0.9 kg a.i. ha^{-1} on treatments sprayed twice. At spraying on 7 February 1995 the unslashed plants were 1 m high with 25% of their foliage dead; the slashed plants had green leaves 25 cm high. At spraying on 22 August 1995 the foliage of both the slashed and unslashed plants was 70% dead due to frosting. A drain was constructed on 23 January 1995 in an endeavour to prevent surface water flowing across the experiment in winter. The seed mixture was hand broadcast on 22 August 1995. It consisted of *T. subterraneum* cv. Leura, *T. repens* cv. Haifa, *Lotus pedunculatus* cv. Maku, *Festuca arundinacea* cv. Demeter, *P. aquatica* cvs. Australian commercial and Sirosa at, respectively, 2, 0.3, 4, 4, 2, 2 kg ha^{-1}. Establishment of pastures species and control of *C. appressa* were measured by visual estimation of ground cover on 16 February 1996. The design of the experiment was a randomized block, blocked for slashing, with four replications.

Figure 2. Application of glyphosate and pasture species controlled *Carex appressa* on sprayed treatments inside the fence at Bigga NSW (Experiment 4).

Results

Experiment 1. Of the eight herbicides applied only glyphosate, 2,2-DPA and imazapyr reduced ground cover of *C. appressa* by >80% (Table 1). At the rates applied the other herbicides were ineffective. Based on price, availability and residual considerations, glyphosate was assessed as the most effective herbicide for killing *C. appressa*.

Experiment 2. The effects of glyphosate on *C. appressa* in spring were superior (P=0.05) to that in other seasons of the year (Table 2). As the results from the summer application had to be disregarded because of drought (64 mm of rain in the three months before spraying) it was concluded that glyphosate was most effective when applied in the warmer months of the year which provided the rationale for Experiment 3.

Experiment 3. The lowest rate of glyphosate applied, 0.9 kg a.i. ha^{-1}, was most effective in killing *C. appressa* in January and February (Table 3). The highest rate, 1.8 kg a.i. ha^{-1}, was effective from January through March. No treatment gave 100% kill and thus spot spraying for 1 or 2 years after the initial spraying will be necessary to completely remove mature plants.

Experiment 4. Establishment of pasture species four months after sowing was higher (P=0.05) on the two-spray than on the one-spray treatment (Table 4). Establishment of legumes was low on both spray treatments whilst, on the unsprayed control, very few plants established. Four years later ground cover of pasture species was similar on the one and two-spray treatments but still low on the unsprayed control (Table 5). The *P. aquatica* content was high on both spray treatments but that of *D. glomerata* and the legumes was low. Mature *C. appressa* was almost eliminated on the two-spray treatment and substantially reduced on the one-spray treatment (Figure 2). Seedlings of *C. appressa* resulted from regeneration between 1991 and 1994. The initial infestation which established in 1990 died in the four dry months from November 1990 to February 1991 (81.4 mm rainfall).

Experiment 5. Establishment of legumes and grasses was highest (P=0.05) where *C. appressa* was slashed on 15 December 1994 and sprayed in either August 1995 or February and August 1995 (Table 6). Slashing and removal of foliage in December 1994 resulted in less dead *C. appressa* litter on the soil surface than the other treatments (Table 6) which allowed seed of sown

Table 4. Effect of treating *C. appressa* with one- or two-sprays of glyphosate in autumn 1990 on establishment of surface-sown pasture species measured on 24 September 1990.

Herbicide treatment	Establishment (plants m^2)			
	T. subterraneum	*T. repens*	*D. glomerata*	*P. aquatica*
Two-sprays (March and May 1990)	2.4 a	1.3 a	23.9 a	12.4 a
One-spray (May 1990)	0.3 b	0.1 b	6.4 b	3.0 b
Control	0 c	0 c	0.1 c	0.9 c

Means in columns followed by a common letter do not differ significantly at P=0.05.

Table 5. Effect of treating *C. appressa* with one- or two-sprays of glyphosate in autumn 1990 on ground cover (%) of mature plants, seedlings and sown species, measured on 15 September 1994.

Herbicide treatment	Ground cover (%)					
	C. appressa					
	Mature	Seedlings	Sown legumes	*P. aquatica*	*D. glomerata*	Other species
Two-sprays (March and May 1990)	1.6 a	14.9 a	10.4 a	36.9 a	1.1 a	35.1 b
One-spray (May 1990)	10.0 b	12.2 a	8.8 a	45.2 a	0.8 a	23.0 c
Control	36.9 c	4.0 b	2.1 b	9.8 b	0.1 b	47.1 a

Means in columns followed by a common letter do not differ significantly at P=0.05.

species to reach the soil surface and seedlings to establish without being shaded. All herbicide treatments reduced (P=0.05) the ground cover of *C. appressa*, the effect being similar on slashed and unslashed plants. The August 1995 application of glyphosate was necessary to kill weeds other than *C. appressa* so that sown species could establish (Table 6). Ground cover of sown perennial grasses was low when measured in 1996 but large numbers of plants were present which have the potential to respond to nitrogen input from the legumes and form a grass dominant pasture.

Table 6. Effect of slashing with a forage harvester and herbicide treatments applied in 1994/95 on establishment of surface-sown pastures and control of *C. appressa* measured on 16 February 1996.

Treatment		Ground cover (%)				
Slashing	Herbicide	Sown legumes	Sown grasses	*C. appressa*	Other weeds	Litter
Nil	Nil	0 f	4 bc	78 a	7 f	10 cd
	Feb 95	6 f	3 c	1 d	31 cde	57 b
	Aug 95	4 f	3 c	1 d	31 cde	58 ab
	Feb + Aug 95	3 f	1 c	1 d	20 ef	74 a
Dec 94	Nil	21 cde	5 bc	43 b	21 e	4 d
	Feb 95	24 bcd	4 bc	1 d	63 a	3 d
	Aug 95	57 a	10 b	2 d	27 de	3 d
	Feb + Aug 95	56 a	16 a	1 d	25 de	1 d
Apr 95	Nil	12 def	2 c	44 b	23 de	16 cd
	Feb 95	11 ef	4 bc	2 d	55 ab	26 c
	Aug 95	25 bc	5 bc	10 c	36 cd	19 cd
	Feb + Aug 95	34 b	5 bc	1 d	44 bc	16 cd

Means in columns followed by a common letter do not differ significantly at P=0.05.

Discussion

Results from these experiments indicate that to control *C. appressa* on unploughed land it is necessary to drain the area prior to treatment, slash in early summer and remove foliage, spray in January or February and again in late winter and sow pasture species in late winter.

Drainage proved necessary to allow improved species to establish. Experiment 4 at Bigga was not drained which resulted in poor establishment and survival of legumes and *D. glomerata* because of periods of water logging in winter. In this experiment *P. aquatica* established and survived well because it is relatively tolerant to water logging. However in areas where *C. appressa* is waterlogged throughout winter even *P. aquatica* will fail to establish. Drainage in Experiment 5 allowed legumes and grasses to establish and develop. However as it was not a well designed system waterlogging occurred for short periods in winter. To solve the drainage problem design expertise should be employed.

Slashing by forage harvester was necessary to remove the dense foliage of *C. appressa* and to provide bare ground for the establishment of improved species. In Experiment 5 establishment of all sown species was much higher on slashed than unslashed treatments. Burning could be a more practical method of removing *C. appressa* foliage than slashing with a forage harvester, but whatever method is used, foliage should be removed by early summer to allow sufficient time for *C. appressa* regrowth to occur so that green foliage is present to take up glyphosate in the following January or February, the optimum time for spraying.

The most cost effective rate of glyphosate for killing *C. appressa* in January and February was 0.9 kg a.i. ha^{-1}. Higher rates were necessary before or after this optimum period. Spraying should be undertaken when *C. appressa* is growing vigorously as poor control resulted from spraying in dry conditions in January 1991 in Experiment 2. Results from spraying prior to sowing indicated that glyphosate should be applied in two operations, one in January/February to have maximum effect on *C. appressa* and the second in late winter, seven days before sowing, to remove weeds that volunteer after the first spraying (Campbell *et.al.* 1981). The alternative would be one spraying after the autumn break but before frosts have reduced the vigour of *C. appressa*. However this method has the disadvantages that sowing would have to be undertaken early, e.g. March or April, which is unfavourable for surface-sown pasture species and spraying would be late which would reduce the effect of glyphosate on *C. appressa*. In these experiments herbicides were applied by a hand-held sprayer which simulated the effect of a high volume boom spray. In practice it is difficult to use a boom spray because of the uneven surface presented by *C. appressa*. Aerial application is an alternative method of application (Campbell *et al.* 1996) that needs testing to ascertain its effectiveness.

In Experiment 5 pasture species were sown in August because periods of waterlogging occurred earlier in winter despite drainage of the site. If an area can be drained effectively then surface-sowing in late May would be preferable as this is the optimum time for aerial sowing pasture species (Campbell 1963).

The pasture species which established most effectively in these experiments, and two others not reported here, were *L. pedunculatus*, *T. repens*, *P. aquatica* and *F. arundinacea*, all species adapted to wet conditions. *T. subterraneum* and *D. glomerata* could only be considered if the area to be treated could be effectively drained.

Pastures were spelled from grazing for 6–9 months after sowing to allow the improved species to establish and compete with *C. appressa* seedlings. Despite this some seedlings survived. These were grazed with the pasture when animals were admitted and thus their development was retarded. To maximize this effect the treated area should be grazed heavily for short periods after the initial 6–9 month spell to ensure the *C. appressa* seedlings are eaten. For *L. pedunculatus* to persist, rotational grazing at intervals longer than four weeks is necessary (Sheath 1980) and grazing should be avoided in late summer and autumn to allow rhizome development (Wedderburn and Lowther 1985). Grazing should only be permitted when the ground is firm because animals, particularly cattle, make hoof indentations in soft wet ground which impede drainage and reduce the growth and persistence of improved species and favour the spread of *C. appressa*.

If scattered seedlings survive pasture competition and grazing, spot spraying with glyphosate would be necessary. However, widespread regeneration of *C. appressa* would necessitate a complete re-spraying. The optimum time for this would be in summer when *P. aquatica* is dormant and *C. appressa* growing actively (Campbell and Ridings 1988). However, *L. pedunculatus* and *T. repens* may have to be resown following this treatment. A more selective alternative would be the use of a weed wiper to apply glyphosate to a grazed pasture to remove the less palatable and thus ungrazed *C. appressa*.

If the appropriate implements are available and the area effectively drained, infested paddocks could be sprayed and ploughed before sowing. In such circumstances glyphosate could be applied in January/February and the area ploughed and sown 12–14 months later. This would allow the *C. appressa* foliage time to break down before sowing and reduce the bank of weed seeds in the soil. An alternative would be to burn in winter, spray the following January/February, plough soon after and sow in April/May or August.

For direct drilling to be used it would be necessary to burn in winter, spray in late spring (to control *Vulpia* spp. other weeds, and *C. appressa*), spray again after the autumn break in the following autumn to kill volunteer weeds and *C. appressa* seedlings and direct drill seven days later.

Depending on conditions there are a number of spraying and sowing programs that could be used to kill *C. appressa* and establish improved pastures by conventional cultivation, direct drilling or aerial techniques but, because the spread of the weed is related to poor drainage, an overall property program embracing tree planting in discharge areas to utilize some of the water and other relevant procedures should be initiated to solve the underlying causes of this problem.

References

Campbell, M.H. (1963). Establishment of pasture species on unploughed ground. Proceedings 3rd Australian Grasslands Conference, Melbourne 1, paper 5-30.

Campbell, M.H. and Burbidge, D.W. (1993). The biology of tussock sedge (*Carex appressa*) and its control on unploughed ground. Proceedings 10th Australian and 14th Asian Pacific Weed Control Conference, Brisbane, pp. 125-9.

Campbell, M.H. and Gilmour, A.R. (1979). Reducing losses of surface-sown seed due to harvesting ants. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19, 706-11.

Campbell, M.H., Gilmour, A.R. and Vere, D.T. (1981). Establishment and development of surface-sown pasture species in a nitrophilous weed association: effect of herbicide rate. *Australian Journal of Experimental Agriculture and Animal Husbandry* 21, 531-7.

Campbell, M.H. and Ridings, H.I. (1988). Tolerance of grazed and ungrazed *Phalaris acquatica* to glyhposate, tetrapion and 2,2-DPA. *Australian Journal of Experimental Agriculture* 28, 747-51.

Campbell, M.H., Watson, R.W. and Vere, D.T. (1996). Pasture establishment using aerial techniques. NSW Agriculture Agfact P2.2.2, pp. 8.

Sheath, G.W. (1980). Effects of season and defoliation on the growth habit of *Lotus pedunculatus* Cav., cv. 'Grasslands Maku'. *New Zealand Journal of Agricultural Research* 23, 191-200.

Shovelton, J.B., Ruzic, I.M., Roberts, A.M. and Mahoney, G.P. (1985). Efficacy of glyphosate for control of tall sedge (*Carex appressa* R.Br.). Department of Agriculture, Wodonga, Victoria, pp. 8.

Wedderburn, M.E. and Lowther, W.L. (1985). Factors affecting establishment and spread of 'Grasslands Maku' Lotus in tussock grasslands. *New Zealand Journal of Experimental Agriculture* 14, 31-6.