Parthenium weed (*Parthenium hysterophorus* L.) research in Australia: new management possibilities

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Summary Parthenium weed (*Parthenium hysterophorus* L.) is a weed of global significance and has become a major weed in Australia as well as many other parts of the world. No single method alone has proven effective in its management. Studies have revealed that the plant owes its success in part to the very high output of viable seed (*c*. 15,000 per plant) and this is maximised under warm (35–28°C) wet (field capacity) soil conditions. Cooler conditions (25–18°C) lead to less seed production due to lower rates of seed formation and fill. The soil seed banks that build up in infested pastures can be very large (*c*. 5000 to 30,000 viable seeds m^{-2}) and present management options do not seem to be able to reduce them below a threshold of *c*. 5000 viable seeds m^{-2}. Even when parthenium weed is present at low densities (two plants m^{-2}) there is a considerable negative effect upon plant community diversity. New management options may include sowing desirable, displacement plant species into infested land. Such plants work well with the already released biological control agents and together can reduce parthenium weed productivity by 47%. However, climate change studies with elevated CO_2 levels indicated that this displacement ability may be reduced in the future as the atmospheric CO_2 levels rise.

Keywords Glasshouse trials, field trials, management, *Parthenium hysterophorus*.

INTRODUCTION

Parthenium weed (*Parthenium hysterophorus* L.) is a weed of global significance and has become a major weed in Australia and many other parts of the world (Adkins *et al.* 1997). Its main impacts are upon agricultural and natural ecosystem production and biodiversity, and on human and animal health. No single method alone has been effective in its management, although integrated management approaches have measurable impact (O'Donnell and Adkins 2005). Within Australia this weed has been present for more than 50 years and during this time a biological control program has been developed and 11 agents have been released (Dhileepan and McFadyen 1997). The Tropical and Subtropical Weed Research Unit (TSWRU) at the University of Queensland has contributed to an understanding of the weed's basic biology, ecology and management and in 2009 created the International Parthenium Weed Network (IPAWN) to support the growing international interest in this weed. The mission of IPAWN is to link international experts devoted to the creation of awareness of the threat and to act as a platform for the sharing of information on this weed and its adverse impacts upon agro-ecosystems, human health and the environment.

A current research program underway at the TSWRU has the aims of developing a sustainable management method for parthenium weed in Australia and other countries and consists of three components:

1. **Reproductive biology and impact** – aimed at appreciating the invasive potential of the weed by understanding seed production and quality;
2. **Competitive displacement of parthenium weed** – aimed at assessing the value of competitive plants used to displace the weed in core infestations and
3. **Seed spread** – aimed at assessing seed spread by vehicles, and the efficacy of removal of these seeds.

REPRODUCTIVE BIOLOGY AND IMPACT

Reproductive capacity Seed production was determined on plants growing under two temperature (35–28°C – 'warm' or 25–18°C – 'cool') and two soil moisture (field capacity – 'wet' or half field capacity – 'dry') regimes in a controlled environment facility. Warm/wet conditions produced the highest number of seeds (*c*. 15,000 Figure 1), while the cool/wet conditions produced the lowest number of seeds per plant (*c*. 6500). However, for each condition a proportion of the seeds were empty (unfilled) as determined by seed X-ray analysis. The greatest number of unfilled seeds was produced under the two cool conditions (wet and dry). These data confirm the long held belief that parthenium weed plants grown under a range of environmental conditions are capable of producing vast amounts of highly viable seed.

Seed dispersal The spread of weed seed (including parthenium weed seed) on vehicles was studied over a 3 year period. Material washed off vehicles, taken from five sites in Central Queensland, at four different times of the year (autumn, winter, spring and summer) was analysed for its viable seed content (Tables 1 and 2). The seeds found included those from both monocot (grasses, sedges) and dicot (broadleaf) species. The viable monocot seed outnumbered the dicot seed 2:1 with parthenium weed seed representing *c*. 2% of the total. The total number of parthenium weed seeds from two locations was higher than that from others and was highest in the summer. These data confirm the long held belief that one mode of parthenium weed seed spread is by vehicles.

Seed banks The species composition and the dynamics of the soil seed bank during a 15 year period of active weed management was studied at two sites (Moolayember Creek and Clermont) in Central Queensland. The 2008 autumn samples collected from both sites show that reduced but large populations of parthenium weed seed still exist at both sites (Figure 2). Integrated management at these sites utilising biological control agents has therefore reduced the parthenium weed seed bank (from *c*. 33,000 to *c*. 5000 seeds m^{-2}) in the first 8 year period but no further reductions have occurred within the last 8 year period. The reduced parthenium weed seed bank at the two sites was replaced with seed from other annual weeds and unfortunately very little improvement in the size of the seed bank of the palatable grasses was observed (data not shown).

Table 1. Viable seeds including parthenium weed (PW) found in one ton of sludge taken from wash-down facilities in different seasons.

	Total	Monocot	Dicot	PW
SA	49,000	29,000	20,000	2,000
A	76,000	60,000	16,000	200
W	96,000	66,000	30,000	750
Sp	12,300	5,800	6,500	0

[A] S = summer, A = autumn, W = winter, Sp = spring.

Table 2. The number of viable seeds including parthenium weed (PW) found in one ton of sludge taken from wash-down facilities in different locations.

Locations	Total	Monocots	Dicots	PW
Clermont	54,000	20,000	34,000	750
Injune	70,000	46,000	24,000	250
Monto	142,000	121,000	16,000	330
Rolleston	54,000	40,000	14,000	4,000
Springsure	26,000	12,500	13,500	500

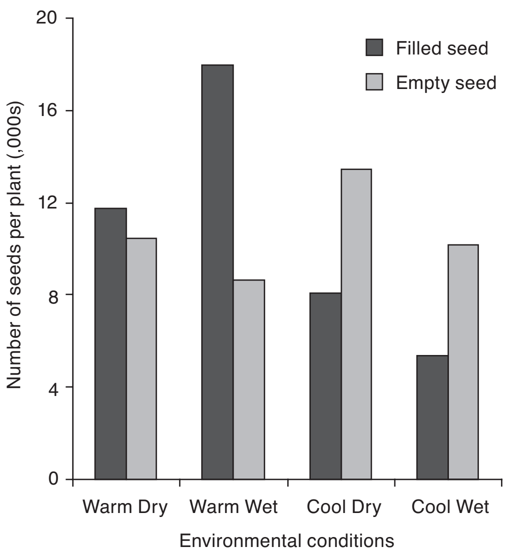

Figure 1. The number of filled and empty seeds produced on a single plant grown under four conditions of temperature and soil moisture.

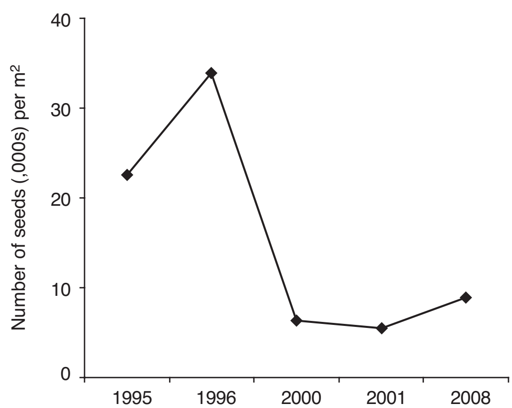

Figure 2. The parthenium weed seed bank from 1995 to 2008 in Moolayember Creek, central Queensland, Australia.

Community diversity The impact of parthenium weed upon community biodiversity and its composition, both in the above-ground community and within the soil seed bank was assessed at a pastoral site near Kilcoy, southern-central Queensland, a site that had been infested with parthenium weed for at least 10 years. The summer study of 2008/09 revealed that the community diversity (as measured by the Shannon index) had been lowered by only low infestations of parthenium weed (two plants m^{-2}). Of all species, it was the broadleaf plants that were most affected by the presence of parthenium weed (Figure 3).

COMPETITIVE DISPLACEMENT

Displacement potential Twenty selected pasture species were grown individually with parthenium weed, at different densities and in different combinations for 40 days in a pot trial in a glasshouse. After this time the above ground dry biomass was determined and, using the experimental design of Rejmanek *et al*. (1989) and the reciprocal yield model analysis of Spitters (1983), a displacement index (DI) value was determined for each plant species against parthenium weed. Twelve plant species were found to have a low displacement ability (displacement indices <1.0) while eight were more able to displace parthenium weed (>1.0, Table 3). A five times replicated pair of field trials, each 1800 m^2, were established at two central Queensland sites evenly infested with parthenium weed. The results showed that the three introduced species (viz. buffel grass, Rhodes grass *Chloris gayana* Kunth and purple pigeon grass) and two native species (bull Mitchell grass and Queensland bluegrass *Dichanthium sericeum* (R.Br.) A.Camus) displaced parthenium weed at both sites.

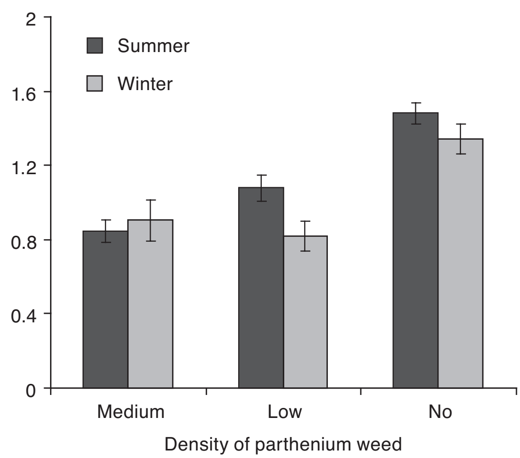

Figure 3. The Shannon index value of plant diversity in the above ground vegetation at a pasture in Kilcoy, Queensland, Australia where low is two plants m^{-2} and medium is 16 plants m^{-2}.

Climate change trials A series of trials was conducted, using two controlled environment chambers, to assess the effect of elevated CO_2 on the competition of displacement plants with parthenium weed. The trials were undertaken under two CO_2 conditions: those of today's atmosphere (380 ppmv) and those predicted for 2050 (550 ppmv CO_2). The competitive ability of

Table 3. Species tested for their displacement ability against parthenium weed in a glasshouse trial.

Test species	Strength
Purple pigeon grass (*Setaria incrassata* (Hochst.) Hack.)	High
Guinea grass (*Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs var. *maximus*)	High
Buffel grass (*Cenchrus ciliaris* L.)	High
Indian blue grass (*Bothriochloa pertusa* L.)	High
Bull Mitchell grass (*Astrebla squarrosa* C.E.Hubb.)	High
Kangaroo grass (*Themeda triandra* Forssk.)	High
Pitted blue grass (*Bothriochloa decipens* (Hack.) C.E.Hubb.)	High
Hoop Mitchell grass (*Astrebla elymoides* F.Muell. ex F.M.Bailey)	High
Lablab (*Lablab purpureus* L.)	Low
Silky browntop (*Eulalia aurea* (Bory.) Kunth.)	Low
Red-leg grass (*Bothriochloa macra* (Steud.) S.T.Blake)	Low
Centurion (*Centrosema pascuorum* Mart. ex Benth.)	Low
Curly Mitchell grass (*Astrebla lappacea* (Lindl.) Domin)	Low
Wallaby grass (*Austrodanthonia richardsonii*)	Low
Black spear grass (*Heteropogon contortus* (L.) Roem. & Schult.)	Low
Cotton panic grass (*Digitaria brownii* Roem. & Schult.)	Low
Weeping grass (*Microleana stipoides* (Labill.) R.Br.)	Low
Dessert blue grass (*Bothriochloa ewartiana* (Domin.) C.E.Hubb.)	Low
Curly windmill grass (*Enteropogon acicularis* (Lindl.) Lazarides)	Low
Forest bluegrass (*Bothriochloa bladhii* (Retz.) S.T.Blake 'Swann')	Low

purple pigeon grass and bull Mitchell grass, two species noted to be competitive with parthenium weed in the field trial, was reduced under the 2050 CO_2 condition compared to the present day condition indicating that their displacement ability against parthenium weed is likely to reduce in the future.

Biological control and competition A glasshouse experiment was set up to quantify the combined effect of a biological control agent (the leaf eating beetle *Zygogramma bicolorata*) on the displacement ability of two pasture plant species (bull Mitchell grass and butterfly pea) against parthenium weed. Both species were more effective in displacing parthenium weed in the presence of the biological control agent. In a field trial it was shown that buffel grass could suppress the growth of parthenium weed by as much as 50% (Table 4). However, when a suite of natural biological agents was present with buffel grass, the growth of parthenium weed could be suppressed by 69%. It was also noticed that when the biological control agents were present, the biomass of buffel grass increased (Table 4). From this study it is concluded that the biological control agents and displacement plants can act synergistically to suppress the growth of parthenium weed as has been previously seen in other species (Sheppard 1996). This has implications in the integrated management of parthenium weed.

CONCLUSION

A current research program at the TSWRU has the aims of developing a sustainable management method for parthenium weed in Australia and then extending the approach to other countries where the weed is also invasive. The program has shown that under a wide range of environmental conditions parthenium weed is capable of producing a large number of viable seeds. This seed has been shown to form large, persistent seed banks in infested pastures and present management approaches do not seem to be able to reduce them to below a threshold of *c*. 5000 viable seeds m^{-2}. Even when parthenium weed is present at low densities (two plants m^{-2}) there is a considerable negative effect upon the plant community diversity. New management options may include sowing desirable plant species into infested land that have the effect of displacing parthenium weed. Such displacement plants are known to work well with the already released biological control agents and together they can reduce parthenium weed productivity by as much as 69%. However, climate change studies with elevated CO_2 levels indicated that this displacement ability may be reduced in the future. The present research program has now been extended into eastern Africa and southern Asia and the present results are being used to develop management programs for these locations as well. The research efforts are linked through the IPAWN, which supports the growing international research interests in parthenium weed.

Table 4. Percentage change in dry weight of test plants and parthenium weed growing with or without biocontrol agents (BC) at a field site near Monto.

	Test plants	Parthenium weed	
Test species	With BC	No BC	With BC
Butterfly pea	+15	−33	−62
Buffel grass	+33	−50	−69
Parthenium			−21

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