Biology and management of the 'take-all' weed, Polymeria longifolia (Peaks Downs curse), in cotton

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Polymeria longifolia

Abstract

Polymeria longifolia (Lindley) is a native species, behaving as a weed throughout many areas of the Australian cotton industry. Seeds are a relatively minor method of reproduction and dispersal compared with the production of underground rhizomes, which are concentrated in the top 40 cm of the soil profile but found to depth of at least 1.5 m. These rhizomes may be dispersed by cultivation and their success in producing new plants is directly proportional to increasing fragment size.

Polymeria longifolia grows concurrently with the cotton crop making management very difficult. Active shoot growth of *P. longifolia* can occur at any time of the year in uncultivated areas and is probably linked to soil water status. *Polymeria longifolia* competes strongly with cotton, and is particularly detectable at soil moisture levels found immediately prior to irrigation. Although competition for major nutrients was suspected, no evidence was found in this study. Anatomical studies suggested there was some evidence that *P. longifolia* interfered with cotton through the production of allelochemicals but this requires further investigation. Densities of over 100 stems per square metre that are commonly found in weed patches reduced the yield of cotton lint and seed below 50%.

Existing control measures based on herbicides and shallow cultivation are largely ineffective and inconsistent in their results, probably due to the large below-ground biomass of the weed. Shallow hand chipping appeared to stimulate shoot recruitment and it was hypothesised that herbicides did not translocate to a sufficient enough depth down the rhizome to prevent further shoot recruitment. The findings from this thesis suggest that intensive and repeated cultivation may reduce the size of *P. longifolia* infestations in the field.

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

Stephen B. Johnson

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Chapter 1

Introduction

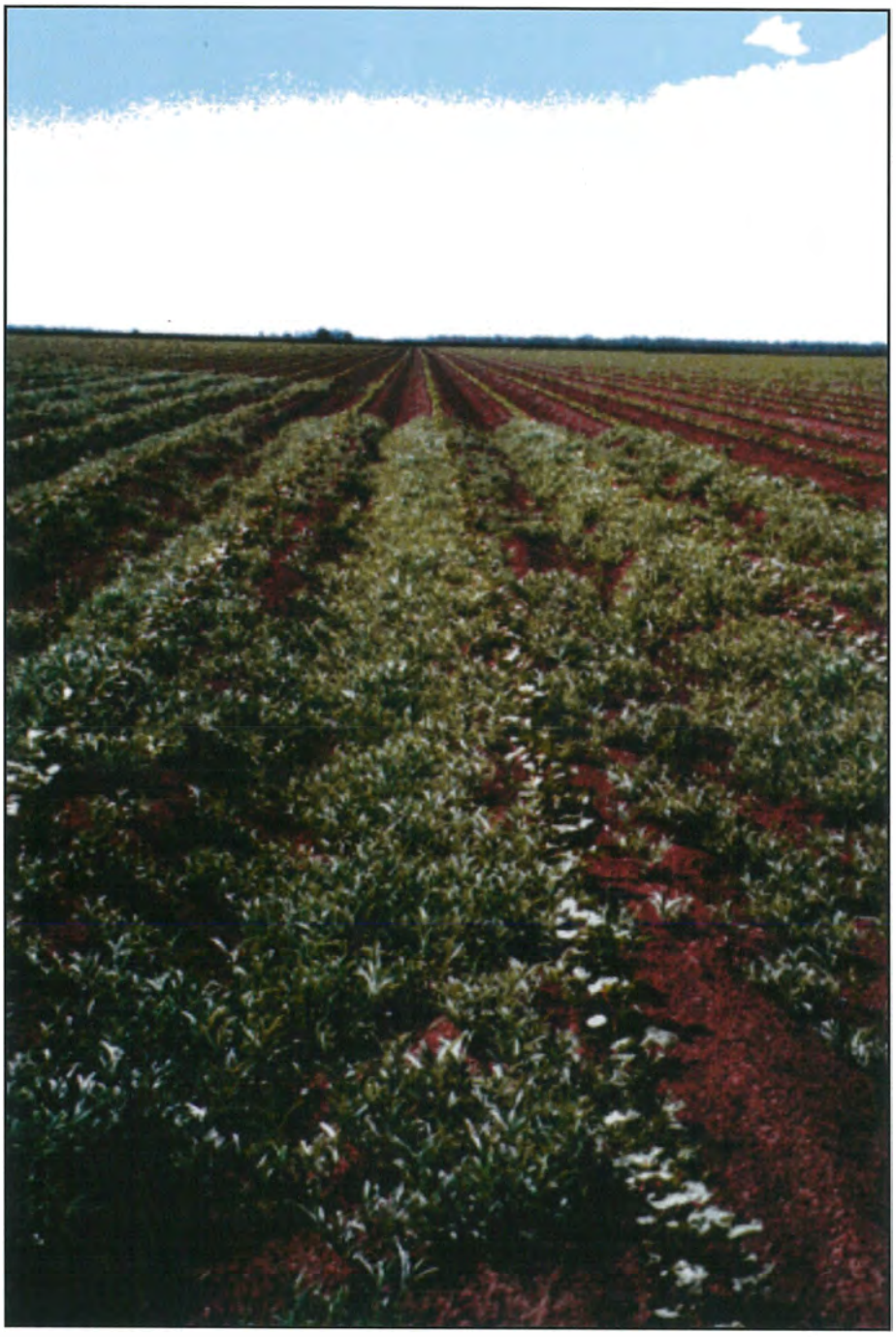
Perennial weeds are increasing under reduced tillage cotton production systems both overseas and in Australia (Murray *et al.* 1992; Gavin *et al.* 1999). There are many reasons why this is the case but two of the more significant may be that such perennial weeds are better adapted to infrequent disturbance (Murray *et al.* 1992), and the resultant increase in herbicide use under reduced tillage systems has not been entirely effective (Bryson and Keeley 1992). The traditional 'spray and pray' mentality for many hard-to-control weeds has not worked and a different and cost effective approach is needed. Since it is recognised that most weed problems are ecological in nature (Everist 1968), ecological and life cycle studies are considered essential to ensure that future strategies for control have the greatest possible impact.

The Australian cotton industry has a number of hard-to-control perennial weeds. *Polymeria longifolia* (Lindley) (Peaks Downs curse or Polymeria take-all), a native species in the Convolvulaceae, is one of these perennials that has been increasing in importance in recent years (Charles 1991). This species has a creeping rhizomatous system with the purported ability to "take all" the resources for plant growth from the soil in the patches in which it grows. Many measures aimed at controlling this weed have failed, while the development of an effective and consistent method has been hampered by a lack of research effort (McMillan 1988a).

This research has been conducted to address this need. There were four aims which, broadly speaking, were to survey the distribution, spread and potential control of *P. longifolia* by means of a mail questionnaire sent to cotton consultants (Chapter 3); to examine the biology and ecology of *P. longifolia* (Chapters 4 - 6); to quantify the competitive impact of *P. longifolia* on cotton production (Chapters 7 and 8) and lastly to elucidate the principles for managing *P. longifolia* based on an understanding of the plant's biology and ecology (Chapters 9 - 11).

Each chapter contains a different number of experiments that have a common theme. All experiments have an individual discussion with a conclusion in the final section of each chapter, summarising the main findings and placing these in context with the overall research. Where a suitable amount of literature was found, a separate literature review is included near the start of each chapter (Chapters 3 and 6), otherwise the relevant literature is covered in the discussion section for the experiment.

Full botanical names of all species have been used in each chapter initially, e.g. *Polymeria longifolia*, but thereafter have been followed with the abbreviated form, e.g. *P. longifolia*. The botanical names have been used in accordance with Harden (1992). Common names, e.g. Polymeria take-all, have been avoided in general. A complete list of all people consulted for personal communication is provided in Appendix 1. The references have been formatted in a style suitable for publication in the Australian Journal of Experimental Agriculture. The thesis is introduced by a short literature review detailing weed research in the Australian cotton industry, the place of Convolvulaceae weeds in cotton and a critique of available information on *P. longifolia*.



Polymeria longifolia in cotton

Chapter 2

Literature review

Polymeria longifolia is a "troublesome weed in cultivation"

(Queensland Herbarium records, 1960)

...and could become an industry-wide

problem (Charles, 1991).

2.1 The Australian cotton industry

The Australian cotton industry is a major rural export earner, contributing well over $1.5 billion to the Australian economy during the 1997/98 cotton growing season (Dowling 1998b). The industry is centred in two states, New South Wales (NSW) where 72% of production occurs, and Queensland (Qld) where 28% of production occurs. Currently, there are experimental cotton areas at various sites in northern Australia including Kununurra and Broome in Western Australia, Katherine in the Northern Territory and Richmond in Queensland (Figure 2.1).

Cotton is grown under both irrigated and dryland systems, although irrigated production predominates with 82% of the area sown. A total of seven regions in NSW contributed to the 312,810 hectares grown during the 1997/98 season. These were in the Macintyre, Gwydir, Namoi, Macquarie and Lachlan Valleys and the Bourke and Tandou areas (Figure 2.1). Four Queensland regions contributed to the 121,500 hectares grown during the same

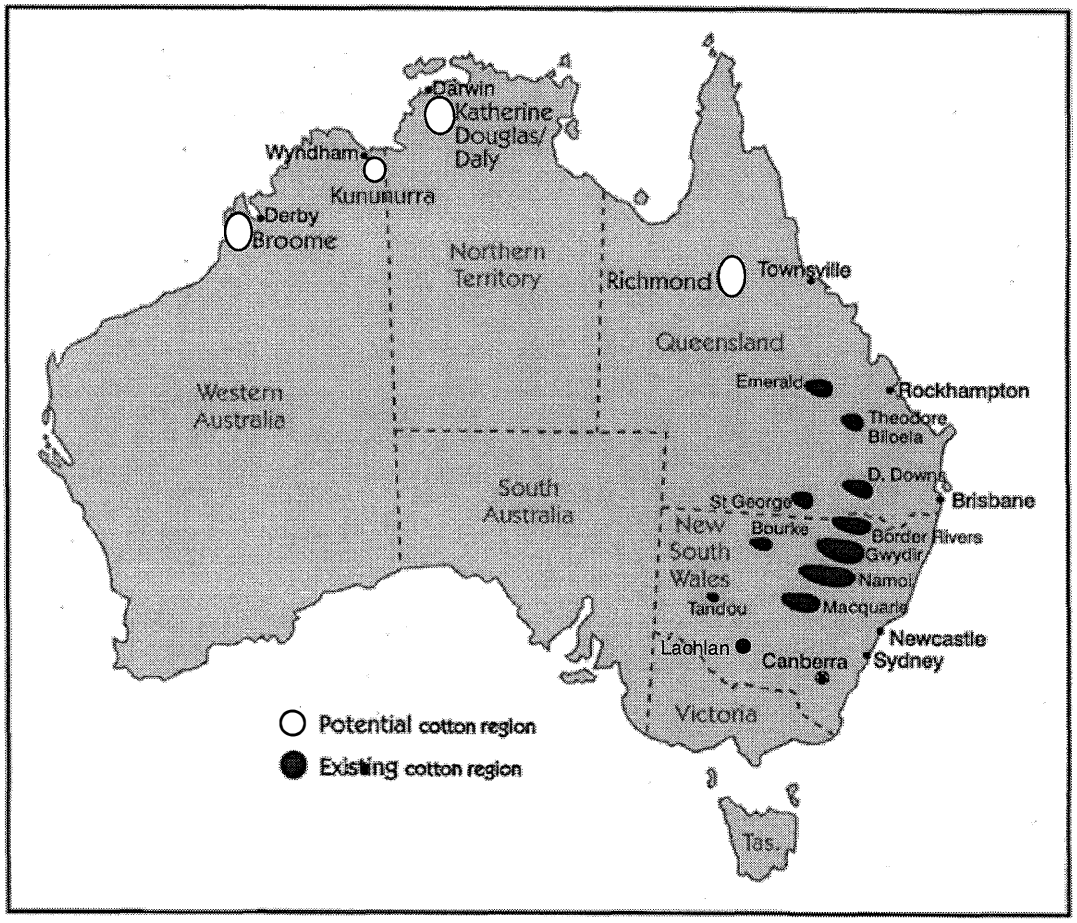


Figure 2.1 Cotton growing areas in Australia. The name Macintyre Valley has been used throughout this research instead of the Border rivers, and Dirranbandi (75 kilometres south of St. George) has not been included on this map. This Figure was courtesy of the Cooperative Research Centre for Sustainable Cotton Production.

season (Dowling 1998b). These regions were Emerald, Theodore/Biloela, the Darling Downs/South Burnett and St. George/Dirranbandi. *Polymeria longifolia* occurs in many of these cropping areas.

2.2 Management of weeds in the Australian cotton industry

2.2.1 A background to weed management in cotton systems

There was very little research published about weeds in the Australian cotton industry prior to 1991. Charles (1991) surveyed 52 NSW cotton growers to address this research deficit and determined that the annual control cost of weeds averaged $187 per hectare of cotton grown in the 1988/89 season. In the cotton crop, this comprised $76 per hectare for herbicide use (both chemical and application costs) and $67 per hectare for hand chipping (the hoeing of weeds by humans). The remaining $44 per hectare comprised of $19 per hectare for cultivation in the cotton crop and $25 per hectare for cultivation and herbicide use in fallow, road and channel areas. However, weed control costs were only 12% of the total variable costs of $1400 per hectare for growing a cotton crop (Patrick *et al.* 1990). Weed presence in individual fields was variable, resulting in some large hand chipping costs exceeding $180 per hectare (Charles 1991). Undoubtedly, costs will have increased since the time of this survey but more recent estimates are not available.

2.2.2 Current weed management in cotton systems

Weed management in the Australian cotton industry has changed little since the time of the survey outlined above and includes:

1. high rates of residual herbicides applied during pre-sowing, sowing or post-emergence operations in the cotton crop (Charles 1991; Charles *et al.* 1995);

2. frequent inter-row cultivation;
3. manual hand chipping (Roberts 1998b);
4. some shielded, directed and spot spraying of weeds (Charles 1991) (for example, glyphosate may be applied through a shielded sprayer to control *Cyperus rotundus* (Charles 1997a)); and
5. the use of rotation crops to allow strategic herbicide application when the cotton is not being grown (for example, atrazine and atrazine/metolachlor mixtures can be used in sorghum crops to control *Salvia reflexa* (Roberts and Gibb 1998)).

2.2.3 Problems with current weed management practices

Although many weed problems are declining with time, there are some problems with the current weed management practices (Charles 1999). The continued use of high rates of residual herbicides is expensive and may contribute to off-farm pollution of waterways that surround cotton growing areas. For example, Muschal (1998) reported that four herbicides registered for use in cotton - diuron, fluometuron, metolachlor and prometryn - were commonly detected in the Macintyre, Gwydir, Namoi, Macquarie and Darling rivers (around Bourke) during the period 1991-1998. Other herbicides that were occasionally detected were pendimethalin and trifluralin. This environmental issue is likely to increase in importance in the future.

The solutions to the off-farm movement of herbicides are varied and include preventing run-off and tail water releases, and limiting dust/vapour transport, spray drift and direct spillage. Importantly, solutions also need to include a decreased and more efficient application of herbicides on farms, thereby decreasing the possibility of off-farm movement. This may be achieved by weed-activated spraying equipment utilising global positioning systems (GPS) technology. A reduction in total herbicide application would help in reducing potential herbicide resistance, which, while it is not yet a problem in

cotton, requires consideration where repeated applications are made of a limited number of herbicides (Roberts 1998a).

The use of cultivation as a weed control option in inter-row and fallow situations is not regarded as a long-term sustainable solution by some (Roberts 1998b), partly due to the shift towards permanent bed, reduced tillage and stubble retention systems. Furthermore, retaining crop residues increases water infiltration and reduces soil loss due to erosion in dryland cropping systems (Yule and Rhode 1996; Charles 1999).

While manual chipping is an accurate means of weed removal, is valuable in variable-density situations and undoubtedly contributes to the prevention of herbicide resistance in cotton weeds, spiralling labour costs and increasingly stringent workplace health and safety regulations (Roberts 1998b) suggest that chipping may be reduced in the future and replaced with increasing levels of herbicide use (Charles 1999). A move in this direction should be considered carefully, particularly with respect to an industry trying to reduce dependence on chemical inputs (Charles 1999). In addition, rotation of crops offers many benefits for the cotton farming system. However, Charles (1998c) showed that volunteer crop plants can become weed problems in subsequent crops.

The current management regimes involving high rates of residual herbicides, frequent inter-row cultivation and hand chipping appear to favour the continued presence of *P. longifolia* in cotton growing systems. This relationship will be discussed in Chapter 3.

2.2.4 Weed management research in cotton

Roberts (1998b) reviewed the potential for integrated weed management in sustainable cotton growing systems and identified several key elements - including reducing total herbicide use and reliance on residual herbicides, improving the timing of weed control,

stopping herbicides accumulating in the soil and waterways, stopping the spread of new and existing weeds from entering fields in irrigation water and on machinery, the elimination of manual chipping and reducing or removing cultivation simply for weed control purposes, which would allow crop residues to be retained.

2.2.4.1 Transgenic herbicide resistant cotton

The introduction of transgenic herbicide resistant cotton should aid in sustainable weed management. The release of glyphosate resistant cotton (Roundup Ready®) is imminent. Other transgenic lines include those with tolerance to bromoxynil, glufosinate-ammonium and 2,4-D (Roberts 1998b). The number and types of herbicides to which cotton can be made tolerant appears to be limited only by a willingness to do so (Roberts 1998b). Apart from weed control benefits, the introduction of glyphosate resistant cotton will help reduce chipping, inter-row cultivation and the use of residual broadleaf herbicides (Charles *et al.* 1995).

Other herbicides previously unregistered for use in cotton may soon be considered as possibilities with the introduction of tolerant cotton lines with transgenic technology. As well as the advantages however, there are some disadvantages. One disadvantage is the poor perception that the public has of genetically modified foods. Use of herbicide resistant plants may also lead to increased herbicide use and therefore the more rapid development of herbicide resistance in weed flora. Transgenic cotton may itself become a weed of fallows and other areas. Other concerns include the potential of movement of genes into other cotton varieties or closely related species and crop damage if the crop is not sprayed at the correct time (Roberts 1999; G. Charles pers. comm.). Despite these concerns, the use of herbicide resistant cotton holds considerable promise for the management of *P. longifolia* and other hard-to-control weeds.

2.2.4.2 New herbicide chemistry

New herbicide chemistry also promises advances in weed control. The introduction of pyrithiobac-sodium (Staple®, registered trademark of DuPont) now allows cotton-safe post-emergent broadleaf weed control in cotton (Roberts 1998b). The success of this herbicide relies upon its application to small weeds, so timing is crucial. The introduction of this herbicide may result in some reduction in the amount of chipping needed (Charles *et al.* 1995). In addition, halosulfuron-methyl (Sempra®, registered trademark of Monsanto) has been introduced to control *Cyperus* spp. in cotton.

2.2.4.3 Precision agriculture

Precision agriculture can be defined as "the management of sites or regions within a field based on local requirements rather than average field requirements" (Boydell *et al.* 1998), and may be used to improve weed management, particularly herbicide application, in cotton farming systems in several ways.

1. Aerial photography, infra-red, thermal imaging and GPS may be used to map the extent and spread of particular weeds for specific management applications.
2. The precision of inter-row cultivation and directed or shielded sprays may be increased (Wilshire 1999).
3. The prophylactic use of residual herbicides may be reduced by up to 75%. Herbicides would then only be applied where weed problems were known to occur (Roberts 1998c).

Precision weed management will only become more widely adopted when the cost of these systems is reduced and equipment is made more accurate (Roberts 1998c).

2.2.4.4 Newer farming systems

Ultra-narrow-row cotton and drip irrigation systems are gaining increased attention in the cotton industry and present new opportunities for weed management. Ultra-narrow-row cotton has row spacings of 18 - 50 cm instead of the standard one metre spacing (Heckendorf *et al.* 1998). In these systems, inter-row cultivation is not possible and so effective pre- and post-emergent weed control is needed, although the potential for cotton crop competition is greater with earlier canopy closure (Dowling 1996; Heckendorf *et al.* 1998). Herbicide-tolerant cotton could have a key role in these systems (Dowling 1996). Drip irrigation systems deliver water below ground and so fewer weed seeds germinate in the drier top soil (Dowling 1998a). Both systems require further research to determine their potential in integrated weed management.

2.2.4.5 Research into weed species and cotton systems

Charles (1991) noted that weed control systems based on large inputs of herbicides and hand chipping were generally reducing problem weeds over time, with the exception of a suite of competitive, often rhizomatous weeds, that include *Cyperus* spp., *P. longifolia* and *Haloragis* spp. Subsequent research has focussed on the *Cyperus* spp. (Charles 1995; 1997a, b) and more recently on *H. apsera* (Osten 1996). With the exception of this work and current research on *Salvia reflexa* (Roberts and Gibb 1998), *Ipomoea lonchophylla* (G. Charles, pers. comm.) and *Sonchus oleraceus* (Widderick *et al.* 1999), research into the biology and ecology of specific weed species is limited. A concerted research effort into the biology and ecology of *P. longifolia* has had to wait until the work reported here.

Cotton systems research has also been undertaken with a focus on changes in the weed spectrum in reduced tillage and permanent bed systems (Charles 1998c), weed management

in rotation systems where crop stubble is retained (Roberts 1998a) and possible herbicide combinations in these systems (Charles 1998b).

2.2.4.6 Other associated research

Additional weed management research in cotton includes a determination of the competitiveness and economic threshold for chipping large weeds (Charles 1998a; Charles *et al.* 1998b), the production of seeds by weeds, seed dormancy and seed bank studies (Charles 1996b); the movement of weed seeds in irrigation water (Hawkey 1995); evaluations of herbicide-tolerant cotton, e.g. 2,4-D (Charles *et al.* 1998a) and glyphosate (G. Charles, pers. comm.); the effect of low rates of fallow herbicides on cotton (Storrie *et al.* 1998), and using fungi as biological control agents of weeds (McRae 1998; Nicol 1998).

Weed control in the Australian cotton industry is generally highly successful but some weeds such as *P. longifolia* are becoming problematic.

2.3 Convolvulaceae weeds in cotton

Randall (1998) listed over 89 species (13 genera) of the family Convolvulaceae as weeds around the world. Of the 89 species, 37 belong to the genus *Ipomoea*, six to the genus *Convolvulus* and 26 to the dodder genus *Cuscuta*.

Nine species in the Convolvulaceae have been recorded as cotton weeds in the USA by Murray *et al.* (1992). These species were *Convolvulus arvensis*, *Ipomoea cordatotriloba* var. *torreyana*, *I. hederacea*, *I. hederacea* var. *integriuscula*, *I. lacunosa*, *I. pondurata*, *I. purpurea*, *I. wrightii*, *I. turbinata* and *Jacquemontia tamnifolia*. These species caused an

estimated 1% yield loss (*Convolvulus*) and between 7 - 15% yield loss (*Ipomoea*) in various cotton growing regions in the USA in 1985 (Bryson and Keeley 1992).

Six species of Convolvulaceae have been recorded as weeds in cotton crops in Australia, with only *C. arvensis* being in common with the USA (Charles 1991: G. Charles pers. comm.). The other species are *C. erubescens* (Australian bindweed), *I. lonchophylla* (peach vine), *Ipomoea plebia* (bell vine), *Polymeria longifolia* (Polymeria take-all) and *P. pusilla* (annual Polymeria).

Randall (1998) reported the presence of the two *Convolvulus* species as weeds in Australia. The species *P. longifolia* and *I. lonchophylla* were not reported but have been reported elsewhere by Charles (1991). Neither Randall (1998) nor Charles (1991) reported *P. pusilla*. The state of knowledge of these three latter weeds is somewhat limited.

2.4 *Polymeria longifolia*

2.4.1 Nomenclature

Polymeria longifolia, in the Convolvulaceae, is a native Australian species that is commonly called either clumped or erect bindweed (Cunningham *et al.* 1981), polymeria, Peak Downs curse (Stanley and Ross 1986; Auld and Medd 1987) and notably Polymeria take-all within the cotton industry. Wilson *et al.* (1995) make a distinction between two species commonly known as Peak Downs curse, *P. longifolia* and *Teucrium integrifolium*, a member of the Lamiaceae. *Polymeria longifolia* is commonly known as one of the "take-all" weeds, so named because of their "perennial rhizomatous habit", their ability to form "dense competitive infestations that smother the ground" and their supposed ability to "take all" the nutrient and water resources available in the soil (B. Sindel, pers. comm.).

2.4.2 Description

Polymeria longifolia is an erect, perennial plant 7.5 - 25 cm tall (see page ii) with stems branching from an extensive deep root system. The stems and leaves are usually covered with silky hairs. The leaves are generally grey-green to silver, long and narrow (linear to linear-lanceolate or narrow-elliptic), 20-70 mm in length and 2-10 mm wide (Harden 1992; Wilson *et al.* 1995). The leaf apex is acute and finely mucronate while the base is abruptly rounded and auriculate or truncate (Harden 1992). The leaf surface may range from glabrous to silky while the petiole is generally less than 4 millimetres in length (Harden 1992).

The inflorescences of *P. longifolia* are single-flowered and extend on 1.5 - 6.0 cm long axillary peduncles. The nearly equal sepals are narrow-ovate to oblong-elliptic, 5 - 9 mm long and 2 - 3.5 mm wide (Harden 1992). The corolla is 10 - 20 mm long and commonly pale pink, mauve or white with a yellow centre (Stanley and Ross 1986; Auld and Medd 1987; Harden 1992). Flowering occurs throughout the year but mainly from spring to autumn (Stanley and Ross 1986; Harden 1992). The capsule is globose and 6 - 8 mm in diameter with a single, rarely two, pubescent seeds (Harden 1992).

There are two species of *Polymeria* that are weed problems in the Australian cotton industry, *P. longifolia* and *P. pusilla* (Plate 2.1). Both species appear to grow on heavy clay soils, in areas which may be flooded seasonally (Williams 1988; Harden 1992). They flower over summer and autumn. The main difference between the two species is that while *P. longifolia* has an erect habit, *P. pusilla* has trailing stems that root at the nodes (Harden 1992). The leaves of *P. pusilla* are oblong to ovate (10 - 30 mm long and 7 - 20 mm wide) while the flower is 6 - 12 mm long. This is opposed to *P. longifolia* leaves which are longer and narrower with longer flowers. The fruit of *P. pusilla* may be borne on a down-turned pedicel which may or may not be buried. Fruit can be produced both above and below

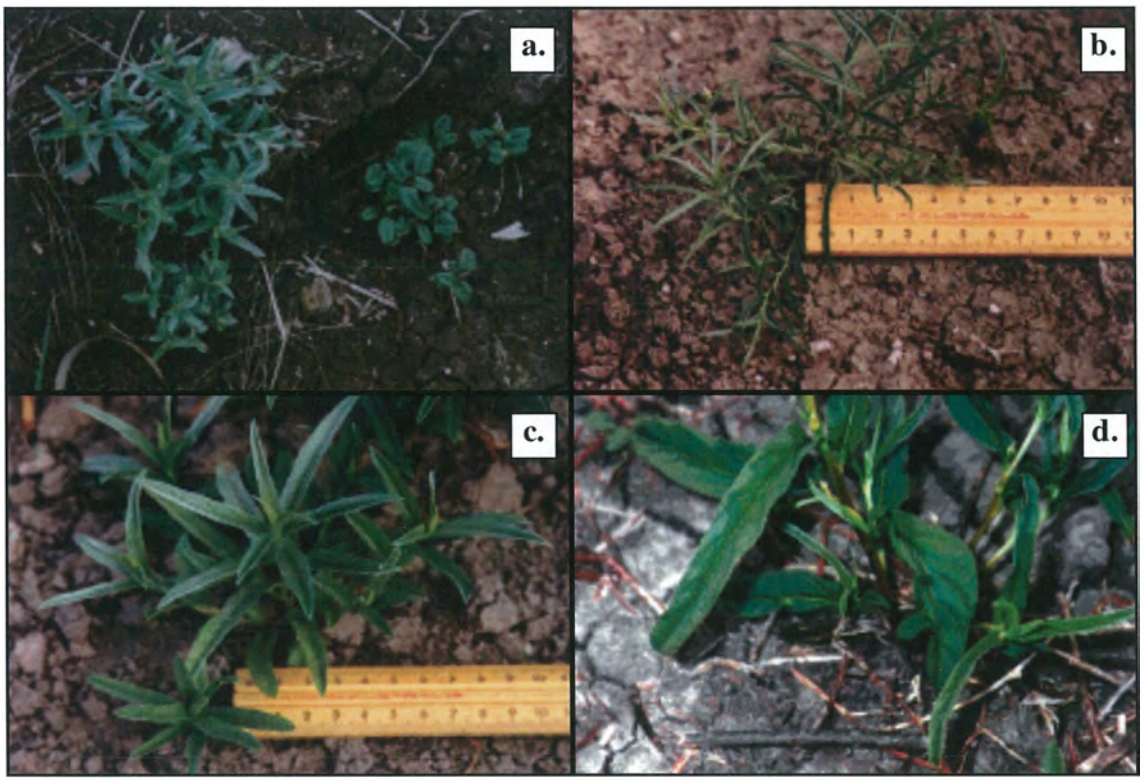


Plate 2.1 A comparison between *Polymeria longifolia* (on the left of 2.1a) and *P. pusilla* (on the right of 2.1a). The natural variation in leaf width in *P. longifolia* has been illustrated with a narrow leaf type in 2.1b, a standard leaf width in 2.1c and the wide lower leaves of another type in 2.1d.

ground in this case. The fruit of *P. longifolia* are always aerially produced (Cunningham *et al.* 1981; Harden 1992; R. Johnson, pers. comm.). Cunningham *et al.* (1981) outline another species, *Polymeria* sp. (aff. *ambigua*) which they record as a weed of western NSW. This species is in fact *P. pusilla* (Harden 1992).

Although strictly a perennial, many in the cotton industry believe that *P. pusilla* behaves more like an annual in cotton crops. *Polymeria pusilla* appears to be controlled effectively by pyrithiobac-sodium, (Staple®, registered trademark of DuPont).

Polymeria longifolia has some morphological variability across geographic locations. Consultations with Dr R. Johnson, a world expert on the Convolvulaceae at the Queensland Herbarium in Brisbane, indicated that specimens of *P. longifolia* collected from northern Queensland and the Northern Territory have a much narrower leaf width

(2 - 5 mm) and smaller flower size (up to 6 mm) compared with those collected from southern Queensland and NSW. Bentham and Mueller (1866) originally described this northern Australian biotype as a separate species (*Polymeria angusta*) but noted that this species may well be a variety of *P. longifolia*. Since there is a gradation in morphological form, the two biotypes or varieties have collectively been described as *P. longifolia.* This taxonomic distinction will remain until revisions are completed for the Flora of Australia project. The author of this thesis believes that the two types are indeed the one species and that the morphological variability exhibited can be observed within southern Australian populations (Plate 2.1).

Voucher specimens of both *P. longifolia* (specimen numbers 68138 - 68143, 68145 - 68148 and 68150) and *P. pusilla* (specimen number 68149) were placed in the NCW Beadle Herbarium at the University of New England, Armidale.

2.4.3 History

Polymeria longifolia was first recorded by J. Lindley (Mitchell 1848, in Chapman 1991). Kleinschmidt and Johnson (1977) recorded that *P. longifolia* emerged in "quantity" when the black soils of the Peak Downs area (near Capella in central Queensland, 23° 05' S, 148° 02' E) were broken up for cultivation in the early 1950s. As early as 1960, Queensland Herbarium records indicated that it was a "troublesome weed in cultivation". This continues to the present day. For more information see Section 2.4.8.

2.4.4 Distribution

Six of the seven species of *Polymeria* found in the world are endemic to Australia (Harden 1992). *Polymeria longifolia* has been recorded in four Australian states (Figure 2.2). In NSW it is commonly found north of Gunnedah on the north-west slopes and in all cotton

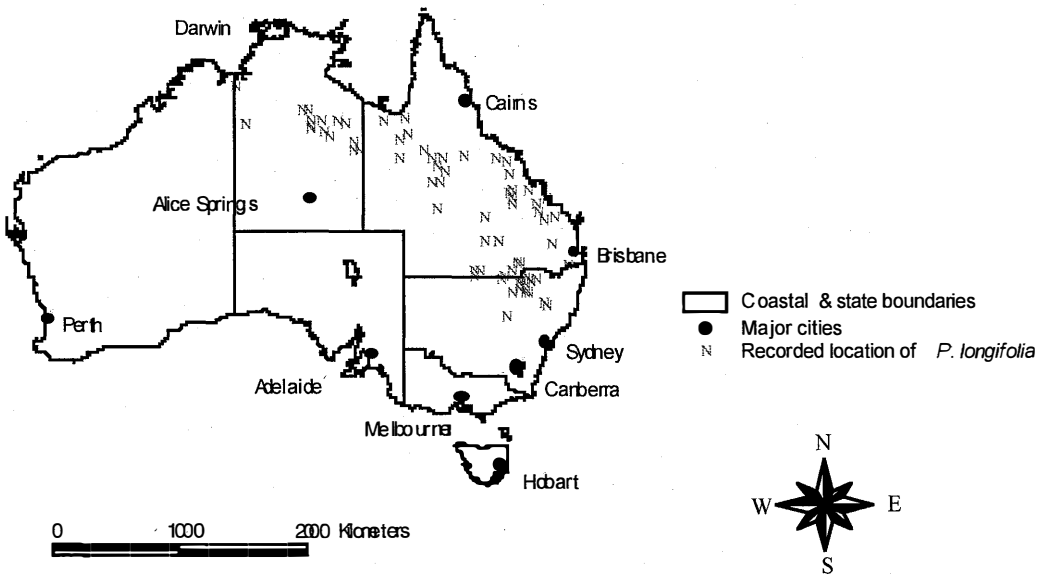


Figure 2.2 The distribution of *P. longifolia* according to Australian herbarium records and collections made by the author. The southern-most recorded instance was in the Macquarie Valley (NSW) and the northern-most in the Kimberley area of Western Australia (WA).

growing areas in northern NSW (Hnatiuk 1990), particularly around the Barringun, Brewarrina and Walgett districts (Cunningham *et al.* 1981). However, the species has been observed as far south as Warren in the Macquarie Valley in central NSW (S. McCalman, pers. comm.).

In Queensland, *P. longifolia* has been recorded in all major pastoral districts except three and all major cotton growing areas (Anon. 1994; R. Johnson, pers. comm.). Stanley and Ross (1986) also noted that this species was common in the Burnett and Darling Downs districts of south-eastern Queensland. *Polymeria longifolia* is present in two pastoral regions in the Northern Territory (Hnatiuk 1990), while a single observation has been made in the Kimberley area of Western Australia near Kununurra (Harden 1992, Wheeler *et al.* 1992, Figure 2.2).

2.4.5 Habitat

2.4.5.1 Climatic requirements

Polymeria longifolia emerges rapidly in spring, often around the time of cotton planting, which occurs at or after the soil temperature has reached a minimum of 14°C at ten centimetres soil depth on three consecutive days just after sunrise (Constable and Shaw 1988). There is active plant growth over the summer period from October until at least April.

Although perennial, *P. longifolia* may disappear in winter in some cotton areas in NSW. Charles (pers. comm.) suggests that this disappearance is linked to frost damage. Both McMillan (1988a) and Williams (1988) suggested that *P. longifolia* is dormant during the dry (winter) season and responds to the onset of rain.

Cunningham *et al.* (1981) reported that *P. longifolia* was generally uncommon except in "seasons of abundant summer rainfall when it may form mats over small localised areas". Records from the Queensland Herbarium also indicate that abundance is enhanced by rainfall but that the species tends to be common in many of the communities in which it grows (R. Johnson, pers. comm.).

2.4.5.2 Plant associations and substratum

Kleinschmidt and Johnson (1977) recorded the presence of *P. longifolia* in open Mitchell and blue grass country, Cunningham *et al.* (1981) found it in Mitchell grass and coolibah communities on heavy grey clay soils, while Harden (1992) recorded the presence of *P. longifolia* in grassland and open grassy woodland on clay soils.

Nelder (1992) surveyed the vascular plants in four western Queensland pastoral districts and found that *P. longifolia* occurred in the following vegetation groups: (1) *Eucalyptus* spp. dominated associations along watercourses (including coolibah communities) and short grass/forb associations on alluvial plains, (2) *Chenopodium auricomum* (bluebush) dominated associations (including swamp, claypan and ephemeral lake vegetation) and (3) *Astrebla* spp. (Mitchell grass) dominated associations on undulating downs and grass/forb associations on stony downs.

The first two vegetation groups were found associated with flood plains, watercourses, drainage lines and localised wet areas while the third vegetation group was associated with flat to undulating plains. Almost without exception, the soils were red, black, brown or grey cracking clays with some alluvial material.

Jessop (1981) reported that this species was found on dark clay soils while Williams (1988) noted that *P. longifolia* had been observed on "heavy, dark brown, alluvial clay loams". There is no discrepancy between these descriptions and those contained on collection labels for specimens of *P. longifolia* at the Queensland Herbarium (R. Johnson, pers. comm.). Dr Johnson suggests that *P. longifolia* is a diagnostic species of heavy black soil country that is often covered by the Mitchell grasslands. This fact has been shown independently by a National Parks and Wildlife report on the Mitchell grass downs in the Northern Territory (Connors *et al*. 1996). The species has also been found on the heavy red clays that support brigalow communities (R. Johnson, pers. comm.).

In general, *P. longifolia* grows in areas that receive a comparatively large amount of run-off or drainage moisture, often in shallow depressions or flood ways (Cunningham *et al.* 1981; Williams 1988; R. Johnson, pers. comm.). *Polymeria longifolia* may be moderately tolerant of flooding. One herbarium record indicated that *P. longifolia* plants were unaffected by 30 cm of water covering them for two weeks (R. Johnson, pers. comm.).

2.4.6 Morphology

This section aims to describe the external morphology of *P. longifolia* by briefly describing plates of three representative plants (Plate 2.2). A fuller botanical description of the shoots of *P. longifolia* is given in Section 2.4.2 with population biology information in Section 5.4. Rhizome morphology and distribution down the soil profile is examined in Sections 4.2 and 4.3.

Polymeria longifolia is distinct from other members of the Convolvulaceae, for example *C. arvensis,* in that aerial shoots do not twine. The shoots of *P. longifolia* are connected to a network of rhizomes below the ground. These rhizomes have been classified by the author into three functional categories - vertical shoot-bearing rhizomes, horizontal rhizomes that usually give rise to vertical shoot-bearing rhizomes but may also give rise to shoots and vertical rhizomes, which penetrate down into the soil and do not give rise to shoots (Plates 2.2a, b).

The point at which the purple colouration on the lower stem runs into the white of the rhizome (Plate 2.2a) is the approximate level of the soil/air interface. In this case, soil came higher up the stem so that roots are clustered at several points above as well as below this level, both on the vertical shoot-bearing rhizome and also on the horizontal rhizome. These roots can also be observed at the junction of the vertical shoot-bearing rhizome and horizontal rhizome and are true roots which function as sites at which soil nutrients and water enter the plant (Section 4.5). Vertical rhizomes commonly arise from this junction (Plates 2.2a and b). These vertical rhizomes probably have two functions. Firstly, they may aid in root exploration and help support the plant by allowing the acquisition of water and nutrients when the soil surface layers become dry and, secondly, they may give rise to other shoot material at some distance from the existing plant. The penetration of vertical

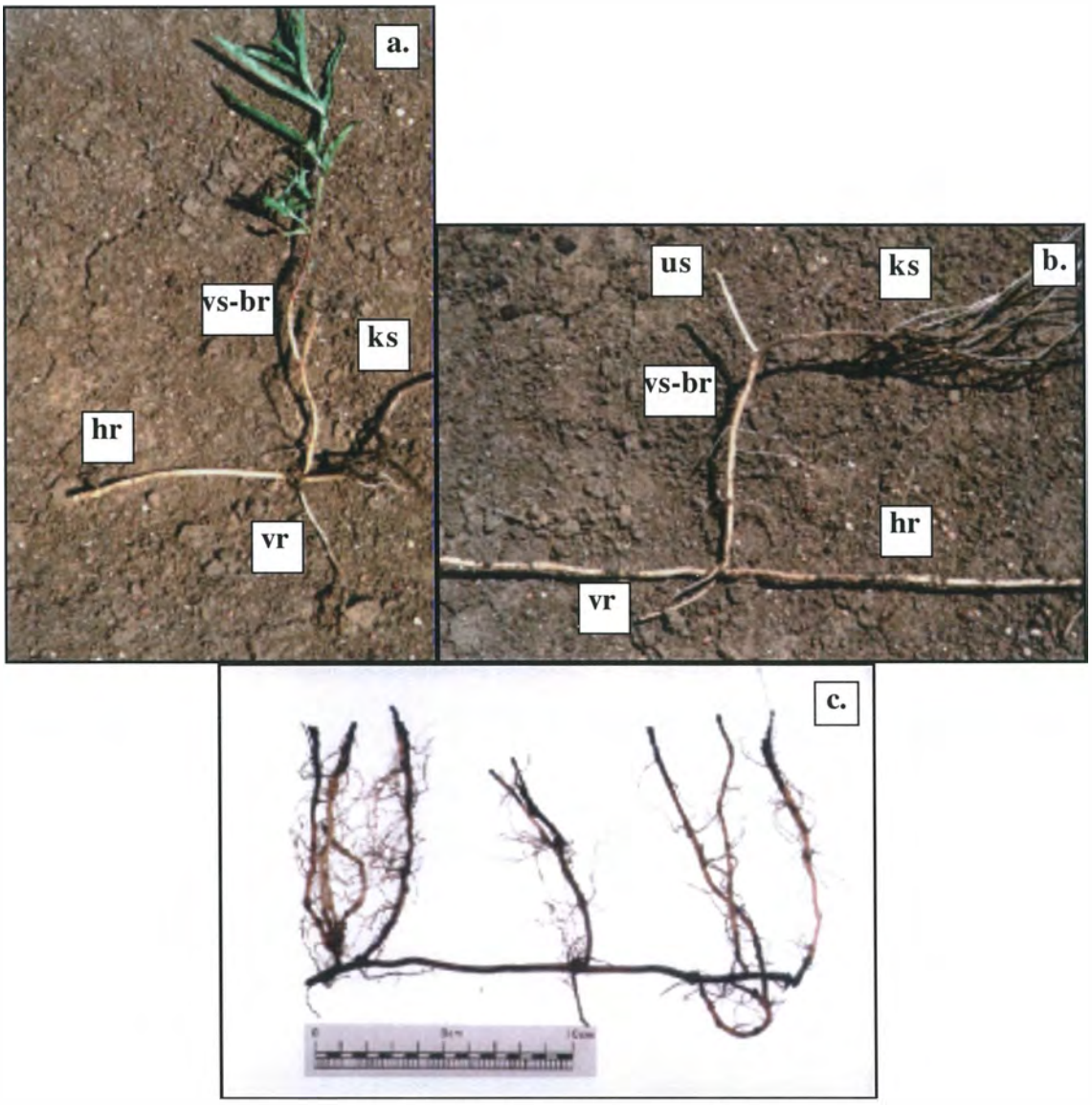


Plate 2.2 The morphology of *P. longifolia* plants. Plate 2.2a shows a typical vertical shoot-bearing rhizome (**vs-br**), approximately 20 cm tall from the node junction to the tip of the tallest leaf. A vertical rhizome (**vr**) arises from a node on the horizontal rhizome (**hr**). Plate 2.2b shows a previously killed *P. longifolia* shoot (**ks**) with a new, but unemerged shoot (**us**) arising from a node on the vertical shoot-bearing rhizome. The distance from the tip of the unemerged shoot to the horizontal rhizome is approximately 15 cm. Plate 2.2c illustrates shoot production by a section of *P. longifolia* rhizome. The horizontal rhizome has produced five shoot-bearing rhizomes; this figure shows the shoots cut off however. The shoot-bearing rhizome on the left has produced four shoots while the rest have produced two.

rhizomes of *P. longifolia* is supported by observations reported in Chapter 4 (Sections 4.3 and 4.4).

New *P. longifolia* shoots arise from rhizome nodes, particularly after defoliation (Plates 2.2a and b). Plate 2.2b illustrates a shoot killed by herbicide then partially buried by cultivation. The vertical shoot-bearing rhizome was dead down to the point from where the new white shoot has arisen. This new shoot is quite distinct in that it has no colouration except the slight green of the curled end which is typical of all unemerged shoots observed. *Polymeria longifolia* responds similarly to defoliation by either herbicide or cultivation in that the next undamaged node down the vertical shoot-bearing rhizome produces a new shoot with the remaining stump becoming brown and lignified (Plate 2.2a).

Horizontal rhizomes may produce vertical shoot-bearing rhizomes, which may give rise to either a single shoot or as many as four or more shoots (see left of Plate 2.2c) from a node on the vertical shoot-bearing rhizome. Thickening of rhizomes and nodes is common (Plate 2.2c).

There is no knowing which shoots are connected to each other by way of rhizomes without complete excavation. Aside from the limited excavations in Section 4.4, no studies were conducted to determine how many distinct plants were present in any study area. For this reason the basic population unit used in this thesis was the density of above-ground shoots (stem density).

2.4.7 Reproduction

Cunningham *et al.* (1981) noted two types of stems that arise from *P. longifolia* plants. The first type were small runners or shoots up to 30 cm long which arise from the central rootstock, presumably on the soil surface. The second were long underground stems or

rhizomes, which may be one metre or more in length. These underground stems (rhizomes) were able to send up new leafy shoots at intervals thus aiding in spread (Cunningham *et al.* 1981; Auld and Medd 1987; McMillan 1988a; Charles 1991; Wilson *et al.* 1995; R. Johnson, pers. comm.).

Anecdotal evidence also suggests that *P. longifolia* spreads vegetatively and that cultivation breaks off viable plant propagules large enough to reproduce independently when distributed within or between fields. However, Osten (pers. comm.) noted that even under continuous cultivation clumps of *P. longifolia* remained persistent and failed to spread either exponentially or rapidly across the field. This spread would be expected if a large number of viable plant propagules were being distributed away from original infestations. The role of soil cultivation in the dispersal of *P. longifolia* therefore needs to be examined. Anecdotal evidence concerning the spatial distribution of *P. longifolia* in the field suggests that where the weed occurred in uncultivated grassland, it may also occur in cultivated cotton fields after the break up of the country.

There are no published reports on the size of *P. longifolia* infestations or its rate of spread. Observations by various workers have included reports of small patches from one metre in diameter to at least 20 metres in diameter. *Polymeria longifolia* is said to grow in clumps which gradually expand in size (McMillan 1988a; R. Johnson, pers. comm.). Charles (pers. comm.) suggests that this species enlarges the diameter of its patches by approximately two metres per year.

Expansion in the size of these patches has been attributed to vegetative reproduction from the dense rhizomatous root system which appears to be largely resistant to chemical and cultural control (McMillan 1988a). However, there has been no research into the way that *P. longifolia* reproduces or spreads. Many people suggest that this species spreads by intact or disturbed rhizome fragments while a few favour reproduction and spread by seeds.

2.4.8 Importance

2.4.8.1 Detrimental

This species has been recorded as a weed of wheat and sunflower (Garah, NSW), wheat and sorghum (Gunnedah, NSW), sorghum (Richmond, Qld) and soybean crops (St. George, Qld) and in other black soil cropping districts, e.g. Burren Junction, Moree and Walgett in NSW and Macalister, Monto, Mungindi and Springsure in Qld (R. Johnson, pers. comm.). Although Felton (1979) did not record the presence of *P. longifolia* in a survey of District Agronomists which assessed the weed problems of irrigated and dryland soybean crops in NSW, it was recorded in northern NSW cropping regions in 1983 as part of the taxa the authors called the "*Polymeria* and *Haloragis* spp." (Martin and McMillan 1984). The species was reported as being among one of the ten major weeds of cotton in a NSW survey conducted in the 1988/89 season (Charles 1991). Further, Charles (1991) noted that *P. longifolia* was becoming a major problem on some properties and that it may become an industry-wide problem. *Polymeria longifolia* was not recorded in other dryland cropping surveys in either winter (Martin *et al.* 1988) or summer crops (Felton *et al.* 1994).

Charles (1996a) reports on field survey data collected by Paul Castor and Max McMillan on 23 properties in the Gwydir and Macintyre Valleys in the 1991/92 season. This research indicated a density of *P. longifolia* of 0.09 plants per square metre (900 plants/ha). *Ipomoea lonchophylla* (peach vine) had a density of 3.08 plants per square metre (30,800 plants/ha) by comparison and was the densest weed surveyed.

An unpublished survey was commissioned by the Cotton Consultants Association (CCA) in 1993, the professional association covering NSW and southern Qld consultants, and achieved an 85% response rate. The number of consultants surveyed was not supplied. The number of times that *P. longifolia* was noted as being in the top ten weeds was 15

compared with 42 for *Tribulus* spp. (yellow vine), the most often mentioned weed. *Polymeria longifolia* was the thirteenth most commonly mentioned weed. Respondents were asked to rate the top ten weeds they encountered from ten to one in terms of abundance. When these abundance scores were summed and divided by the total number of entries for each weed, *P. longifolia* had a score of 4.2 (rated seventeenth), while *Hibiscus trionum* (bladder ketmia), the most abundant weed, had a total score of 7.3.

Respondents were asked to rate their ten worst weeds in terms of difficulty of control. *Polymeria longifolia* was rated as the third most difficult weed to control with a score of 8.7, compared with *Haloragis glauca* (raspweed) as the most difficult to control (score 9.5) and *Cyperus* spp. (nutgrass) the second most difficult to control (score 9.1).

Polymeria longifolia appears to be increasing in incidence. When consultants were asked to rate the incidence of each weed mentioned with a (-) to indicate a decrease, 0 to indicate it was stable or (+) to indicate an increase, a score of +8 was obtained. The "highest" upward trend was recorded for *Cyperus* spp. (nutgrass) with consultants rating it +23. *Polymeria longifolia* had the fourth "highest" trend (D. Clark, pers. comm.).

Charles (1991) surveyed 52 properties in the major cotton growing areas of NSW (i.e. Macintyre, Gwydir, Namoi, Mooki, Darling and Macquarie Valleys) using a postal questionnaire to growers followed up by an interview (Table 2.1). Although this survey found that only 3% of these areas were covered by *P. longifolia*, there was a perceived increase in the incidence of this weed.

An unpublished mail survey about perennial weeds in the central Queensland shires of Belyando, Peak Downs, Emerald and Bauhinia (Central Highlands) also indicated the presence of *P. longifolia* (Osten 1988). In this survey of 100 growers, a 49% response rate was obtained. A total of 54,981 hectares of cultivated land was surveyed which included

Table 2.1 Weed species that growers identified as important problems in NSW cotton growing areas. Weed importance (mean ± s.e.) was ranked from 10 to 1, where a 10 indicated that all growers considered the weed to be the most important. For trend in incidence (mean ± s.e.), 10 indicates a rapid increase, 0 a stable incidence and -10 a rapid decrease (from Charles 1991).

Weed species	Percentage of properties affected	Weed importance	Percentage of area affected	Trend in incidence
Xanthium occidentale	87	6.6±0.5	44±6	-3.6±1.1
Cyperus spp.	79	5.3±0.5	15±3	7.1±0.8
Xanthium spinosum	60	4.7±0.6	34±6	-1.5±1.0
Physalis spp.	46	3.2±0.6	18±4	-1.7±1.2
Ipomoea lonchophylla	42	3.1±0.6	20±4	-1.8±0.9
Hibiscus trionum	40	2.9±0.6	22±5	-2.9±1.2
Datura spp.	38	2.6±0.5	14±4	-3.3±1.0
Tribulus spp.	37	2.5±0.5	16±4	-2.5±1.0
Haloragis glauca	37	1.8±0.4	4±2	4.2±0.9
Polymeria longifolia	**23**	**1.5±0.4**	**3±2**	**3.3±1.3**
Sesbania cannabina	25	1.4±0.4	4±2	6.3±1.1
Echinochloa crus-galli	21	1.1±0.3	10±4	-3.3±1.3
Salvia reflexa	17	1.1±0.4	5±1	-2.5±1.4

42,486 hectares of open downs soils (heavy black clays) and 12,495 hectares of scrub or brigalow soils (heavy red clays). Of the 49 respondents, 21 (43%) reported *P. longifolia* infestations covering 2,512 hectares (6%) of open downs soils and 606 hectares (5%) of scrub soil surveyed. There appeared to be no preference of *P. longifolia* for soil type. Only 24% of respondents reported infestations were increasing in size.

A total of 33% of respondents reported that infestations occurred on recently-broken up fields (1 - 5 years since break-up) while another 5% identified fields cultivated for five to

ten years. A further 14% reported infestations on soils that had been cultivated for more than ten years. Another 10% of respondents reported this weed on cultivation of any age while 38% were unsure of cultivation age of their fields. A total of 76% of respondents believed that this weed was "very difficult" or "difficult" to control (33% and 43% respectively). A further 19% believed that *P. longifolia* was easy to control but did not offer any management advice. Only 5% of growers were unsure (Osten 1988).

An earlier survey about perennial weeds was conducted at a meeting with 46 growers from the highlands of central Queensland (Hazard 1974). The survey conducted by Osten (1988) included the same general area but not all properties were resurveyed. Properties had been sold, divided or had changed farming enterprise between 1974 and 1988. Hazard's survey indicated that *P. longifolia* infestations covered 1.09% of open downs soils and 0.78% of scrub or brigalow soils surveyed. On a ten point scale, 2% of farmers ranked this weed as a one (the most difficult to control in fallow) while 3% ranked this as a two, and 4% ranked it as a three. In the same survey, *Haloragis aspera* (raspweed) was ranked the most difficult weed to control in fallow situations (16%).

The competitive impact that *P. longifolia* had on summer crops was also ranked on a ten point scale. While 10% of growers ranked *P. longifolia* impact to be in the top five rankings, 19% of growers ranked *H. aspera* the most prevalent perennial weed. Of all growers surveyed, 9% indicated *P. longifolia* was increasing while 21% indicated that infestations were static. No one indicated that the weed was decreasing. A total of 21% of growers indicated that *P. longifolia* was a weed of cultivated fields that had been broken up less than ten years ago (6%, one to five years ago; 15%, five to ten years ago). Another 6% indicated that this weed was a problem on fields that had been cultivated ten to twenty years previously. There were two reports that safflower and wheat, both winter crops, reduced the incidence of this weed.

One general trend from the surveys outlined above is that the area of *P. longifolia* infestations is increasing. This conclusion must be treated with caution, however, as other factors may complicate this perception. As annual weed problems have become increasingly controlled in cultivated areas the attention of many growers may have shifted to the perennial weeds that are more difficult to control. Therefore, *P. longifolia* may be perceived to be more important or may be increasing simply because no effective control measures are available.

Polymeria longifolia remains a difficult weed to control in cultivation. Various growers and researchers have noted that yields of either wheat or cotton in patches infested with *P. longifolia* approach zero due to the competitive impact of this species.

2.4.8.2 Beneficial

There is only one record of a beneficial importance of *P. longifolia*, and that is that it may be grazed (Cunningham *et al.* 1981).

2.4.9 Management of Polymeria longifolia

Control measures for *P. longifolia* are far from satisfactory and progress towards improved control systems have been slow due to a lack of research effort (McMillan 1988a).

2.4.9.1 Herbicides

Polymeria longifolia appears to grow actively over the summer period from October until at least April. In general, the treatment of *P. longifolia* in winter with fallow herbicides appears to be ineffective because the plant is not actively growing (McMillan 1988a). The

results of five separate herbicide trials on *P. longifolia* are outlined in Table 2.2. This information is derived in part from trial results taken from Tables 2.4 - 2.7.

All herbicides that were commonly applied as either pre- or post-emergent applications in cotton were ineffective on *P. longifolia.* Harvey (1989) also supported these observations in trials conducted under central Queensland conditions (Table 2.3). The only herbicides to show any promise were the phenoxy group and fluroxypyr (Starane® registered trademark of Dow AgroSciences) with the best results obtained in March under excellent moisture conditions (McMillan 1988a).

Kleinschmidt and Johnson (1977) noted that *P. longifolia* was susceptible to 2,4-D amine and that effective control could be achieved by spraying at 2 L/ha (trade product rate) at the pre- to early flowering stages. More than one spray was thought to be necessary to kill the rhizomes found deeper in the soil. These conclusions were shared by Charles (1991) but it is important to remember that 2,4-D amine cannot be used in cotton crops due to susceptibility problems.

Scarsbrick *et al.* (1979) showed that glyphosate rates above 2 L/ha (trade product) resulted in a 60% reduction in infestation density over untreated controls (Table 2.4). Strachan (1983) outlined research particularly dealing with 2,4-D ester and herbicide mixtures (Table 2.5). Treatments of 2,4-D amine, 2,4-D ester and a mixture of picloram and 2,4-D amine (Tordon 50-D® registered trademark of Dow AgroSciences) alone as well as mixtures of these herbicides killed over 90% of *P. longifolia* stems compared with controls. Aside from fluroxypyr and the phenoxy herbicides referred to above many other herbicides were ineffective in reducing the incidence of this weed when compared with untreated controls (Table 2.6 - 2.7).

Table 2.2 The effectiveness of various herbicide treatments applied at the pre- and post-emergence stages in cotton in the control of *P. longifolia*, until 1988 (from McMillan 1988a).

Apparent effectiveness	Herbicide treatment	Application time	Active ingredient
Effective	2,4-D amine	post	-
	Starane®	post	fluroxypyr (300g/L)
	MCPA	post	-
	Tordon 50-D®	post	picloram (50g/L) and 2,4-D amine (200g/L)
Moderately effective	glyphosate	post	-
	dichloroprop	post	-
Ineffective	fluometuron	pre and post	-
	diuron	pre and post	-
	prometryn	pre and post	-
	Goal®	pre and post	oxyfluorfen (240g/L)
	Bladex®	pre	cyanazine (500g/L)
	Probe®	pre	methazole (800g/kg)
	MSMA	post	-
	Glean®	post	chlorsulfuron (750g/kg)
	Basta®	post	glufosinate-ammonium (200g/L)
	Ally®	post	metsulfuron-methyl (600g/kg)
	amitrole	post	-
	dicamba	post	-

Registered trademarks - AgrEvo (Basta®); Cyanamid Agriculture (Bladex®); Dow AgroSciences (Starane®, Tordon 50-D®); DuPont (Ally®, Glean®); Monsanto (Goal®); Novartis Crop Protection (Probe®).

Table 2.3 A guide to the herbicide susceptibility of *P. longifolia* in central Queensland (from Harvey 1989). The effectiveness measures were indicated as R (resistant); and S (substantial damage).

Herbicide treatment	Active ingredient	Effectiveness
Ally®	metsulfuron (600g/kg)	R
Roundup®	glyphosate (360g/L)	S
Spray.seed®	paraquat (125g/L) and diquat (100g/L)	S
Atrazine	-	S
2,4-D amine	-	S

Registered trademarks - Ally® as for Table 2.2; Rohm and Haas (Spray.seed®) and Monsanto (Roundup®).

Table 2.4 The effectiveness of varying rates of glyphosate applied in December 1978 to actively growing (early flowering) *P. longifolia* at Moree in north western NSW. The application rate is the amount of trade product used per hectare. Values are the means of three replicates (from Scarsbrick *et al.* 1979).

Treatment	(L/ha)	Percentage reduction compared with nil treatment	
		Mean	Range
Glyphosate	1	23	20-30
Glyphosate	2	60	50-70
Glyphosate	4	73	70-80
Glyphosate	6	77	70-80
Glyphosate	8	80	60-90
Control		0	0

Table 2.5 The effectiveness of varying herbicides and herbicide mixtures on the control of actively growing (flowering) *P. longifolia* at Moree in north western NSW. The application rate is the amount of trade product used per hectare. The percentage kill of *P. longifolia* was compared with non treated controls and the mean percentage ground cover was assessed after spraying (from Strachan 1983).

Treatment	**Application rate** (L/ha)	**% kill of *P. longifolia***	**Mean % ground cover**
2,4-D amine	2	100	0
Roundup® + 2,4-D ester	2 + 1.5	99	0.3
2,4-D ester	1.25	98	0.5
Tordon 50-D® + 2,4-D amine	1.4 +2	98	0.5
Dicamba + 2,4-D amine	1.4 + 2	98	0.7
Tordon 50-D®+ Dicamba	1.4 + 1.4	96	1.0
Tordon 50-D®	1.4	96	1.2
Roundup®	2	46	12.5
Weedazol TL Plus®[a]	5.6	43	13.3
Dicamba	1.4	11	24.0
Glean®	30 g	0	34.0
Control	-	0	23.0

Registered trademarks - Roundup® as for Table 2.3; Tordon 50-D® and Glean® as for Table 2.2; and Rhone-Poulenc (Weedazol TL Plus®).

[a] Active ingredients - amitrole (250g/L) and ammonium thiocyanate (220g/L).

Table 2.6 The effectiveness of varying herbicides on the control of actively growing *P. longifolia* near Moree in north western NSW. The application rate is the amount of trade product used per hectare. The Polymeria score indicated by 2.1 - 3.0 indicated moderate weed damage and 3.1 - 4 .0 indicated severe damage. A score of 4.1 - 5.0 would be used for total plant death. Values are the means of four replicates and measurements were taken 39 days after treatment. There was no significant difference in these treatments using the 5% l.s.d. ($P < 0.05$) (from McMillan and Cook 1989).

Treatment	Application rate (/ha)	Active Ingredient	Polymeria score (0-5)
Solicam®	2.5 kg	norflurazon (800 g/kg)	3.7
Ronstar®	4.0 L	oxadiazon (20g/kg)	3.5
Probe®	2.7 kg	methazole (800g/kg)	3.1
Goal®	4.0 L	oxyfluorfen (240g/L)	2.7
Bladex®	3.5 L	cyanazine (500g/L)	2.6
Control	-	-	2.7

Registered trademarks - (Goal®) and (Bladex®) as for Table 2.2; Novartis Crop Protection (Solicam®, Probe®); and Rhone-Poulenc (Ronstar®).

The ability of this species to regrow from rhizomes after herbicide application or defoliation of the shoot by cultivation or chipping needs to be investigated. Defoliation by any one of the above means, or even frosting off, may release the dominance that existing shoots have over the buds on the rhizome and promote emergence of further shoots once suitable conditions permit.

The release of the new herbicide pyrithiobac-sodium (Staple® registered trademark of DuPont) - will not have any real effect on *P. longifolia* infestations. At best, pyrithiobac-sodium will suppress *P. longifolia* growth and turn shoots yellow but shoots soon recover (DuPont representative, G. Cornwell, pers. comm.).

Table 2.7 *Polymeria longifolia* control using various herbicides at Garah, north of Moree in north western NSW. The application rate is the amount of trade product used per hectare. The Polymeria brownout and score indicated by 0 indicated no damage, 0.1 - 1.0 indicated slight traces of herbicide activity, 1.1 - 2.0 indicated commercially unacceptable damage present, 2.1 - 3.0 indicated moderate weed damage and 3.1 - 4.0 indicated severe damage. A score of 4.1 - 5.0 would be used for total plant death. Values are the means of three replicates and measurements taken 24 days (*P. longifolia* brownout) and 65 days (other measurements) after treatment. The 5% l.s.d. significance test was undertaken, (from McMillan and Cook 1989).

Treatment	**Application rate** (L/ha)	**Polymeria brownout (0-5)**	**Polymeria score (0-5)**	**Stem count/m^2**
Starane®	2	4.0	3.1	19.0
Starane®	1	2.8	2.7	16.9
2,4-D amine	2	2.5	2.2	28.1
2,4-D amine	1	1.7	1.2	43.8
MCPA	2	2.2	2.1	36.4
MCPA	1	1.2	1.1	70.9
2,4-D amine + Ally®	1 + 10 g	1.2	0.8	45.5
2,4-DP	1.7	1.8	0.6	46.6
Basta®	3.0	0.8	0.3	68.5
Control	-	0	0.5	59.9
5% l.s.d.		0.7	1.3	29.8

Registered trademarks - Starane®, Ally® and Basta®as for Table 2.2.

2.4.9.2 Other treatments

McMillan (1988a) made several recommendations regarding the management of *P. longifolia* in cotton fields. Fields that were infested were best left out of production for a season while the weed was attacked with cultivation and herbicide during the summer. A rotation

with soybeans was seen to be feasible as this would allow a herbicide pre-treatment and the soybeans would then be able to shade out later emerging plants. Spray drift of herbicides onto susceptible cotton areas is a risk with this approach.

In fields where only light infestations occur, diligent and frequent inter-row cultivation and heavy chipping were regarded as the most effective management options (McMillan 1988a). Various pieces of anecdotal evidence confirm these conclusions, particularly with respect to the control of *P. longifolia* infestations with cultivation until cotton is able to overtop the weed and shade it out.

Weed control measures used in cotton crops are often very costly but largely ineffective against *P. longifolia*. A better understanding of the ecology of the plant is needed in order to design effective, cheaper and more sustainable management practices.

2.4.10 Insects, nematodes and fungi of P. longifolia

Various insects, a nematode and fungi have been recorded on *P. longifolia*. The beetle, *Carpophilus* spp. (Coleoptera), appears to feed on the pollen and corolla of open flowers early in the cotton growing season (observed by the author and identified by Marie Louise Johnson, UNE). This insect was not observed after December in any season of this study, perhaps due to increasing insecticide spray pressure. Damage to maturing seeds of *P. longifolia* was observed in February 1997. *Helicoverpa* spp. were probably devouring the developing seeds and an estimated 10 - 30% of all maturing seeds were destroyed in this way.

The root knot nematode (*Meloidogyne* spp.) has been positively identified on the roots of *P. longifolia* grown in pot culture. This nematode has not been observed in the field.

Prior to the current study, *Puccinia* rust had been collected on *P. longifolia* on at least four occasions. Three of these collections were identified as such by John Walker at the Biological and Chemical Research Institute at Rydalmere (NSW) and lodged in their herbarium as accessions DAR 23295 (Feb 1972), an unknown accession number (May 1977) and DAR 41434 (April 1982). A further specimen was recorded in Queensland. Two rust specimens collected in 1997 were sent to the curator of Plant Pathology Herbarium for NSW Agriculture at Orange. The first specimen could not be identified to the species level and it was postulated that the species may not have been described previously. This specimen was added to a number of other NSW and Queensland specimens lodged since 1982. There was strong evidence that the rust was not *Puccinia dichondrae* which is the only other widespread rust on plants in the Convolvulaceae family. The second specimen had been heavily parasitised in the field by the hyperparasite fungus *Sphaerellopsis filum*. A slime mould fungi *Physarum cinereum* was found on a third specimen sent. The slime mould had evidently moved up the plant stems to sporulate.

The *Puccinia* rust was the only disease recorded on *P. longifolia*. This rust is unlikely to hold significant prospects for long term biological control because it has not been aggressive enough to have caused serious damage in the past. Moreover, rust pathogens cannot be easily cultured in the laboratory but must be cultured on live plants in an artificial situation (D. Nehl, pers. comm.).

2.5 Summary

Polymeria longifolia is a native Australian species and a weed of summer cropping systems, particularly cotton throughout NSW and Qld. There is a lack of information regarding the distribution and importance of this weed in the cotton industry and for this reason a survey of key industry personnel would be helpful. This survey is outlined in Chapter 3.

Since current control measures are costly but largely ineffective against *P. longifolia,* a better understanding of the biology and ecology of the species is needed in order to design effective, cheaper and more sustainable management practices. To this end, and since no other biology or ecology studies on *P. longifolia* exist, an examination of the population biology of the weed has been undertaken in Chapter 5. Of particular importance is an understanding of the rhizomatous root system which is largely resistant to chemical or cultural control (Chapter 4) and how this species reproduces and spreads (Chapter 6). In addition, there is a conspicuous lack of information on the competitive impact of *P. longifolia* on cotton and the mechanisms by which the weed interferes with cotton growth. These aspects have been examined in Chapters 7 and 8.

If control measures are to be improved then an understanding of why management has failed in the past is needed (Chapter 9). Finally the factors that promote the growth of *P. longifolia* in cotton farming systems have been examined to elucidate some of the principles for more effective management of this weed (Chapter 10).

Polymeria longifolia in wheat

Chapter 3

Polymeria longifolia and its place in the cotton industry:

A consultant's perspective

"The importance of a weed, economic or otherwise, cannot be fully appreciated unless the actual extent of the problem is known" (Smith 1975).

3.1 Introduction

Polymeria longifolia affects both irrigated and dryland cropping in Australia. In a survey of cotton growers conducted during the 1988/89 growing season, *P. longifolia* was found to affect 23% of cotton properties and appeared to be increasing in abundance (Charles 1991).

While there has been extensive research into the distribution, basic biology and control of many weeds in Australia, for example Groves *et al*. (1995) and Panetta *et al*. (1998), there is a notable lack of accurate, easily obtained, published data on many others (Cuthbertson 1978). This is particularly the case with the 34 weed genera indicated as problems in the Australian cotton industry, including *P. longifolia* (Charles 1991).

This work aimed to ascertain biological and distribution information about *P. longifolia* using a questionnaire[1] mailed to cotton consultants. In particular, information was sought on the relative importance of *P. longifolia* among other weeds of cotton, where *P. longifolia* occurred and what problems it caused, the cost of control, effective management methods and factors that favoured the growth of *P. longifolia* in cotton.

3.2 Literature review of survey methodology

3.2.1 Survey types

Field surveys allow the collection of a wide range of data including species presence, abundance, altitude, aspect, habitat and soil and water relationships (Cuthbertson 1978). Such surveys require a stratified (non-random) sampling procedure to be undertaken by researchers (Auld and Scarsbrick 1970; Burdon *et al.* 1981; Amor and Francisco 1987; Martin *et al.* 1988; Felton *et al.* 1994) or trained personnel (Smith 1975). They are expensive in terms of money and time.

Remote sensing of weeds is increasing in use. Aerial photography saves both time and money and has been used successfully for rangeland and aquatic weeds (Arnold *et al.* 1985; Pitt and Miller 1988; Everitt *et al.* 1992; Miller 1996). Satellite or air-borne video imagery has also been used to an increasing extent (Ullah *et al.* 1989a, 1989b; Everitt *et al.* 1992; Kerr and Westbrooke 1996; Lass *et al.* 1996; Lamb and Weedon 1998). As resolution improves these techniques may become more common as a means of detecting, mapping and monitoring stands of weeds.

[1] The word questionnaire and survey have been used interchangeably throughout the thesis.

Other survey methods include literature reviews, the examination of herbarium samples and Department of Agriculture records. These techniques are often limited by author experience, the information may be collected from limited areas, or it may be difficult to obtain (Cuthbertson 1978).

3.2.2 Questionnaires

Questionnaires can be a time-effective method of determining the general distribution of a weed (Cuthbertson 1978). Their success depends on the co-operation of a large number of individuals, with the accuracy of the final distribution being a function of the accuracy of the respondents' answers. Questionnaires may be conducted by personally interviewing each respondent or by mailing a questionnaire to the relevant sample group.

The advantage to personal interviews is that a 100% response rate can be achieved. The disadvantages are that fewer responses can be obtained because of time limitations and the cost of travel (Smith 1975; Shovelton 1979; Dellow and Seaman 1987). In comparison, mail questionnaires generally have a low return rate but techniques exist to enhance this. In general, the questions should be ordered logically, set out as attractively as possible and expressed clearly, unambiguously and precisely i.e. capable of being answered in a limited number of ways. In addition, questions should be framed to get the desired information and they should be capable of being answered objectively. Leading questions should be avoided. The categories included in questions should be exhaustive and mutually exclusive and have clear specifications with respect to the type of answer required (Robinson and Agisim 1950; Karmel and Polasek 1970; Warwick and Liniger 1975). In addition, Freebairn (1967) suggested that adding space for the respondents to make their own comments added an element of individuality and ownership to the survey process, increasing the return rate.

A pilot or trial survey should be undertaken to elucidate any ambiguities or other problems that are intrinsic in the questioning (Freebairn 1967; Karmel and Polasek 1970; Warwick and Liniger 1975; Sudman and Bradburn 1983). This pilot study is usually carried with a small group of respondent individuals from the larger respondent population. Such a trial survey will also give some idea of the final response rate (Gray 1957; Freebairn 1967).

The inclusion of a reply-paid envelope will increase returns (Freebairn 1967; Warwick and Liniger 1975). The use of follow-up reminder mailings may also be necessary. As the most important reasons for non-reply were misplacing or overlooking the questionnaire, each follow-up mailing should include an additional questionnaire and reply-paid envelope (Robinson and Agisim 1950; Gray 1957). The use of a short accompanying letter with initial and reminder mailings may be an important tool in increasing response rate (Freebairn 1967; Warwick and Liniger 1975; Sudman and Bradburn 1983). Any accompanying letter should aim to gain the interest of the respondent and impress on them the importance of completing the questionnaire.

Dillon and Jarrett (1964) reviewed a number of mail surveys which did and did not include reminder letters. They recommended that two reminder notices be sent to non-respondents at intervals ten days after the initial mailing, although an interval of two to three weeks has been recommended by others (Freebairn 1967). A total response rate of 65% was achieved using two reminder notices, comprising 31% initial replies and 24% after the first reminder (Dillon and Jarrett 1964). Similarly, Freebairn (1967) achieved an overall return rate of 73% using this practice, with 32% responding initially and 31% after the first reminder.

The size and layout of the questionnaire is an important determinant in the questionnaire return rate. Sudman and Bradburn (1983) noted a generally acknowledged principle; that questionnaires should be as short and succinct as possible so that the quality of information will not be compromised. Eastwood (1940), in Robinson and Agisim (1950), noted that

more questionnaires were returned from light-coloured rather than dark-coloured or white stationary, as these colours stood out relative to ordinary paper on a surveyed person's desk.

A survey should be carried out when a weed species will be conspicuous by its growth habit or flowering and avoided at periods when the species is being controlled (Auld 1978). Such pertinent timing and considerable advance publicity contributed to the high return rate of 74% from a survey conducted on *Senecio madagascariensis* (Sindel and Michael 1988). Both factors were seen to have raised awareness of the weed and the problems it caused.

Other techniques have been used by some researchers to increase the return rate of questionnaires. Robinson and Agisim (1950) offered a universally attractive financial incentive to enhance return rate. They reported that the regular enclosure of 25 cents (the cost of postage at the time was four times less, i.e. 6 cents) with questionnaires sent to people on magazine reader lists, regularly resulted in response rates of between 60 - 80%. Further, the enclosure of $1 produced an equally high response. This result lead to the conclusion that while the value of the enclosure was not so important the psychology of doing it was. This psychology appeared to have been responsible in helping achieve an 85% return rate from a questionnaire sent to members of the Cotton Consultants Association (CCA) (D. Clark, pers. comm.). That survey was done for a chemical company on a contract basis by the CCA. The money from the company commission for the report was returned to the CCA for the use of its members. This consultant group was one of the two groups surveyed in the questionnaire reported in this chapter (Section 3.3). Unfortunately, information on the benefits of financial incentives was not obtained before the initial survey of this study was sent and so they were not used.

Warwick and Liniger (1975) suggested that deadline dates be included to increase response rate. Such dates must be thoughtfully set, if used. Robinson and Agisim (1950)

summarised nine nationwide studies in the USA and considered all had a very uniform and definitive pattern of return. An average of 90.5% of all respondents had returned the questionnaire by 14 days after mailing and at least 98.2% had responded by 21 days after the initial mailing. Dates set after this 21-day time period will not be effective in increasing response rates.

These results illustrate that many of the shortcomings of mail questionnaires can be overcome by careful design and explanation of the questionnaire.

3.3 Methods

The survey was given advance publicity by way of a poster presentation at the Eighth Australian Cotton Conference held from 14 - 16 August 1996 (Appendix 2) and piloted using consultants and growers at the conference.

Professional consultants were chosen to be surveyed over growers for several reasons. Firstly, liaison with potential respondents was thought to be easier, as only two professional associations existed, one in New South Wales (NSW) (Cotton Consultants Australia Inc.) and the other in Queensland (Qld) (Crop Management Consultants Association). On the other hand, there were many cotton grower associations. Secondly, consultants give a large proportion of the agronomic advice regarding weeds. Thirdly, because consultants were known to consult for a large number of separate growers, or on individual properties for large corporate companies, e.g. Auscott, Colly Farms, Tandou and Twynam, a more comprehensive picture of the many fields/properties would be obtained. It was hoped that this broader perspective would show less distortion than evaluations by individual growers.

Only consultant members who offered advice on a fee-for-service basis rather than those involved in the sale or promotion of individual products used in cotton production were surveyed. This avoided biasing the responses with regard to chemical use. The Cotton Consultants Australia group had previous exposure to weed and chemical surveys, and high return rates had been achieved (D. Clark, pers. comm.).

A short presentation about *P. longifolia* was delivered at a Cotton Consultants Australia meeting at Moree in northern NSW on 18 September 1996. Directly afterwards, the pink double sided survey form (Appendix 3) was handed out so that consultants could fill out the form at the meeting and provide feedback.

Questionnaires were then mailed to all consultant members who had not been present or had failed to complete the form at the meeting. Attached were a covering letter, a coloured information sheet to aid in the identification of *P. longifolia* (Appendix 3) and a pre-paid, self-addressed envelope for return of the form. In total, 66 surveys were sent to members of the Cotton Consultants Australia Association on 3 October 1996 with 12 additional letters to the Crop Management Consultants Association (Qld) on 11 November 1996.

The timing of the survey was such that the weed was either just emerging or starting to grow in fields after planting of the 1996/97 cotton crop. Data were manipulated using the statistical program SPSS-X. Percentages quoted are percentages of actual respondents for each question unless otherwise stated. Because respondents could give more than one answer for some questions, percentages do not always add to 100%.

3.4 Results and discussion

3.4.1 Survey response rate

In total, 96 consultants were contacted, of which 60 consultants (62.5%) replied. The response rate of this survey was comparable to that of other surveys that had utilised techniques to enhance the response rate, for example 47 - 74% (Dillon and Jarrett 1964; Freebairn 1967; Auld 1971; Sindel and Michael 1988; Stoller *et al.* 1993).

3.4.2 General consultant information

The largest percentage of respondents were from the Gwydir and Namoi Valleys (Table 3.1). The total number of properties covered was highest in the Namoi Valley, the Darling Downs/South Burnett region and the Gwydir Valley.

Consultants who responded to this survey covered between 46 and 100% of each cotton production region (Table 3.1). The consulted areas in the Gwydir Valley and Tandou areas were overestimated when compared with the Yearbook estimates, while specific Lachlan Valley estimates could not be found (Dowling 1997). A total of 72% of cotton production areas were covered by consultants in this survey. This proportion gives considerable confidence in the results.

3.4.3 The worst weeds

The importance of *P. longifolia* amongst cotton weeds was evaluated by asking consultants to list the five worst weeds they encountered in cotton crops in the 1995/96 season. The results are presented in Table 3.2.

Table 3.1 General information from consultants on the location, number and size of properties. The number and percentage of respondents do not add to the totals because consultants were able to indicate more than one growing region. The total number of hectares consulted on (irrigated and dryland), was compared with the Cotton Yearbook estimates for the 1996/97 season (Dowling 1997). Therefore the proportion of the actual area covered by this survey could be derived.

Cotton growing region	Number and % of respondents		Number of properties in survey	Total area in survey	Total cotton area[a]	Proportion of cotton area covered by survey (%)
	(No.)	(%)	(No.)	(ha)	(ha)	
Namoi Valley	16	27.6	154	39,250	83,000	47
Gwydir Valley	20	34.5	114	95,930	95,500	100
Macintyre Valley	10	17.2	70	47,350	57,000	83
Macquarie Valley	5	8.6	45	24,130	34,000	71
Lachlan Valley	1	1.7	1	1,670	-	-
Tandou	1	1.7	1	10,000	5,400	100
Bourke	2	3.4	5	10,100	12,500	81
Darling Downs/Sth. Burnett	7	12.1	146	33,950	62,500	54
St George	4	6.9	46	15,300	20,000	77
Theodore/Biloela/Moura	0	0	0	0	7,000	0
Emerald	2	3.4	28	5,550	12,000	46
Total	**60**	**100**	**610**	**283,330**	**388,900**	**72**

[a] Cotton Yearbook estimate (Dowling 1997).

These results indicate that *P. longifolia* was the fourth worst weed in Australian cotton crops, a significant increase since the last survey of NSW cotton growing regions in the 1988/89 season (Charles 1991, Table 3.2). *Polymeria longifolia* was ranked as the tenth worst weed in that survey, the thirteenth most mentioned and abundant weed in the CCA survey in 1993 (D. Clark, pers. comm.) and the eighth most abundant weed, included in a

Table 3.2 The ten worst weeds encountered in cotton crops in the 1995/96 season.

Weed	Common name	Percentage of respondents[a]	Score (out of 5)[b]	Rank	Rank Charles (1991)
Cyperus spp.	Nutgrass	57	2.11	1	2
Xanthium occidentale	Noogoora burr	63	1.89	2	1
Ipomoea lonchophylla	Peach vine	48	1.66	3	5
Polymeria longifolia	Polymeria take-all	29	1.16	4	10
Hibiscus trionum	Bladder ketmia	34	1.00	5	6
Datura spp.	Thornapple/Castor oil	34	0.88	6	7
Xanthium spinosum	Bathurst burr	29	0.75	7 (equal)	3
Sesbania cannabina	Sesbania pea	23	0.75	7 (equal)	11
Salvia reflexa	Mint weed	16	0.63	9	13
Tribulus spp.	Yellow vine/Caltrop	25	0.61	10	8

[a] This percentage represents the number of times that the weed was mentioned as one of the five worst weeds.

[b] The weeds were ranked from 1 to 5 (1 being the worst). Scores were allocated to each weed i.e. a score of 5 was given to the worst weed, through to a score of 1 for the fifth worst weed. The score above is the average score across all respondents.

take-all species composite as "*Polymeria* and *Haloragis* spp.", in northern NSW cropping regions in 1983 (Martin and McMillan 1984).

There are at least three possible reasons for the increased importance of *P. longifolia* since these latter surveys. Firstly, this weed may have increased in area and level of infestation during this time. Secondly, the importance of this weed was elevated in the minds of respondents because the survey dealt specifically with *P. longifolia* which was possible given that *P. longifolia* was not rated as highly in another benchmarking survey (Inglis 1999). Finally, the increased importance of *P. longifolia* may have been due to specific seasonal conditions in 1995/96 which favoured the weed more than in other years.

The most important weeds encountered in the 1988/89 season were *Cyperus* spp. and *Xanthium occidentale* and these continued to be the major weed problems in the industry in

the 1995/96 season. These weeds were mentioned by 57 and 63% of respondents, respectively. Many other species remained at the same relative level of importance, for example *I. lonchophylla*, *H. trionum*, *Datura* spp. and *Tribulus* spp.

The 28 genera mentioned were slightly fewer than the 34 genera found by Charles (1991). The worst weeds encountered in this survey were similar to those encountered by Charles (1991), with the exception of *Physalis* spp., *Haloragis glauca* and *Echinochloa crus-galli*. Furthermore, the ten species mentioned in Table 3.2 were mentioned in the top 12 most abundant weeds in the CCA survey in 1993 (D. Clark, pers. comm.) and in the top 20 most abundant weeds in cotton fields in 1991/92 (Charles 1996a). A similar list of weeds was obtained from surveys of irrigated soybean crops (Felton 1979) and summer weeds in non-irrigated cropping situations during the mid to late 1980s in northern NSW (Martin and McMillan 1984; Martin *et al.* 1988; Felton *et al.* 1994).

When the problem weed species were examined with respect to region, a total of 21 species (18 genera) were rated among the ten worst weeds in the Namoi, Gwydir, Macintyre and Macquarie Valleys and the Darling Downs/South Burnett and St. George regions (Table 3.3). The ten worst weeds overall featured prominently in this list, as would be expected (Table 3.2 c.f. Table 3.3). Some of these weeds are illustrated in Plate 3.1.

The equal seventh rated weed, *S. cannabina*, did not rate as an important weed in the Namoi Valley and failed to be mentioned by respondents in the Macquarie Valley (Table 3.3). *Sesbania cannabina* was found in the more northern cotton growing regions. Furthermore, both *Anoda cristata* (Anoda weed) and *Rhynchosia minima* (rhyncho) were rated as the top ten weeds in cotton growing regions in Qld (the Macintyre Valley, the Darling Downs/South Burnett and St. George regions). *Ipomoea plebia* was found in the latter two regions. The presence of these three species in Qld, but not in the NSW cotton growing regions, suggested that specific weed floras existed in the two states.

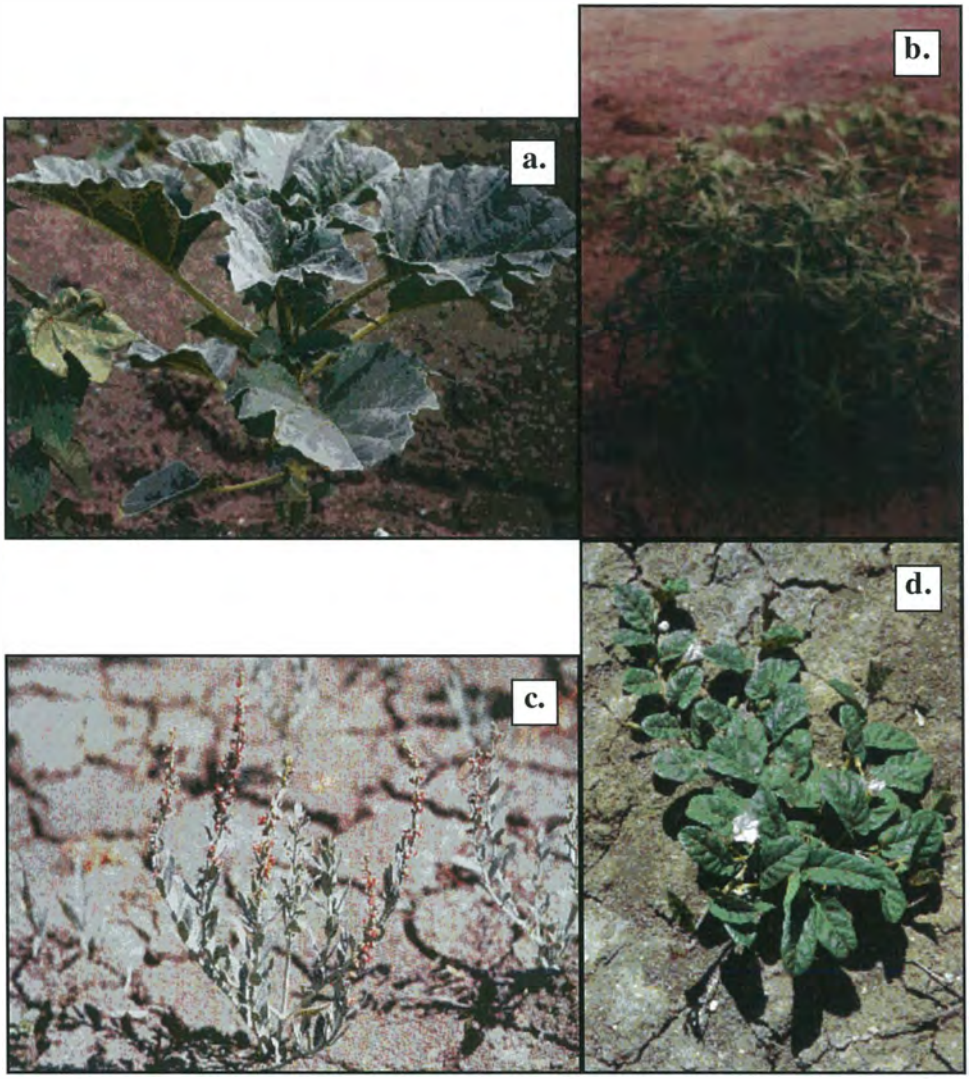


Plate 3.1 Some weeds of cotton crops. Plate 3.1a shows a *Datura* species (thornapple), 3.1b *X. spinosum* (Bathurst burr), 3.1c *Haloragis* spp. (haloragis take-all or raspweed) and 3.1d *Polymeria pusilla* (annual polymeria). Plate 3.1c is courtesy of NSW Agriculture.

Table 3.3 Ranking of the ten worst weeds encountered in cotton crops in the 1995/96 season in the various cotton growing regions. Those regions with at least four respondents were examined (overleaf). Dashes "-" in the table indicate that while the weed may have been present, its ranking was lower than 10.

Weed	Common name	Weed rating by region[a]					
		Namoi	Gwydir	Macintyre	Macquarie	Darling Downs/ Sth. Burnett	St. George
Cyperus spp.	Nutgrass	1	2	3 (equal)	1 (equal)	3	1 (equal)
Xanthium occidentale	Noogoora burr	2	3	2	3 (equal)	7 (equal)	8 (equal)
Polymeria longifolia	Polymeria take-all	3	4	5	-	-	1 (equal)
Datura spp.	Thornapple/Castor oil	4	7 (equal)	9 (equal)	5 (equal)	7 (equal)	-
Hibiscus trionum	Bladder ketmia	5	-	7 (equal)	7	1	-
Ipomoea lonchophylla	Peach vine	6	1	1	-	2	5
Salvia reflexa	Mint weed	7	-	6	1 (equal)	-	6
Xanthium spinosum	Bathurst burr	8	7 (equal)	-	5 (equal)	-	8 (equal)
Echinochloa crus-galli	Barnyard grass	9	-	-	-	-	-
Tribulus spp.	Yellow vine/Caltrop	10	5	-	-	7 (equal)	-
Sesbania cannabina	Sesbania pea	-	6	3 (equal)	-	5 (equal)	4
Cucumis spp.	Paddy melon	-	7 (equal)	-	-	-	-
Polymeria pusilla	Annual polymeria	-	10	-	-	-	-
Urochloa panicoides	Liverseed grass	-	-	7 (equal)	-	-	-
Anoda cristata	Anoda weed	-	-	9 (equal)	-	5 (equal)	3
Rhynchosia minima	Rhyncho	-	-	9 (equal)	-	10	8 (equal)
Solanum nigrum	Blackberry nightshade	-	-	-	3 (equal)	-	-
Cynodon dactylon	Couch grass	-	-	-	8	-	-
Physalis spp.	Ground cherry	-	-	-	9 (equal)	-	-
Haloragis spp.	Haloragis take-all/Raspweed	-	-	-	9 (equal)	-	-
Ipomoea plebia	Bell vine	-	-	-	-	4	7

[a] The ranking that each weed received was derived by scoring the five weeds mentioned by respondents on the survey form from 1 to 5 (1 being the worst). This score was averaged across all respondents in the region and ranks allocated for the ten weeds which had the lowest average scores. For example, the first ranked weed had the lowest average score.

The problem weed flora of the Macquarie Valley is distinct from those of the Namoi, Gwydir and Macintyre Valleys (Table 3.3). There was a notable absence of *P. longifolia* and *I. lonchophylla,* but another take-all, *Haloragis* spp., was present, combined with *Solanum nigrum*, *Cynodon dactylon* and *Physalis* spp.

3.4.4 Where is P. longifolia a problem ?

In the overall survey, 45% of respondents indicated *P. longifolia* was a problem, whether minor, moderate or major (Table 3.4). *Polymeria longifolia* was a particular problem in the Gwydir (77% of respondents) and Namoi Valleys (54% of respondents) and to a lesser extent in the Macintyre Valley (27%).

There were 29% of respondents who indicated that *P. longifolia* did not occur on the properties for which they consulted (Table 3.4). Furthermore, respondents noted that *P. longifolia* was not present in the Lachlan Valley, Tandou and Bourke regions. However, personal communication with a non respondent at Darling Farms at Bourke (Tony Taylor) indicated that a small infestation area of five hectares of *P. longifolia* was present. The weed was of little concern in the Macquarie Valley. Only 5 - 20% of respondents in any region felt that the problem, while present, had been controlled.

3.4.5 Infestation levels of P. longifolia

Actual infestations of *P. longifolia* covered at least 2,595 hectares (Table 3.5). This was approximately 1% of the total cotton production area surveyed during the 1995/96 season. Charles (1991) indicated that 3 ± 2% of the area he surveyed in NSW was covered by this weed. That area, which represented 2,028 hectares, was comparable with the 2,261 hectares in cotton growing regions in NSW in this survey. This indicates that the area covered by *P. longifolia* has not increased rapidly in the time between the surveys. This is

Table 3.4 The severity of the *P. longifolia* problem with respect to geographical cotton growing region. No responses were received from the Biloela/Theodore/Moura region.

Polymeria rating	Overall survey	Percentage of respondents by region who indicated a rating									
		Namoi	Gwydir	Macintyre	Macquarie	Lachlan	Tandou	Bourke	Darling Downs/ Sth Burnett	St. George	Emerald
Does not occur	28.8	17.7	14.2	9.1	80.0	100.0	100.0	100.0	57.1	20.0	33.3
Present, not a problem	20.5	29.4	4.8	45.4	-	-	-	-	42.9	-	33.3
Present, controlled	5.5	-	4.8	18.2	20.0	-	-	-	-	-	-
Minor problem	15.1	23.5	23.8	9.1	-	-	-	-	-	20.0	-
Moderate problem	17.8	11.7	42.9	9.1	-	-	-	-	-	-	33.3
Major problem	12.3	17.7	9.5	9.1	-	-	-	-	-	60.0	-

Table 3.5 Actual and potential field areas of infestation for *P. longifolia* in each cotton growing region. Actual areas were estimates of ground area covered by *P. longifolia* while potential areas of infestation are the total areas of fields which had some level of infestation on them. The total number of hectares consulted on was included for comparison with infestation areas.

Cotton growing region	Actual infestation area (ha)	Potential infestation area (ha)	Total area in survey (ha)
Namoi Valley	629	5,008	39,250
Gwydir Valley	1,245	11,508	95,930
Macintyre Valley	377	2,803	47,350
Macquarie Valley	10	10	24,130
Lachlan Valley	0	0	1,670
Tandou	0	0	10,000
Bourke	0	0	10,100
Darling Downs/Sth. Burnett	80	130	33,950
St George	251	2,840	15,300
Emerald	3	60	5,550
Total	**2,595**	**22,358**	**283,330**

consistent with anecdotal observations indicating a slow creep rather than a rapid spread of this species in infested fields.

The major geographical regions with infestations were the Gwydir Valley, where nearly 1,250 hectares were covered, and the Namoi Valley where 629 hectares were infested. Infestations covered 377 hectares in the Macintyre Valley and 251 hectares in the St. George region while there were small infestations in the Macquarie Valley and Emerald region. The area of infestation in the Darling Downs/South Burnett area may be artificially elevated because two consultants did not differentiate between infestation areas in this region and the Macintyre Valley.

At least 22,350 hectares of cotton fields had infestations covering part of the field area (Table 3.5). The spread of these actual infestations to clean areas within these fields is a real possibility, particularly with cultivation. The potential infestation area (if the weed spread over the total field area) was largest in the Gwydir Valley with over 11,500 hectares of fields with infestations on them. Potential infestation areas are seven to twelve times greater than current infestation areas in most cotton growing regions.

3.4.6 P. longifolia presence in fields

Polymeria longifolia was found in both 'dense clumps'[2], up to 60 metres in diameter, and as 'scattered infestations'. Some 71% of respondents indicated that the presence of *P. longifolia* was increasing and only 6% that it was decreasing (Table 3.6). When the geographic regions were considered separately, 100% of respondents in the Macquarie Valley and Emerald region and 89% in the Gwydir Valley thought that the weed was increasing. Less than 11% of respondents felt that *P. longifolia* was decreasing in any region. This increase in incidence has been indicated by Charles (1991) and in the CCA survey 1993 (D. Clark, pers. comm.). The increase contrasts with the unpublished reports by Hazard (1974) and Osten (1988) where 2.5 times the number of respondents stated that infestations were static rather than increasing. These latter surveys were of dryland grain cropping areas only and did not include cotton (irrigated or dryland) production areas at all.

[2] The word clumps has been used in Chapter 3 because of the use of the word in the consultant questionnaire. Clumps is synonymous with the word patch used in later chapters and throughout the Australian cotton industry.

Table 3.6 The change in the presence of *P. longifolia* over time.

P. longifolia presence	Overall survey	Percentage of respondents by region who indicated a rating						
		Namoi	Gwydir	Macintyre	Macquarie	Darling Downs/ Sth Burnett	St. George	Emerald
Decreasing	6	7	6	11	-	-	-	-
Not changing	22	29	6	33	-	67	33	-
Increasing	71	64	89	56	100	33	67	100

3.4.7 Growth conditions that favour P. longifolia

Cropping practices, soil types and seasons influenced the growth of *P. longifolia* (Tables 3.7 and 3.8). There were 90% of respondents who indicated that irrigated production favoured *P. longifolia* more than dryland production (12% of respondents) - one respondent indicated both. The proportion of the cotton growing area that was irrigated compared with dryland in the 1995/96 season was similar to the respondent percentages, that is 80% irrigated production compared with 20% dryland (Dowling 1997). While it is possible that responses for this question merely reflected irrigation practice, other observations suggest that *P. longifolia* may be a greater problem in irrigated fields. For example, several authors have suggested that *P. longifolia* grows in wet areas and often in shallow depressions and floodways (Cunningham *et al.* 1981; Williams 1988; R. Johnson, pers. comm.). In addition, 17% of survey respondents noted that the growth of *P. longifolia* was favoured in irrigation channels and watercourse areas.

Respondents indicated that conventional tillage favoured the growth of *P. longifolia* over reduced tillage (54% c.f. 22% of respondents). The proportion of conventional tillage to permanent beds (a form of reduced tillage) during the 1995/96 season was 24.6% to 75.4%

Table 3.7 The situations and soil types that favoured the growth of *P. longifolia*.

Situation or soil type	% of respondents
Situation	
Irrigated production	90.2
Dryland production	12.2
Reduced tillage practices	22.0
Conventional tillage practices	53.7
Land recently brought into crop production	17.1
Long term cropped country	43.9
Land that has never been cropped	2.4
Along or in irrigation channels or watercourses	17.1
Along roadsides	7.3
No particular situation	4.9
Other situations specified	
Previous floodplain areas	2.4
Wet areas of the field	2.4
Soil type	
Light	14.6
Heavy	85.4
Other specified, moderate	2.4

Table 3.8 The seasons in which *P. longifolia* was obvious.

Season	% of respondents
Spring	78.0
Summer	87.8
Autumn	43.9
Winter	2.4

respectively. This information was derived from a NSW cotton disease field survey (Allen and Lonergan 1998). These data were in contrast to those obtained in a benchmarking survey of over 300 cotton growers in all areas of the industry (with the exception of the Macintyre and Lachlan Valleys, and the St. George, Bourke and Tandou areas) (Inglis 1999). The benchmarking survey found that 60% of growers still practised some form of conventional tillage while 53% practised reduced tillage of some description. The differences between the surveys may be an artefact of the respective survey methodologies. An increasing shift towards reduced tillage systems in cotton farming systems has occurred in over half the fields surveyed since the 1990/91 season (Allen and Lonergan 1998).

Conventional tillage appeared to favour *P. longifolia* which was opposite to the trend in the permanent bed/reduced tillage data outlined above. Both Felton *et al.* (1994) and Charles (1996a) predict that perennial and rhizomatous weeds, for example *P. longifolia* and *Cyperus* spp., will increase in reduced tillage and permanent bed cotton farming systems. Gavin *et al.* (1999) confirmed that perennial species did increase in fields where no tillage was practised in northern NSW and southern Qld. Likewise, both Bryson and Keeley (1992) and Murray *et al.* (1992) showed that the incidence of perennial weeds increased in the USA under reduced tillage systems, particularly when herbicide use was increased. With increased herbicide use and decreased use of cultivation in these systems, herbicide-tolerant weeds may be selected (Charles 1999). The survey results indicate that conventional tillage actually favoured the growth of *P. longifolia,* which was a result counter to the evidence outlined above. Furthermore, perennial rhizomatous weeds have not always increased in ongoing reduced tillage experimentation (Hickman *et al.* 1998; Charles 1999). The small amount of cultivation necessary in these reduced tillage systems could also be limiting an increase in incidence of *P. longifolia* and other perennial weeds or there may be a lag period after which these perennial weeds will become a major problem in reduced tillage systems.

Over 85% of respondents said that the weed was found on heavy soil types rather than the lighter soils (Table 3.7). Inglis (1999) stated that 88% of cotton production in the season after this survey was on these heavier cracking clay soils while another 11% occurred on lighter red brown earths and river alluviums. It could be suggested that the incidence of *P. longifolia* on the cracking clays is a direct reflection of the soil types used for cotton production, except that *P. longifolia* is a known diagnostic species of heavy cracking clay soils and was probably present on much of this country before cotton production occurred (R. Johnson, pers. comm.).

Over 78% of respondents said that *P. longifolia* was most obvious in spring and summer with only 2% of respondents indicating the weed was obvious in winter (Table 3.8). Although *P. longifolia* was present from Emerald in the north to the Macquarie Valley in the south, there was no noticeable difference in the season the weed was present with respect to cotton growing region.

Two factors intrinsic to most cotton production appeared to favour *P. longifolia*. These were irrigated production and conventional cultivation. Furthermore, *P. longifolia* appears to be more prevalent on heavier soils and in the seasons when cotton was grown. These facts demonstrate that *P. longifolia* is suited to the factors that are involved with cotton production in terms of the cultural practices used, the main soil type and the season in which it grows. Management of the weed may rely on altering some of these cultural practices.

3.4.8 Why is P. longifolia a problem ?

Polymeria longifolia is a problem on cotton farms for many and varied reasons. The difficulty in controlling this weed has been realised for many years (McMillan 1988a) and this was again emphasised by 86.5% of respondents (Table 3.9). This compares similarly

Table 3.9 The reasons why *P. longifolia* was a problem. Respondents were asked to indicate as many responses as were appropriate.

Why *P. longifolia* is a problem	% of respondents
Original clumps are increasing in size	75.7
New clumps are appearing in infested fields	51.4
Clumps appearing in uninfested fields	24.3
Plant removes moisture from the soil	75.7
Plant is difficult to control	86.5
Plant results in large yield reductions	64.9
Others specified,	
Some yield reduction	5.4
Plants use nutrients	2.7

with 76% of central Queensland growers who believed this weed was 'difficult' or 'very difficult' to control (Osten 1988).

Nearly 65% of respondents indicated large yield reductions occurred with *P. longifolia* infestations (Table 3.9) although, when respondents were asked more specifically about this, a small yield reduction of 0 - 25% was the most common response (39% of respondents, Table 3.10). Another 17% of respondents indicated no yield reduction and only 32% of respondents indicated a 50% or above yield reduction.

Other reasons why *P. longifolia* is a problem were also indicated (Table 3.9). For example, 76% of respondents believed that *P. longifolia* removed moisture from the soil and that the original clumps were increasing in size. This was undoubtedly a result of difficulties encountered in controlling the weed.

Table 3.10 The yield reduction of cotton within *P. longifolia* infestations.

Yield reduction	% of respondents
No reduction	17.1
Yes, by 0-25%	39.0
Yes, by 25-50%	14.6
Yes, by 50-75%	22.0
Yes, by 75-100%	9.8

Over 50% of respondents indicated that new clumps appeared in infested fields while nearly 25% of respondents noted that clumps of *P. longifolia* appeared in uninfested fields. These results are notable as they suggest that there is less spread from one field to another than within fields, but that spread does occur.

3.4.9 How does P. longifolia spread ?

Since the presence of *P. longifolia* appeared to be increasing (Table 3.6) and between 24 and 76% of respondents indicated that *P. longifolia* was a problem because some spread was occurring in that new clumps were appearing in uninfested and infested fields and original clumps were increasing in size (Table 3.9), the obvious question to ask is how does *P. longifolia* spread ?

Most respondents suspected that *P. longifolia* spread naturally by an underground root or rhizome (82.9%) or by a shoot or root segment moved by cultivation (78%) (Table 3.11). Only 20% of respondents thought that *P. longifolia* spread by seeds. Since *P. longifolia* is not being effectively controlled at present, the areas of infestation are expected to increase in the future.

Table 3.11 Respondent's suggestions as to how *P. longifolia* spreads.

Means of suspected spread	% of respondents
Underground root or rhizome	82.9
Aboveground shoot or runner	7.3
Root or shoot segment moved by cultivation	78.0
Seed	19.5
Seed in irrigation water	12.2
Not known	12.2

3.4.10 Management of P. longifolia

A total of 83% of respondents with infestations of *P. longifolia* had attempted control and they estimated that the additional cost for the treatment of *P. longifolia* (over and above other weeds) in fields where the weed occurred averaged $36.20 per hectare per year, but ranged anywhere from $12 to $100 per hectare per year. Hence, while the *P. longifolia* problem is currently small (but increasing), attempts to control it are expensive.

Of the various methods of managing *P. longifolia,* herbicide application resulted in a decrease in the occurrence of the weed in only 37% of cases and no change in the problem in another 58% of cases (Table 3.12). Some 5% actually indicated an increase in *P. longifolia* after using herbicides. None of the herbicides that were registered for in-crop use in non-herbicide resistant cotton crops were successful in controlling *P. longifolia* infestations, for example diuron, fluometuron and prometryn (Table 3.13). The most successful herbicides reported were 2,4-D amine, fluroxypyr, glyphosate and 2,4-D ester (14 - 17% of respondents). Conversely, glyphosate, fluroxypyr and 2,4-D amine were listed by other

Table 3.12 The overall effect of control methods on *P. longifolia.*

Control method	% of total respondents who used each method	Effect of control method on weed occurrence (Percentage of respondents who used each method) Decrease	No change	Increase
Herbicides	63.3	36.8	57.9	5.3
Cultivation	56.7	14.7	32.4	52.9
Hand chipping	33.3	20.0	80.0	-

respondents as the most unsuccessful herbicides used. This indicates that the action of herbicides on *P. longifolia* is very variable, and while not the focus of this thesis, this area of work requires thorough investigation.

Cultivation was not successful in reducing *P. longifolia,* as shown by the 53% of respondents who had used cultivation and who indicated an increase in the occurrence of the weed after cultivation. Another 32% indicated no change after cultivation. Hand chipping had little effect on the incidence of the weed in general. While over 50% of total survey respondents noted that they had attempted control of *P. longifolia* using herbicides or cultivation, only one third of respondents had attempted control using hand chipping. Anecdotal information indicates that hand chipping contractors will not attempt chipping large and dense infestations of *P. longifolia* because the method is ineffective. Chipping effects on *P. longifolia* are examined in Section 9.2.

This survey has highlighted the fact that all existing methods of managing *P. longifolia* infestations have had only limited success. This result concurs with previous research by McMillan (1988a) and Charles (1991).

Table 3.13 Survey responses as to which herbicides were used successfully and unsuccessfully in an attempt to control *P. longifolia*.

Active ingredient of herbicide	% of respondents who stated herbicide used	
	Successfully	Unsuccessfully
2,4-D amine	17	10
2,4-D ester	14	3
dicamba	-	9
diuron	2	5
fluometuron	3	5
fluometuron/prometryn	-	7
fluroxypyr	17	12
glyphosate	15	33
glyphosate-trimesium	-	2
imazapyr	7	-
MCPA	2	-
metsulfuron	2	-
paraquat	-	2
paraquat/diquat	3	2
pendimethalin	-	2
prometryn	-	3
triclopyr	2	2
trifluralin	-	3
Herbicide combinations		
2,4-D amine + glyphosate	3	-
2,4-D ester + glyphosate	2	-
2,4-D amine + glyphosate-trimesium	2	-
2,4-D ester + glyphosate-trimesium	2	-
glyphosate + chlorsulfuron	2	-
glyphosate + dicamba	2	-
glyphosate + fluroxypyr	3	-
glyphosate + oxyfluorfen	2	-

3.5 Conclusions

Cotton consultants and agronomists were able to provide valuable insight to the extent and importance of *P. longifolia* in the Australian cotton industry. For instance, *P. longifolia* is a small but significant problem in many areas of cotton production, but particularly in the Gwydir, Namoi and Macintyre Valleys and in the St. George area. The weed does not appear to have spread rapidly the last ten years but it is likely that the slow vegetative

encroachment on production areas will continue. The means by which this species is dispersed will affect the rate of this encroachment and this is examined in Chapter 6.

One of the main reasons why *P. longifolia* was perceived as a problem was because it was difficult to control. Comparison of the effects of *P. longifolia* with those of other cotton weeds revealed that most of the worst weed species encountered were annuals. Annual species cause persistent problems for entirely different reasons, such as seed production and dispersal. Therefore, further research is needed into both annual and perennial species.

Although helpful information was gained from the survey on the biology and ecology of *P. longifolia* and its competitive impact on cotton, more precise data on the biology, ecology and competitive impact could not be supplied and for this reason experiments were designed to collect this data. These have been outlined in the following chapters.

Polymeria longifolia in an irrigation channel

Chapter 4

The morphology and anatomy of *Polymeria longifolia*

"The intelligent use of cultural practices or chemical agents depends upon a knowledge of the anatomy....of the weed concerned, especially if it is perennial" (Kennedy and Crafts 1931).

4.1 Introduction

This chapter examines some aspects of the rhizome morphology and the plant anatomy of *Polymeria longifolia* with a view to suggesting potential control options. Specifically, it focuses on the morphology and distribution of rhizomes and roots down the soil profile (Sections 4.2 and 4.3), the relationship between individual *P. longifolia* shoots within a weed patch (Section 4.4) and the anatomical structure of *P. longifolia* (Section 4.5). Earlier descriptions of the external morphology of *P. longifolia* have been outlined in sections 2.4.2 and 2.4.6. Such information has been obtained to understand and more effectively manage other weeds, for example *Euphorbia esula* (Raju *et al.* 1964), but to date has been lacking for *P. longifolia*.

4.2 Growth and morphology of rhizomes of *P. longifolia*

4.2.1 Aim

These observations were made to determine some basic morphological parameters of *P. longifolia* rhizomes.

4.2.2 Methods

Plants of *P. longifolia* growing amongst cotton in Field 11 on the Midkin Farm, Auscott, Moree were measured on 23 January 1998. A total of 16 rhizome fragments were recovered to a soil depth of 20 cm from the centre of one patch of *P. longifolia* and ten from the edges. These were a mixture of vertical shoot-bearing rhizomes, horizontal and vertical rhizomes but since there were no discernible differences in external rhizome morphology among these rhizome types and rhizomes between the two parts of the patch, these data were combined. The rhizomes were excavated with a hand trowel.

The length of rhizomes was measured while node and shoot numbers were counted, including the presence of unemerged shoots. The way in which horizontal rhizomes ended whether as a tip or whether broken off in the ground, and the cross-sectional diameter of various parts of the rhizome were also recorded. At least one end of all horizontal rhizomes recovered had been broken off in the excavation process and could not be traced to its source. The diameter of rhizomes was measured with a pair of vernier callipers with appropriate care taken to ensure that the rhizome tissue was not crushed. The diameter of rhizomes was measured two centimetres from the following areas: unemerged shoot tips, broken off ends, two centimetres below the ground for vertical shoot-bearing rhizomes, and two centimetres from any rhizome junctions i.e. on each rhizome arising from a node.

4.2.3 Results and discussion

The maximum length of any rhizome recovered was 103.5 cm although the mean length was half this at 53.1 cm (Table 4.1). Longer rhizomes than this were difficult to recover because parts of the rhizomes were buried deeper in the soil. Each rhizome fragment recovered had at least two nodes (and up to 11 nodes) with a mean of 4.9 nodes per fragment (Table 4.1). The mean data for rhizome length per node indicated that a node occurs at an average of every 11.4 cm (range 6.3 - 20.6 cm).

Table 4.1 A summary of the parameters measured to quantify the morphology of *P. longifolia* rhizomes. The mean, minimum, maximum and total number of observations has been presented. Section 2.4.6 and Plate 2.2 outline the differences between the different rhizome types.

Parameter measured	Mean	Number	Range	
			Minimum	Maximum
Rhizome length (cm)	53.1	24	19.7	103.5
Node number	4.9	24	2	11
Length/node (cm)	11.4	24	6.3	20.6
Above ground shoots	0.8	26	0	4
Unemerged shoots	0.5	26	0	2
Total shoot number	1.3	26	0	5
Length/shoot (cm)	28.3	24	0	94.1
Vertical rhizome number	1.3	33	0	5
Diameters (mm)				
unemerged shoots	2.6	13	1.8	3.8
broken-off ends (horizontal rhizomes)	2.4	38	1.7	5
vertical shoot-bearing rhizomes	2.1	16	0.9	2.8
vertical rhizomes	1.5	32	0.9	2.5
rhizome junctions	2.3	33	1	5

An average of 0.8 above-ground shoots and 0.5 unemerged shoots were found on each rhizome (Table 4.1). Up to four emerged shoots and two unemerged shoots were recovered on the rhizomes examined. The shoot number per rhizome ranged from zero to five. A shoot occurred on average every 28.3 cm of total rhizome length although the range for shoot number per total rhizome length was large (0 - 94.1 cm). These data indicated that long rhizome fragments may not produce any above-ground or unemerged shoots, although in many cases any length of rhizome excavated will have at least one shoot present.

Aside from an estimate of *P. longifolia* rhizomes being at least one metre in length (Cunningham *et al.* 1981), no other published data are available. The results from this experiment concur with the one metre estimate but suggest that greater lengths may be found as *P. longifolia* rhizomes grow through the soil. Further, shoots and roots of *P. longifolia* are produced along the rhizome length, aiding in the further capture of plant resources.

Each main rhizome length recovered had an average of 1.3 vertical rhizomes branching from it. There was a maximum of five vertical rhizomes that branched from any one rhizome. The mean rhizome diameters of the vertical shoot-bearing or horizontal rhizomes was similar at 2.1 - 2.6 mm, however the mean diameter of vertical rhizomes was smaller at 1.5 mm.

The vertical rhizomes were attached to horizontal rhizomes and not recovered independently because they were broken off from the horizontal rhizome easily. Fragility in some parts of the plant tissue may aid in the retention of a larger part of the plant intact in the soil following disturbance. A similar fragility, but in above-ground plant tissues, was observed in *Portulaca oleracea* (Miyanishi and Cavers 1981).

The maximum diameter of rhizomes near broken off ends or rhizome junctions was up to 5 mm and this indicated that rhizomes may become thickened as they get older, particularly if prior defoliation had occurred and new rhizome production had taken place from the node junction. The end point of all rhizomes was also examined. There were 11 that ended in unemerged shoot ends, one that ended in an above-ground shoot, six that arose from rhizome junctions and 34 that were broken off and could not be traced to their point of origin. These quantitative observations will be used to help understand the growth of *P. longifolia* as examined in other areas of this thesis.

4.3 Rhizome and root distribution of *P. longifolia* down a cotton soil profile

4.3.1 Aim

These observations aimed to determine the distribution of rhizomes and roots of *P. longifolia* down a soil profile under commercial cotton field conditions.

4.3.2 Methods

Two soil pits were excavated using a backhoe in a commercial cotton field, Field 27, at Colly Farms, Collarenebri on the 22 - 23 April 1997 before *P. longifolia* had stopped growing for the season. A description of Colly Farms and the management of this field can be found in Appendix 4.

The excavation site was approximately halfway between the centre and edge of a large 90 metre diameter *P. longifolia* patch which had been present in the field for more than 15 years. The mean density of *P. longifolia* around the area of excavation was 168 shoots per square metre (range 96 - 232 shoots per square metre, n = 15), while the density of cotton

plants around the area of excavation was 0 - 10 plants per square metre. Although some cotton was found growing within the *P. longifolia* patch, no cotton plants were exposed in either soil profile face. The possibility that cotton roots were exposed from plants further behind the face could not be excluded but some discernment regarding the plant of origin, whether cotton or *P. longifolia,* was possible given obvious external differences in root morphology. For example, the roots of cotton were white and often thicker than the brown *P. longifolia* roots and *P. longifolia* roots were often observed attached to rhizomes and no rhizomatous tissue was produced by cotton.

The two pits were either 2 or 1.2 metres deep, 2.5 metres in length, at 90° to the cotton row direction and approximately 1 metre wide. Three profiles were examined, two on opposite sides of the 2 metre deep pit, to a depth of 1.5 metres and one in the 1.2 metre pit, to a depth of 1 metre. These depths were chosen as excavation of rhizomes and roots below these depths in each pit was physically difficult. Each profile was 1.5 metre wide and divided up into a 10 cm x 10 cm grid (Plate 4.1). The 10 cm x 10 cm grids were obtained by dividing a 50 x 50 cm quadrat into 10 cm increments by nylon line, secured at the quadrat edges by grooves cut into the quadrat frame. Steel tent pegs (20 cm in length) were hammered into the exposed profile to hold the quadrat to the soil face.

Each 10 x 10 cm grid was examined for the incidence of rhizomes and roots and the number of each was recorded separately. Each rhizome and root was recorded only once in each grid but may have been recorded in a number of different adjacent grids depending on its length. Approximately 0.5 cm of soil was chipped away from the soil faces using a small garden trowel where the backhoe had smeared the damp subsoil. This process exposed both friable soil and the root system. Although the hill and furrow heights differed by up to 15 cm, this difference was overcome by having the top of the profile start at the median level between the hill and the furrow height.

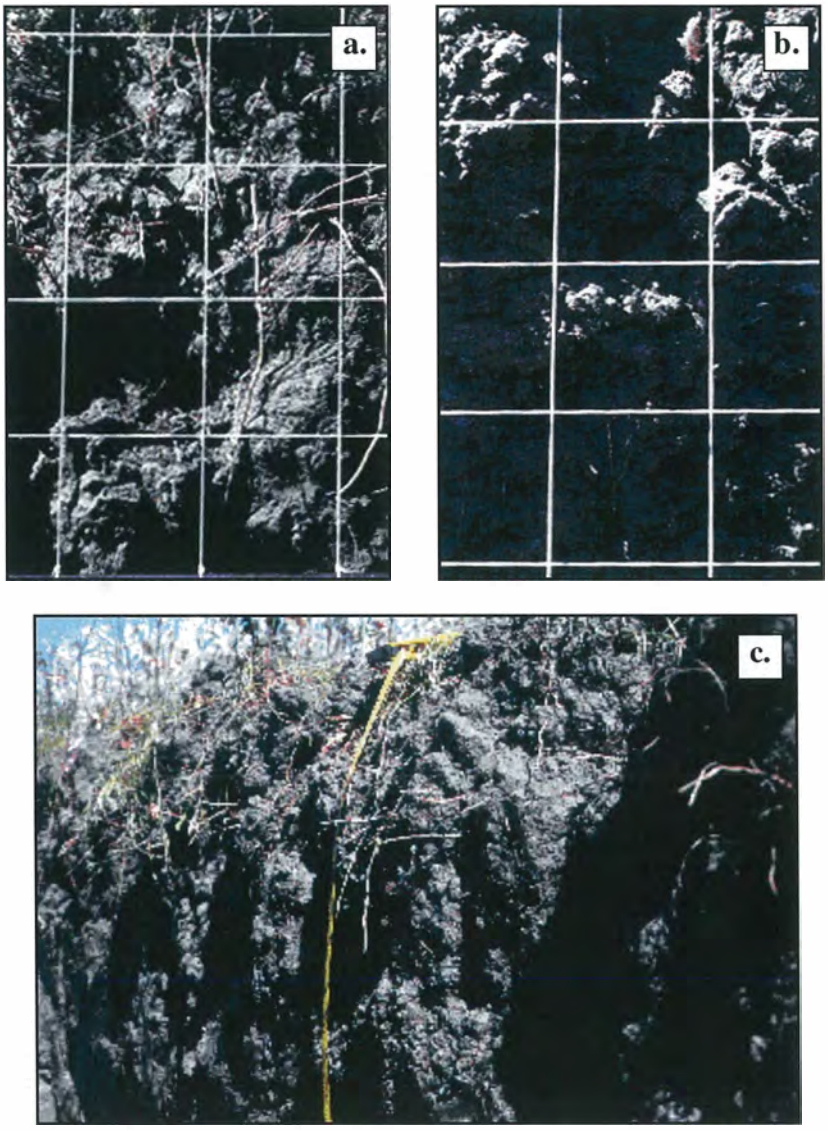


Plate 4.1 The rooting profile of *P. longifolia.* Plates 4.1a and b illustrate the rhizomes and roots found in the top 10 - 50 cm and 50 - 90 cm respectively. Plate 4.1c illustrates the top 90 cm of the soil profile. A number of rhizomes can be seen in the 10 - 40 cm profile.

4.3.3 Results

A total of 80% of rhizomes and 65% of roots of *P. longifolia* were found in the top 40 cm of the soil profile (Table 4.2, Plate 4.1). The bulk of these rhizomes (49%) and roots (37%) were in the 10 - 30 cm layer. Although rhizomes were found to a depth of 150 cm, very few were found deeper than 100 cm (Table 4.2). In the two replicates observed, an average of 12.5 rhizomes and 277 roots number were observed below 100 cm.

4.3.4 Discussion

The high percentage of *P. longifolia* rhizomes and roots in the top 40 cm of the soil profile was similar to that recorded for *Convolvulus arvensis*, where 70% of the total root mass was found in the top 60 cm of soil, and this mostly in the top 30 cm (Timmons 1941, in Mitich 1991; Davison 1970) and for *Ipomoea purpurea* where between 57 and 81% of roots were found in the top 37 cm of soil (Scott and Oliver 1976). In addition, the results for *P. longifolia* are similar to those for *Cynodon dactylon* where 88% of rhizomes were found in the top 30 cm with almost no rhizomes found deeper than 45 cm in the soil (Horowitz 1972), for *Euphorbia esula* where 56% of the total root weight was found in the top 15 cm of the soil profile (Raju *et al.* 1964) and likewise for *Cirsium arvense* which had 54% of the total root length and 62% of the total root dry weight in the top 40 cm of the soil profile (Nadeau and Vanben Born 1989). These results indicate that active shoot recruitment for *P. longifolia*, like *C. arvense, C. arvensis*, *C. dactylon* and *E. esula,* occurs in the upper layers of the soil profile. No comparative excavations were conducted in uncultivated areas to assess the influence of cultivation on root and rhizome distribution.

The proliferation of rhizomes and associated roots in the top 40 cm of the soil profile is important. Inter-row cultivation (commonly to a depth of ten centimetres) would do little

Table 4.2 The numbers and percentages of rhizomes and roots of *P. longifolia* in the 15 grids of 10 cm x 10 cm at each soil depth. Means of the three replicates have been presented, although only two replicates were excavated to 1.5 metre in depth and the other to one metre. The percentages given are to a depth of one metre only and include the three replicates. The standard error of the means has been recorded.

	Total number of		Percentage of	
Soil depth (cm)	**Rhizomes**	**Roots**	**Rhizomes**	**Roots**
0 - 10	94.7 ± 1.9	391.3 ± 49.7	18.2 ± 0.8	17.5 ± 1.1
10 - 20	116.7 ± 2.7	458.3 ± 67.6	22.4 ± 1.3	20.4 ± 1.7
20 - 30	141.3 ± 10.4	368.3 ± 18.2	27.0 ± 1.1	16.7 ± 1.4
30 - 40	66.3 ± 10.9	231.0 ± 6.5	12.6 ± 1.5	10.5 ± 0.5
40 - 50	33.3 ± 5.9	174.3 ± 11.1	6.3 ± 0.9	7.9 ± 0.2
50 - 60	20.3 ± 2.3	131.7 ± 4.3	3.9 ± 0.5	6.0 ± 0.3
60 - 70	16.7 ± 1.5	140.0 ± 6.4	3.2 ± 0.4	6.3 ± 0.1
70 - 80	12.0 ± 0.6	129.7 ± 7.4	2.3 ± 0.1	5.8 ± 0.2
80 - 90	16.3 ± 2.0	118.3 ± 8.8	3.1 ± 0.3	5.4 ± 0.5
90 - 100	5.0 ± 1.5	78.7 ± 6.4	1.0 ± 0.3	3.6 ± 0.3
100 - 110	3.0 ± 3.0	74.0 ± 38.0		
110 - 120	2.5 ± 1.5	82.0 ± 37.0		
120 - 130	3.0 ± 2.0	49.5 ± 15.5		
130 - 140	2.5 ± 2.5	42.5 ± 10.5		
140 - 150	1.5 ± 1.5	29.0 ± 12.0		

to disturb the bulk of the rhizomes of this plant, because less than 20% of the total rhizome and root numbers occurred at this depth.

To disturb or kill the bulk of the rhizomes deep ripping to 40 cm in depth or herbicide translocation to this depth would be needed. Raju *et al.* (1964) has questioned the use of deep ploughing for species such as *E. esula* that are able to emerge from between 90 - 180

cm of soil (Raju *et al.* 1964; Zimdahl 1993). Observations from this research and those made by a number of cotton consultants indicate that *P. longifolia* shoots can emerge from rhizomes at a depth of at least 20 cm. Whether *P. longifolia* can produce shoots from deeper seated rhizome material is unknown although research on a similar creeping perennial species, *Haloragis aspera*, indicated that reshooting can occur from as deep as 50 cm (Osten *et al.* 1996). This subject requires further research. Until this information is available, the use of deep ripping for *P. longifolia* control should be questioned. This research has certainly shown that rhizomes may be present to a depth of one to one and a half metres in the soil.

The proliferation of rhizomes and roots of *P. longifolia* in the top 40 cm of the soil profile is important in terms of competition with the cotton crop. The rooting depth of many cotton crops has been shown to extend down to at least 80 cm, although up to 80% of all cotton roots can be found in the top 45 cm of the soil (Mantell *et al.* 1985; Kapur and Sekhon 1985; Hodgson *et al.* 1990). The most severe competition for water and nutrients would occur in this layer (Mitich 1991). This aspect has been investigated by water extraction measurements using a neutron probe (to 130 cm) and nutrient analyses from the top 30 cm of the soil surface. These data are presented in Chapter 8. Rhizomes and roots recovered down to a depth of one and a half metres indicate that the exploitation of soil resources may be occurring down to this depth.

4.4 An examination of a small *P. longifolia* patch

4.4.1 Aim

These observations aimed to determine the extent to which individual above-ground shoots were connected to one another by rhizomes in a small patch of *P. longifolia*.

4.4.2 Methods

A small, roughly circular and relatively undisturbed patch of *P. longifolia* two square metres in area was located between the edge of a graded farm road and a cotton field. This area had previously been graded but was unlikely to have been treated with herbicide. The shoots within the patch were between 2 and 15 cm tall, in the early vegetative phase, and had very few flowers or buds. Active shoot emergence was continuing at the time of observation (14 October 1997).

A large clear plastic sheet was laid over the entire patch area and the location of the *P. longifolia* shoots was recorded. The point of origin of the shoot-bearing rhizomes was traced by excavating soil with a shovel and trowel down to approximately 25 cm in depth. It was impossible to manually recover rhizomes buried deeper than this in the hardened soil. In many cases, the shoot-bearing rhizome was traced to a node junction which gave rise to other rhizomes. Alternatively the shoot-bearing rhizome may have been directly joined to other shoot-bearing rhizomes or may have ended in an unemerged shoot. In still other cases, the rhizome end was dead or could not be traced any further due to the depth of excavation needed. In this way, the interconnections of the various plants within the patch could be established, at least to the depth of excavation.

The number of emerged and unemerged shoots was counted and their connections to other shoots were ascertained. The number of dead rhizome ends, broken or otherwise, and non-recoverable ends was also noted.

4.4.3 Results and discussion

Sixty four emerged shoots and 20 unemerged shoots were recorded over the patch. A large number of unemerged shoots was recorded because the observation date was approximately

one month after the usual start of *P. longifolia* emergence. Shoot emergence was found to continue throughout the season, however, and unemerged shoots would have been found at whichever time in the season that the site was excavated (Section 5.4.3).

There were 40 rhizomes that linked the 84 shoots together. There were 19 rhizomes that had only one shoot on them and a further nine with only two shoots. Four rhizomes had three shoots each, five rhizomes had four shoots each and three rhizomes had five shoots each. This indicated that in the patch there was a maximum of only 40 distinct plants. The number may have been less than 40 because not all rhizome ends could be traced.

There were 64 broken off or non-recoverable rhizome ends. In addition, there were 17 places where two or more rhizomes were joined to a central vertical rhizome. This vertical rhizome was no more than a slightly thicker rhizome that descended below recovery depth with at least two, but up to five, rhizomes arising from it. There were nine rhizome ends that ended in either dead shoots or tips of the rhizome that had died.

These results indicate that there was a high level of interconnection between shoots within the *P. longifolia* patch examined. This level of interconnection is important for the exploitation of soil resources and translocation of these and other resources around the plant. Such a network of rhizome connections is also important in the production of new shoots by vegetative means (Chapter 6) and may explain why the plant is so difficult to kill.

Although interconnection between various shoots has been observed, anecdotal evidence suggests that herbicide applied to *P. longifolia* is not fully translocated around the plant network, with very few exceptions. Foliage directly sprayed often dies but shoots connected to the treated shoot via rhizomes do not necessarily die. Rhizome death does not appear to extend lower than ten centimetres on the shoot-bearing rhizome and certainly not

to other shoots that are connected to the affected shoot in many cases (Plate 2.2). Often rhizomes die above the first or second major node below the ground and that new shoots arise from the next unaffected node below this.

4.5 The anatomy of *P. longifolia*

4.5.1 Aim

Observations were made to determine the anatomical differences among various organs of *P. longifolia.*

4.5.2 Materials and methods

Above- and below-ground plant material of *P. longifolia* was collected from Field 11 at the Midkin Farm, Auscott, Moree on 25 March 1999 (Appendix 4). This material was collected from actively growing plants in the centre of a small (ten metre diameter) patch. Below-ground material was exposed using a trowel and plant material was cut into lengths of not more than seven centimetres. Between ten and 20 individual sections of each of what were thought to be shoots, rhizomes and roots were collected. These sections were immediately placed in bottles containing Formalin Propionic Acid (FPA) made by adding 5 mL of propionic acid and 5 mL formalin to 90 mL of 70% ethyl alcohol.

The sections were fixed in the FPA solution for 48 hours before being transferred to 70% ethyl alcohol where they remained until sectioning on 26 May 1999. Microscopic transverse sections were made by first mounting the plant organ in a carrot and then using a slide microtome to cut sections of between 50 and 80 μm (micrometres) thickness. The

following steps were taken to prepare the sections for microscopic observation after sectioning.

1. Sections were placed in 50% then 25% ethyl alcohol for five minutes for each concentration.
2. Sections were stained with 1% aqueous saffranin solution for five minutes.
3. Sections were rinsed twice with distilled water for three minutes each wash. The distilled water had five drops of 5% hydrochloric acid added to it to assist in the removal of excess saffranin.
4. Sections were then passed through an increasing alcohol series of 50%, 70% and 95% ethyl alcohol for three minutes at each concentration.
5. Sections were stained with 0.5% Fast Green in 95% ethyl alcohol for ten seconds.
6. To wash the sections, a 1:1 mixture of Histoclear and ethyl alcohol was then used.

The sections were gently agitated for ten seconds in this solution before they were transferred to pure Histoclear for a further 60 minutes. Any overstained sections were washed briefly in absolute ethyl alcohol before being transferred back to the Histoclear solution.

Sections of rhizome and stem material were stained for the presence of starch. This procedure involved a two minute stain in dilute IKI solution (iodine-potassium iodide) before transferral to pure Histoclear for 60 minutes and then mounting.

All sections were mounted permanently on glass slides with Eukitt mounting media (Zeiss Pty Ltd). The slide covers were sealed with nail polish to ensure that sections did not dry out. All sections examined were transverse and included upper and base (near ground level) portions of the stem, leaf sections, internode sections of the rhizome and the roots connected to the rhizome. Between 8 and 18 individual sections were mounted on the slides for each organ. Representative sections are described here.

The anatomy of vertical shoot-bearing rhizomes was examined but not that of horizontal rhizomes. There was some difficulty in recovering horizontal rhizomes and also in differentiating horizontal rhizomes that gave rise to shoots from vertical shoot-bearing rhizomes (Section 2.4.6). Because of this latter fact, and the fact that the external morphology of both rhizome types was similar, it was assumed the anatomy would also be similar. Sections of rhizome tissue were taken to at least 15 cm in soil depth in an effort to ensure the rhizome tissue sampled was as different as possible from the shoot tissue.

4.5.3 Results and discussion

The anatomy of *P. longifolia* is typical in many ways of the Convolvulaceae (Metcalfe and Chalk 1950). Anatomical studies have been conducted on *Convolvulus arvensis,* a creeping perennial (Kennedy and Crafts 1931), and *Ipomoea hederifolia,* a twining annual (Lowell and Lucansky 1986). The similarity of *P. longifolia* to these species will be evaluated in the text.

4.5.3.1 Stem anatomy

The stem anatomy of *P. longifolia* (Plate 4.2), which is similar to that of many other species in the Convolvulaceae (Metcalfe and Chalk 1950), will be described by moving inwards from the epidermis to the central pith area of the stem base (Plates 4.2a - e) and upper stem sections (Plate 4.2f).

The single layer of epidermal cells surrounding the stem section is covered by a thin waxy cuticle and contains a number of chloroplasts (Plates 4.2a - c; Kennedy and Crafts 1931; Lowell and Lucansky 1986). The epidermal and parenchyma cells immediately underneath the epidermal layer also contain chloroplasts. Some chloroplasts are visible in the stem base

Plate 4.2 Anatomy of the base and upper stem of *P. longifolia*. Plate 4.2a shows the entire section of the stem base (40X magnification), 4.2b shows a section of tissue between the epidermis and the pith in the stem base (100X), while 4.2c further illustrates the epidermis and outer stem tissues (400X). Plates 4.2d and 4.2e are magnified sections of the vascular tissues in the stem base (200X and 400X respectively), while 4.2f is a section of an upper stem of *P. longifolia* (200X). Plates 4.2a - e were overstained with saffranin and have retained their red colouration (overleaf).

Plate 4.3 Anatomy of internode sections of the vertical shoot-bearing rhizome of *P. longifolia*. Plate 4.3a shows the entire section of the rhizome (40X magnification), while Plates 4.3b and 4.3c show sections of tissue between the epidermis and the pith of the rhizome (100X). Plate 4.3d is a similar rhizome section which has been stained with IKI to highlight the presence of starch in the cortex and pith tissue (100X). Plate 4.3e shows both starch grains and crystallised secondary metabolites within parenchyma cells (400X) while 4.3f illustrates the vascular tissues of the rhizome (200X) (overleaf).

A complete list of section labels has been given in alphabetical order below.

as = air space
cu = cuticle
cl = chlorophyll
cr = crystals
ep = epidermis
fb = fibre bundle
ip = inner phloem
la = laticifer
op = outer phloem
pa = parenchyma
pe = periderm
ph = phloem
pi = pith
pm = palisade mesophyll
rh = root hair
sg = starch grains
st = stomata
tr = trichomes
ux = unlignified xylem
vb = vascular bundle
vc = vascular cambium
xy = xylem
xp = xylem pole
xr = xylem ray

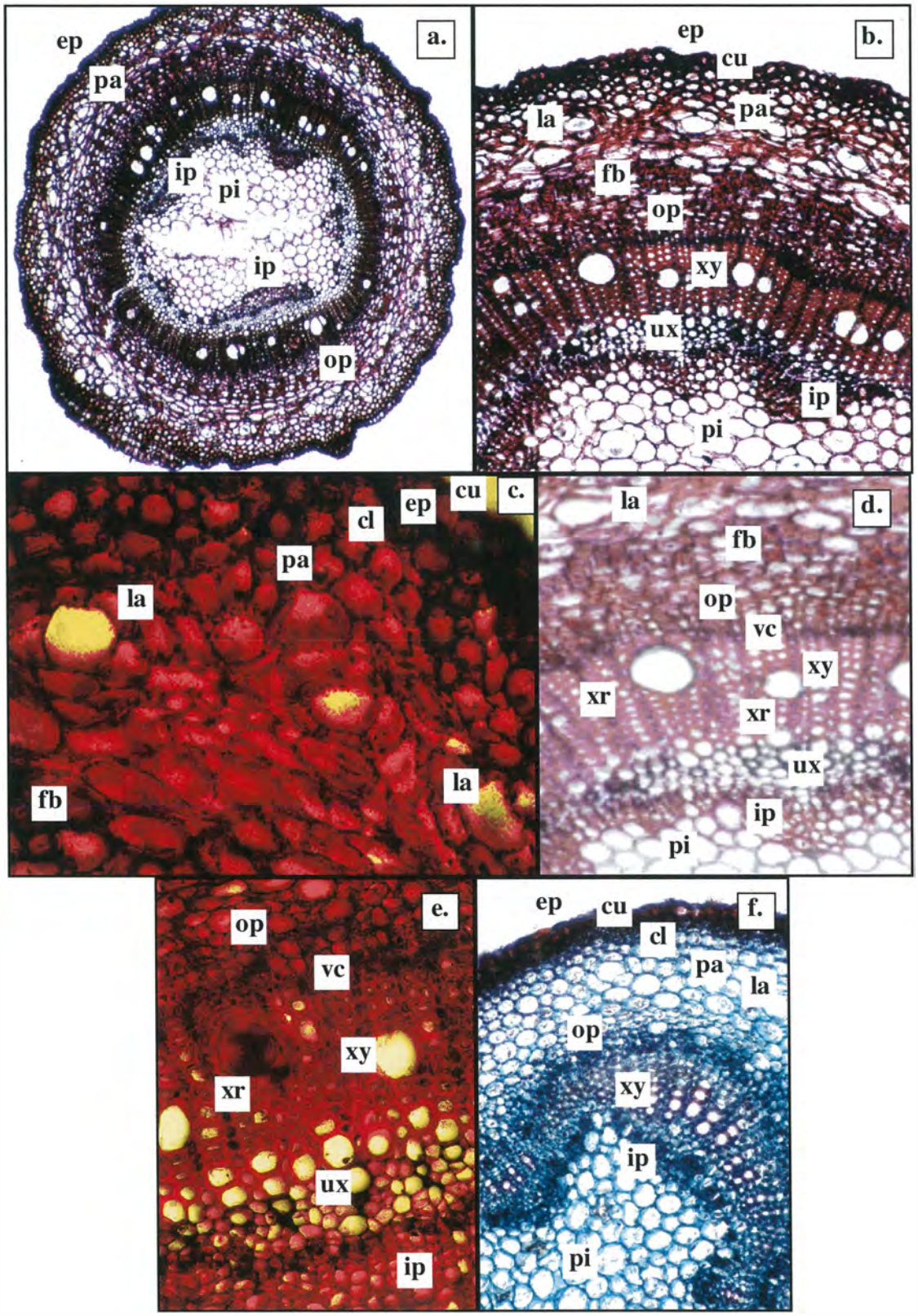


Plate 4.2 (for the Plate title see page 82).

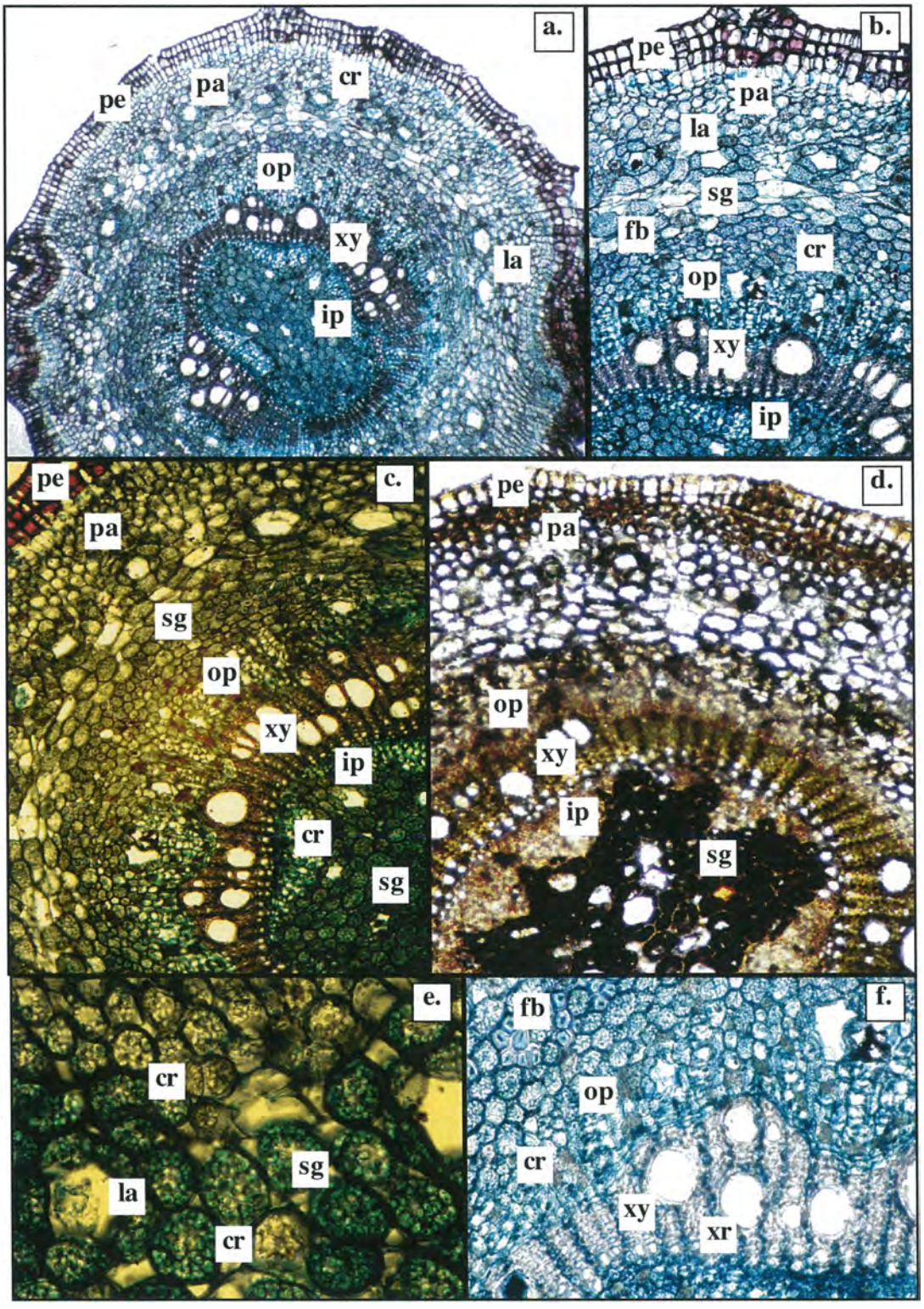


Plate 4.3 (for the Plate title see page 82).

sections (Plate 4.2c) and in the upper stem section where they have been stained red (Plate 4.2f).

There are four to five layers of parenchyma cells containing chloroplasts before the next parenchyma cell layer. This latter layer contains large angular parenchyma cells in the stem base section (Plates 4.2b and c) and large, but less angular, cells in the upper stem section (Plate 4.2f). The cortical parenchyma cells commonly become less rounded and more flattened as the stem ages, owing to the crushing effect of the internal growth of the stem (Kennedy and Crafts 1931; Lowell and Lucansky 1986). The large parenchyma cells in the stem base section are probably responsible for the temporary storage of starch and other metabolites, although very little starch was found in IKI stained stem sections. These sections have not been presented for that reason.

Laticifers are cells that are responsible for the production of latex. They can be found in the cortex tissue in the stem sections and are composed of the latex canal and the secretory cells surrounding it (Kennedy and Crafts 1931; Lowell and Lucansky 1986). These laticifers appear as large spaces in the cortical tissue halfway between the epidermis and phloem tissue in the stem base and again in the upper stem section (Plates 4.2b - d, f). Laticifers can also be found between the periderm and phloem in the rhizome section (Plates 4.3a and b; Kennedy and Crafts 1931; Metcalfe and Chalk 1950). The rhizome section is discussed under the next heading.

Latex exudates have been observed in broken stem and rhizome material of *P. longifolia* and these exudates arise from the laticifers (Fahn 1967). The laticifer cells are known as articulated nonanastomising laticifers in members of the Convolvulaceae, particularly in *Convolvulus*, *Ipomoea* and *Dichondra* species (Esau 1965). An articulated laticifer is one in which a series of cells is involved in latex production rather than just one cell, while a nonanastomising laticifer is one where no lateral connections between the different laticifers

exist. The laticifers may be part of the secretory system that contains and excretes metabolic by-products (Fahn 1967).

Within the vascular cylinder, the vascular elements observed closest to the cortex are deeply stained, thick walled sclerenchyma cells (Plate 4.2b). These cells may be either pericyclic fibre bundles or protophloem fibres and are responsible for giving the stem some rigidity and support (Kennedy and Crafts 1931; Lowell and Lucansky 1986). In older stem sections than the section illustrated in Plate 4.2d, these fibres form a continuous layer around the vascular cylinder (section not shown; Kennedy and Crafts 1931). They are not visible in the upper stem section (Plate 4.2f). The endodermis, which contains the vascular bundle, could not be differentiated clearly, although it is probably found in the two to three layers of cells external to the fibre bundles.

Large parenchyma cells can be found around the fibre bundles and in the two to three layers of cells towards the centre of the section inside the fibre cell bundles (Plate 4.2d). These parenchyma cells give way to distinctly smaller cells which are part of the phloem tissue. The phloem tissue is made up of sieve elements, which are principally responsible for the transport of compounds around the plant, companion cells, which control the loading and unloading of the sieve elements, and phloem parenchyma, in which various compounds may be stored. The compounds that phloem transports around the plant include sucrose and other plant assimilates, water, dissolved ions, amino acids and plant hormones (Raven *et al.* 1987). This phloem tissue is known as the outer phloem tissue.

Inner phloem tissue, which is found between the pith and xylem tissue in the centre of the section and stained darker than the surrounding tissues, has the same function as the outer phloem tissue (Plates 4.2a, b, d - f). The presence of phloem on both the inside and outside of the xylem is known as bicollateral phloem (Esau 1965). The formation of bicollateral phloem is common in a number of dicotyledonous families including the Asteraceae,

Convolvulaceae, Cucurbitaceae, Myrtaceae and Solanaceae (Fahn 1967). Inner phloem generally develops a little later than the external phloem. McLean and Ivimey-Cook (1958) state that this internal phloem may be in a continuous zone around the centre of the stem, as is the case here. Many plant species have phloem only to the outside of the xylem tissue and such phloem is known as collateral phloem.

In the outer phloem tissue, the vascular tissue is located immediately inside the phloem tissue. Differentiation of the individual cells in the vascular cambium is not clear in Plates 4.2d and e; rather this layer appears more as a darkened tissue layer. The vascular cambium contains one or two layers of rectangular cells and is responsible for the production of both phloem tissue to the outside of the stem section and xylem tissue to the inside (Plates 4.2d and e).

There are a number of xylem cells in the xylem tissues that are differentiated by thickened cell walls in the stem base (Plates 4.2d and e) and that have been stained red in the upper stem section (Plate 4.2f). The xylem tissue is also made up of a number of different cell types, which include tracheary elements that are lignified and responsible for the movement of water and solutes, xylem fibres for support of the xylem tissue and xylem parenchyma, which have various functions (Raven *et al.* 1987).

Darkly stained xylem ray cells can be observed radiating out through the xylem tissue (Plates 4.2d and e). These ray cells are responsible for the transport of plant assimilates from the phloem to various parts of the plant including the cortex and pith.

Towards the centre of the section there are a number of cells of unlignified xylem tissue (Plates 4.2d and e). This unlignified xylem tissue is separated from the inner phloem tissue by another vascular cambium. In the centre of the sections are undifferentiated parenchyma

cells which are collectively known as pith cells (Plates 4.2a, b, d and f). The pith may be used as a storage area for various compounds including starch.

The anatomy of the stem tissue of *P. longifolia* is similar to that of other Convolvulaceae species like *C. arvensis* (Kennedy and Crafts 1931), *Ipomoea hederifolia* (Lowell and Lucansky 1986) among others (Esau 1965; Fahn 1967). In addition, these anatomical studies on the stem tissue of *P. longifolia* will form a useful comparative baseline for the rhizome anatomy examined in the next section.

4.5.3.2 Rhizome anatomy

A rhizome is a fleshy underground stem that lacks chlorophyll and has modified scale-like leaves at each node (Kigel and Koller 1985). The rhizome functions as a carbohydrate storage organ and reproductive structure responsible for the production of new rhizomes, roots and aerial shoots. The vertical shoot-bearing rhizome of *P. longifolia* is anatomically similar to the above-ground stem tissue (Plates 4.3a - f). Because of this similar anatomy, part of the tissue previously known as rhizome tissue in *P. longifolia,* that is the vertical shoot-bearing rhizome is assumed to have been correctly identified. Further, it is postulated that all tissue previously known as rhizome tissue, including the horizontal and vertical rhizomes, is similar, although the anatomy of these sections was not directly examined. The rhizome tissue, however, is distinctly different from the root sections (Plates 4.4a - c). The terms rhizome and root will be used throughout this thesis to differentiate the two underground plant organs. Anatomical differences between the rhizome and stem sections will be highlighted in this section while differences between rhizomes and roots are discussed in the next section.

The cells that are found on the circumference of the rhizome section are suberised periderm cells and are stained red (Plates 4.3a and b; Kennedy and Crafts 1931). These closely

packed periderm cells are responsible for preventing desiccation of the rhizome tissue. The shoot tissue of *P. longifolia* is protected from desiccation by the presence of a waxy cuticle covering the epidermal cells. Esau (1965) noted the presence of a periderm layer in the rhizome of another Convolvulaceae species, *C. arvensis*.

Immediately inside the periderm layer are the cortical parenchyma cells which appear to be filled to differing extents with starch grains. In Plate 4.3c, the number of starch grains appears to be increasing in cells closer to the centre of the section. This contrasted to the IKI stained rhizome section in Plate 4.3d where the brown starch-filled cells were concentrated closest to the periderm and outer phloem tissue. This difference may have resulted from using sections from different plants.

Starch was stored in both the cortical and pith cells in the rhizome sections (Plates 4.3a, c and d). The structure of the starch grains can be clearly observed in Plate 4.3e. Esau (1965) stated that the starch grains in *C. arvensis* show a Maltese cross formation under polarised light, indicating radial or circumferential molecular structure. A similar structure for the starch grains in *P. longifolia* would probably be found here.

The fibre bundles in the rhizome have been described previously in the stem anatomy section (Plates 4.3b and f). Further toward the centre of the section, the outer phloem tissue can be distinguished by a decrease in cell diameter (Plates 4.3b, c and f). The xylem tissue has thickened cell walls and was stained purple in these sections. The vascular cambium can be observed in Plate 4.3f as the narrow band of long rectangular cells between the outer phloem and xylem tissue. The inner phloem is easily distinguished from the pith cells inside the xylem tissue because the pith cells have a large number of starch grains in them (Plates 4.3a - d; Kennedy and Crafts 1931). These pith cells were stained black by the IKI stain, a striking contrast against the inner phloem tissue which was stained light brown (Plate 4.3d).

There are a number of darkly stained or yellow stained cells in the cortex, phloem and pith tissues of the rhizome (Plates 4.3b, c and e). These were presumed to contain some form of crystallised secondary metabolite. Solitary and clustered crystals have been found in the palisade cells of leaves and the stem cortex and pith in various genera of the Convolvulaceae (Metcalfe and Chalk 1950). Secondary metabolites have been recorded in other species in the Convolvulaceae including species of *Ipomoea*, e.g. *I. purga*, *I. violacea*, *I. orizabensis* and species of *Convolvulus*, e.g. *C. scammonia*. These metabolites can be found in root resins and seeds and have been used for pharmaceutical purposes as cathartics and drugs (Schery 1972; Anaya *et al.* 1990). These compounds may include the alkaloids atropine, hyoscine and hyoscyamine, which have long been associated with plants of the Solanaceae and the Convolvulaceae (McLuckie and McKee 1954). The identity of the presumed metabolites found in *P. longifolia* is not known, however the strong benzene-type smell given off by *P. longifolia* rhizomes when stored in damp rags prior to use in Chapter 6 may indicate the presence of phenolic acids (C. Jones, pers. comm.).

The presence of presumed secondary metabolites in the rhizomes suggests that *P. longifolia* may produce and exude allelochemicals that contribute to the weed's interference with surrounding vegetation, including the cotton crop. Possible allelochemical interactions between *P. longifolia* and cotton were not investigated in this study.

Two other areas of potential research have been raised with respect to the rhizome tissue of *P. longifolia*. Firstly, research into the time at which starch and carbohydrate accumulation occurs in the rhizomes is needed. Species-specific differences occur with respect to carbohydrate accumulation although these differences are often phenologically related to the onset of seed set and dormancy (Kigel and Koller 1985).

The second area of research suggested by these results is that of the action of auxin-based herbicides on the rhizome of *P. longifolia.* The results outlined above show that at least

part of the rhizome is anatomically similar to stem or shoot tissue and therefore likely to be susceptible to herbicides that affect shoot growth. The application of auxins inhibits the growth of lateral buds on shoots by disrupting cell growth. This fact has been exploited in the manufacture and use of the phenoxy auxin based herbicides such as the 2,4-D compounds (Raven *et al.* 1987). The application of phenoxy auxin-based herbicides should, theoretically, inhibit rhizome bud formation and reshooting on *P. longifolia*.

4.5.3.3 Root anatomy

Plates 4.4a - d illustrate sections of the root of *P. longifolia*. There are two distinctions between the arrangement of tissues in roots and rhizome or shoot tissue. The first distinction is that the first-formed, or primary xylem, is always endarch in shoot and rhizome tissue but always exarch in the root tissue (Fahn 1967). The terms endarch and exarch refer to the direction of maturation of the xylem cells. Endarch primary xylem in the shoots and rhizomes refers to this first-formed xylem being found closest to the centre of the plant axis and the last formed outside of this. With exarch primary xylem in the roots, the first-formed xylem is furthermost from the centre of the plant axis and younger xylem tissue is closer to the centre of the plant axis. The second distinction between tissues in roots and those in rhizome or shoot sections is that the xylem and phloem strands in the roots do not form common bundles like those found in the stem but are arranged alternately (Fahn 1967).

As is typical in the majority of roots, the roots of *P. longifolia* have radially arranged vascular tissues (Kennedy and Crafts 1931). The xylem tissues of the roots of *P. longifolia* have been stained red (Plates 4.4a - c). This xylem has a number of poles or extensions which stretch outwards towards the periphery of the vascular cylinder. The phloem tissue alternates between these poles with the vascular cambium, which is a single layer of cells that separates the two tissue types. As new cells are formed in the cambium, the older

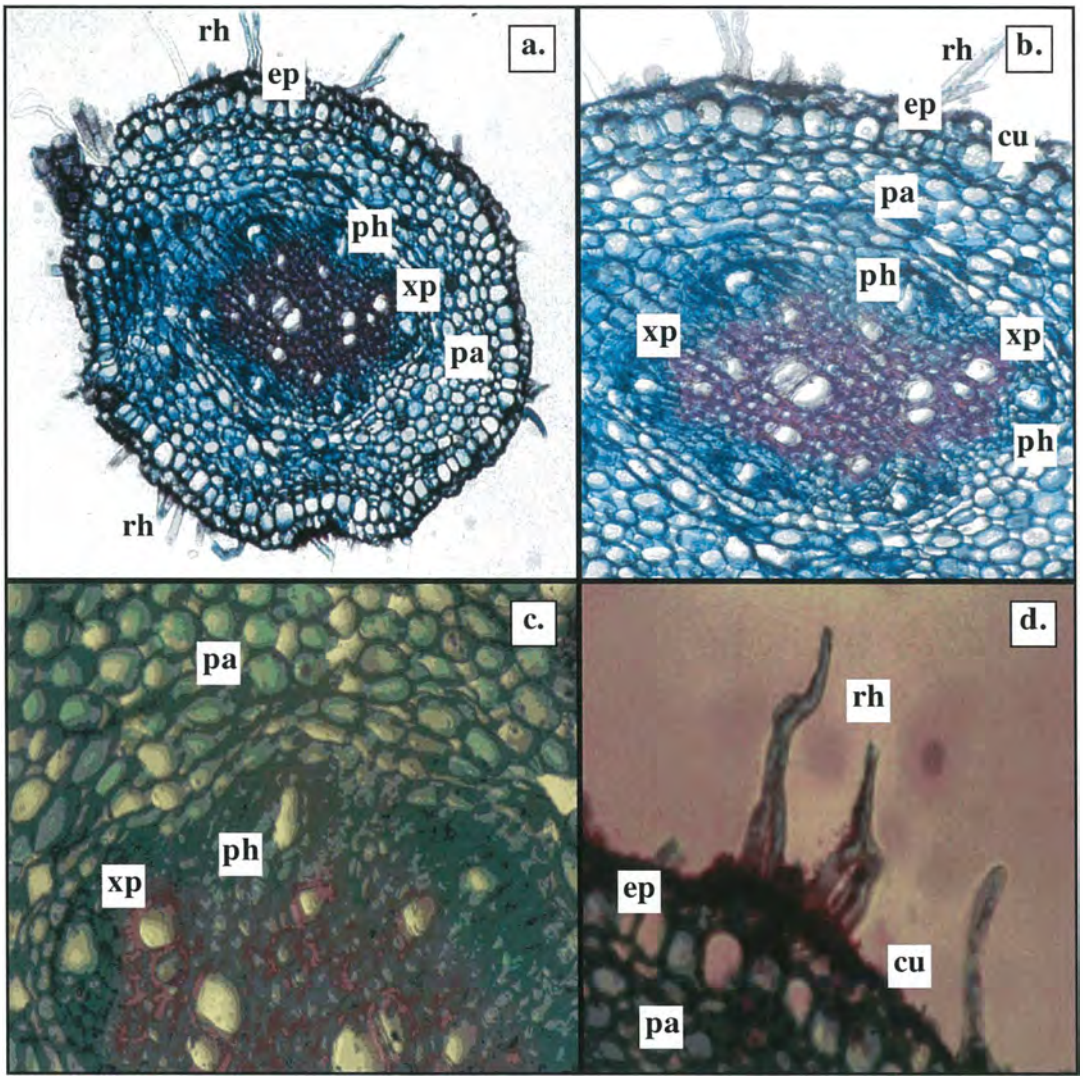


Plate 4.4 Anatomy of root sections of *P. longifolia.* Plate 4.4a is a section of a root (100X magnification) while 4.4b and 4.4c are magnified sections of this root tissue across the section (200X and 400X magnification). Plate 4.4d shows the root hairs present around the epidermal perimeter (400X). A complete list of section labels (e.g. **pa** = parenchyma) can be found on page 82.

xylem and phloem cells are pushed away from the cambium and move further out on the poles, in the case of the xylem, or further toward the periphery of the vascular cylinder in the case of the phloem (Plates 4.4b and c).

A number of root hairs can be observed around the epidermal perimeter (Plates 4.4a, b and d). These root hairs are responsible for the absorption of water and minerals. Plates 4.4b and d show a thin cuticle around the outside of the epidermal cells through which absorption also occurs. Below the epidermal cell layer there are a number of layers of cortical parenchyma cells. Esau (1965) stated that many dicotyledonous roots with limited secondary growth retain cortex tissue and cite *C. arvensis* as an example. Similarities can be observed in *P. longifolia*. Differentiation of the pericycle, the site where lateral roots arise, was not seen in these sections (Plates 4.4a - c).

4.5.3.4 Leaf anatomy

The morphology of the *P. longifolia* leaf (Plates 4.5a - d) is typical of species which are found in dry areas, e.g. *Eucalyptus* spp. The plant has a number of means of reducing water loss. For example, trichomes or hairs can be found on both surfaces of the leaf (Plate 4.5a, Fahn 1967). These trichomes are of the 'simple' type and have a long terminal cell (Metcalfe and Chalk 1950). Trichomes on the leaves help in maintaining high localised air humidity near the leaf surface and prevent continual transpirational water loss.

Upper and lower epidermal cells are similar in that they are thick and are covered in a waxy cuticle, although the waxy cuticle on the upper epidermis appears slightly thicker (Plates 4.5b and c; Kennedy and Crafts 1931; Lowell and Lucansky 1986). In contrast to true xerophytic plant leaves, the stomata are not sunken into the leaf but can be found on both leaf surfaces, although only a lower epidermal stomata has been photographed here (Plate 4.5c, Kennedy and Crafts 1931; Raven *et al.* 1987). Morphologically, the stomata in the

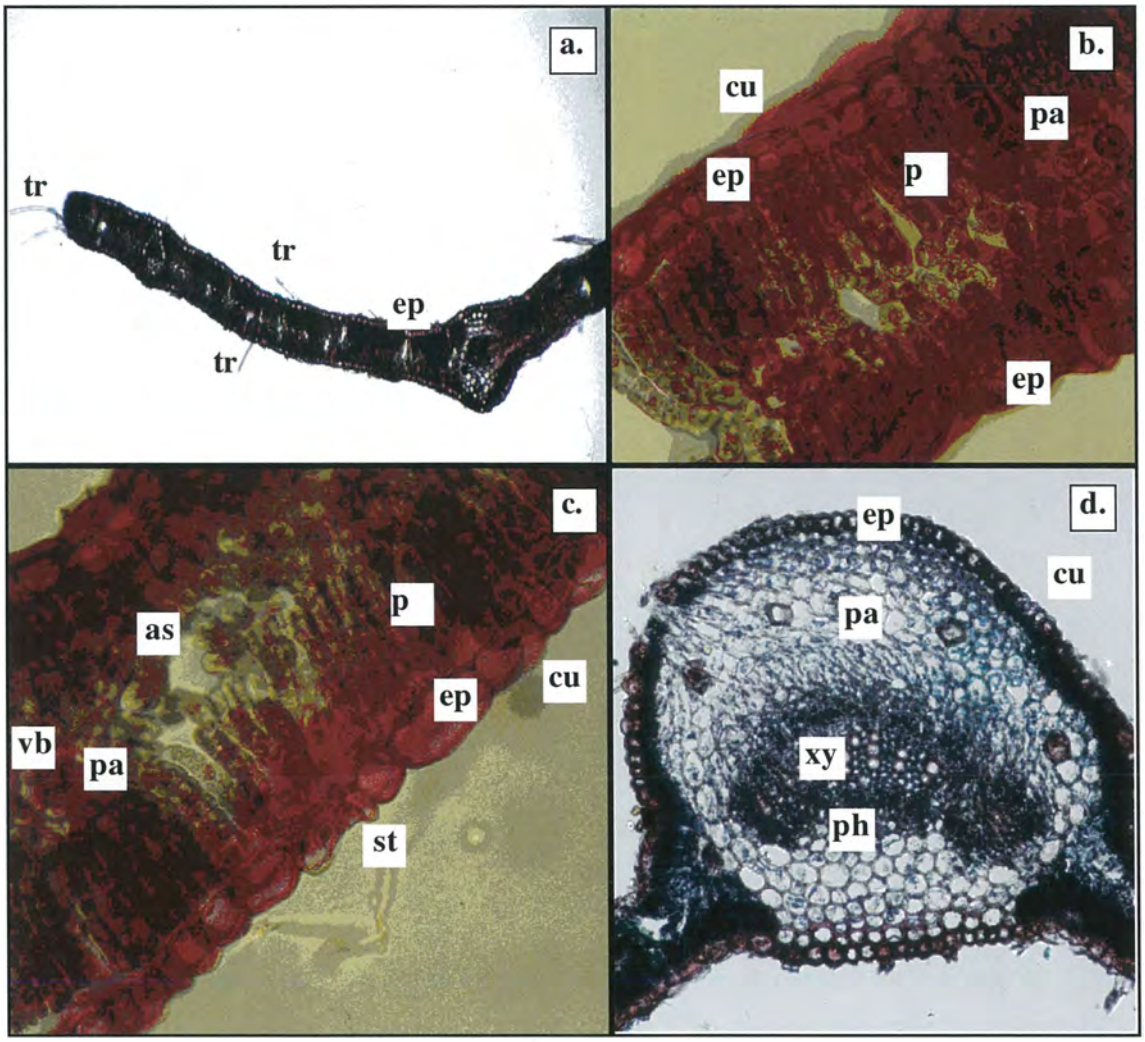


Plate 4.5 Anatomy of leaf sections of *P. longifolia.* Plate 4.5a shows a section of the leaf blade and the arrangement of the vascular bundles (40X magnification). Plates 4.5b and 4.5c show a section of the leaf blade and the tissue types contained within (400X), while 4.5d is a section through the mid vein of a leaf (100X). A complete list of section labels (e.g. **pa** = parenchyma) can be found on page 82.

Convolvulaceae are of the rubiaceous type (Metcalfe and Chalk 1950). This arrangement has each stomatal guard cell accompanied by one or more subsidiary cells with the longitudinal axes of these subsidiary cells parallel to the guard cells and the axis of the stomatal opening (Fahn 1967).

There are comparatively large air spaces within the leaf directly underneath each stomate, but otherwise the leaf is tightly packed with palisade mesophyll cells (Plates 4.5b and c). The arrangement of the xylem and phloem tissues within the vascular bundle in the midrib is similar to that in the stem tissue and appears to be arranged in a concave arc (Lowell and Lucansky 1986). Loosely packed parenchyma cells are arranged around each vascular bundle in the leaf (Plate 4.5c) and in the mid vein (Plate 4.5d; Lowell and Lucansky 1986).

There are a number of mechanisms that *P. longifolia* plants have to reduce water loss from the leaves and to source water from deep in the profile, e.g. deep rhizomes (Section 4.3). These mechanisms aid in the survival of *P. longifolia.* Anecdotal observations and those made by the author show that *P. longifolia* will survive after the death of all surrounding herbaceous vegetation suggesting that *P. longifolia* is an extremely effective competitor for resources available for plant growth. This aspect is examined further in Chapter 8.

4.6 Conclusions

These results indicate that the rhizome and root distribution of *P. longifolia* is concentrated in the upper levels of the soil profile (0 - 40 cm) where shoot recruitment is likely to occur. Both rhizome and root material have been found at greater depths, however, and this material may be important in the exploration of the soil for resources necessary for plant growth and survival. Shallow cultivation events to a depth of ten centimetres will do little to disturb the bulk of the rhizomes, however, as less than 20% of rhizome and root material

occurs above ten centimetres. Deep ripping to 40 cm in depth or herbicide translocation would be more effective management options, although the use of deep ripping may be questionable given that reshooting from depth may occur. The high level of interconnection between shoots within *P. longifolia* patches helps to explain how the species exploits soil resources and perhaps why the plant is so difficult to kill.

There is been little anatomical research published that is based on a single species in the Convolvulaceae. Thus, these studies on *P. longifolia* make an important contribution to the literature. The studies on *P. longifolia* revealed at least two important findings. Firstly, part of the tissue that has traditionally been called a rhizome is in fact a rhizome i.e. a modified underground stem, anatomically similar to a stem. Given that auxins inhibit the initiation of lateral buds on the stem, auxin based herbicides may inhibit shoot initiation from these rhizomes and hence *P. longifolia* growth. These herbicides appear to be more effective in controlling *P. longifolia* than non-auxin based herbicides (Table 3.13). An experiment designed to compare the effects of auxin and non-auxin based herbicides is needed to test this hypothesis.

Secondly, the crystals that were found in rhizome tissue may have contained allelochemicals, given the isolation of similar chemicals from other Convolvulaceae species. The possibility of an allelochemical interaction between *P. longifolia* and cotton has been suggested by others (G. Charles, C. Jones and T. Haynes) and requires further research.

Mass emergence of *P. longifolia* in an uncultivated area

Chapter 5

The population biology of Polymeria longifolia

Weed control research in the Australian cotton industry "must cover ecological aspects" and "it is particularly important to study the.....growth and development of the main weed species" (Basinski 1963).

5.1 Introduction

Without a basic understanding of the population biology of a weed, management will be at best *ad hoc* and at worst ineffective (Groves 1992; Norris 1992). For example, reducing the lateral root growth of *Chondrilla juncea* by promoting competitive pastures has been shown to reduce the density of this species (Cullen and Groves 1977). By way of contrast, not knowing that there were three biotypes of this weed resulted in limited success of the initial bio-control agent released against only one biotype.

To date, there have been no studies on the population biology of *Polymeria longifolia*. There is some anecdotal understanding of this species among cotton growers, agronomists and consultants in the cotton industry, and this has been used to recommend some management practices in the past (McMillan 1988a).

Polymeria longifolia shoots emerge in spring, often around the time of cotton planting and shoots grow actively from October to April (Section 2.4.5). Although perennial,

P. longifolia may disappear in winter in some cotton areas in northern New South Wales (NSW), perhaps because of frost damage (G. Charles, pers. comm.). Both McMillan (1988a) and Williams (1988) suggested that *P. longifolia* becomes dormant during the dry (winter) season and responds to the onset of spring rains.

In this chapter, both experimental and observational information about the population biology of *P. longifolia* have been collated to provide a stronger foundation for the design of effective management strategies.

5.2 Recruitment of new *P. longifolia* shoots in the field

5.2.1 Aim

These observations aimed to determine the main method of recruitment in *P. longifolia,* whether vegetative or reproductive.

5.2.2 Methods

Newly emerged *P. longifolia* shoots were excavated before they were five centimetres in height at, or around, the time of cotton planting (Table 5.1). These excavations aimed to expose the point of origin and to determine whether the shoot was from a rhizome or a seed. Shoots were surveyed at three locations: Colly Farms, Collarenebri; Auscott, Moree; and Walma, Walgett in the 1996/97 and 1997/98 cotton growing seasons (Table 5.1) by randomly selecting no more than four shoots in each of 25 rows in at least two patches of *P. longifolia* at each location. All shoots were at least 50 cm apart. Six shoots were also sampled along a roadside near Walma (Walgett).

The mean individual seed weight of mature *P. longifolia* seeds was determined by weighing

Table 5.1 The number and percentage of newly emerged shoots that were of vegetative and reproductive origin at three locations at the start of the 1996/97 and 1997/98 seasons.

Property and location	Date	Field	Total shoots excavated	Newly emerged shoots			
				Vegetative		Reproductive	
				Number	%	Number	%
Colly Farms (Collarenebri)	2/10/96	27	**54**	54	100	0	0
	15/10/97	12	**52**	52	100	0	0
Auscott (Moree)	25/10/96	11	**61**	60	98	1	2
	17/10/97	11	**53**	52	98	1	2
Walma (Walgett)	3/12/96	?	**50**	50	100	0	0
	3/12/96	roadside	**6**	6	100	0	0
Total			**276**	**274**	**99**	**2**	**1**

six x 100 seed samples. Peds of soil of an equivalent volume to a seed were weighed for comparison. Examination of the outer surface of the seeds was conducted using a stereo microscope. Five seeds were floated in water for several minutes to assess if the seeds were able to float.

5.2.3 Results and discussion

Only two seedlings (less than 1%) were observed out of the 276 newly emerging shoots excavated (Table 5.1). The remainder were of vegetative origin. Vegetative and seedling shoots were quite distinct in leaf shape (Plate 5.1). New vegetative shoots had leaves that were long and narrow, similar to adult leaves, while seedlings had distinctly rounded

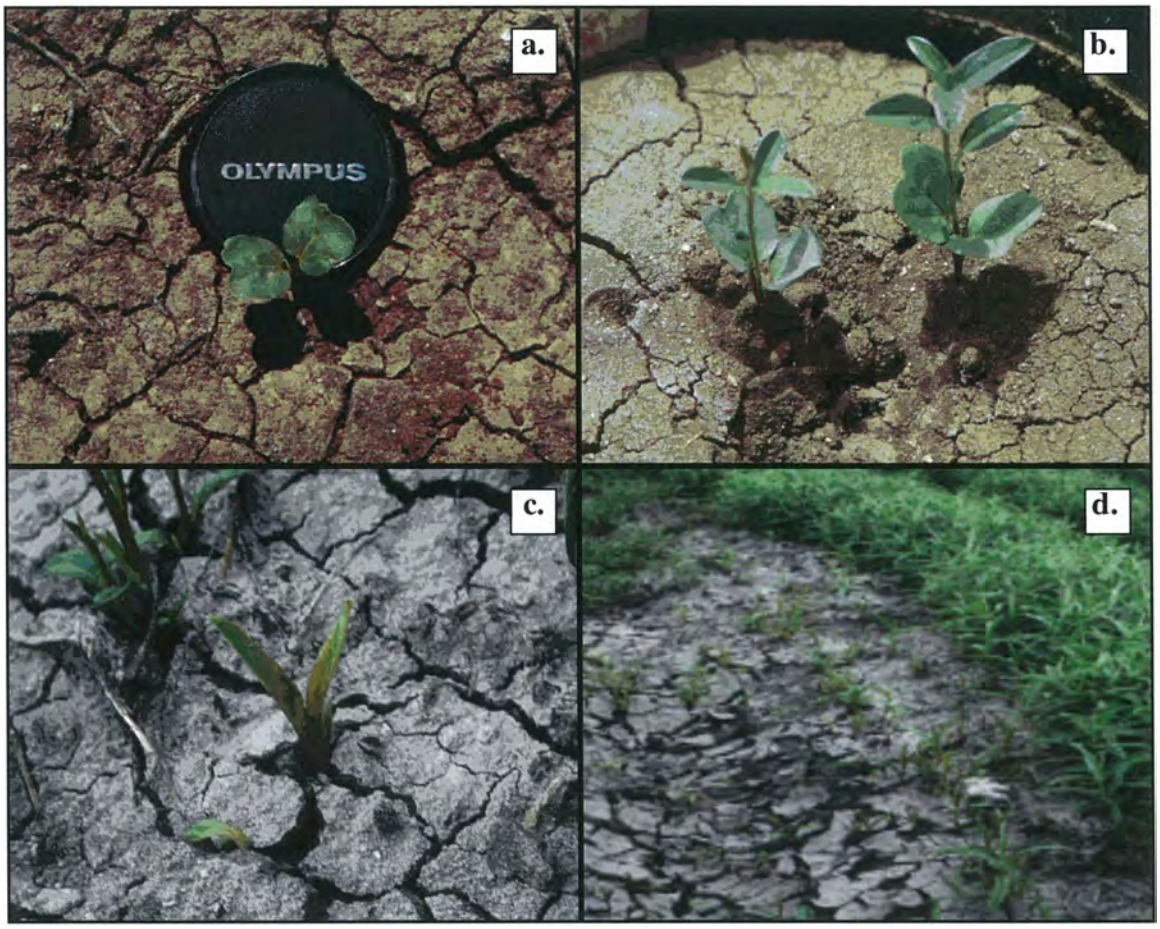


Plate 5.1 A comparison between seedlings (5.1a and b) and new vegetative shoots (5.1c and d) of *P. longifolia*. The seedling in 5.1a is one week old while those in 5.1b are four to six weeks old. The vegetative shoot in 5.1c emerged no more than one week before this photograph and is part of the mass emergence that occurs on the sides of the cotton hill after cultivation (5.1d).

coat were found attached to the roots of the seedlings. The rhizomes to which vegetative shoots were traced were 5 - 20 cm below the soil surface and often the thickness of the stem but, in the case of roadside excavations at Walgett, rhizomes were two to three times this thickness, presumably as a result of previous defoliation of shoots.

The lack of active seedling recruitment of *P. longifolia* in arable fields and under natural conditions was similar to that in another creeping perennial species, *Haloragis apsera* (Osten *et al.* 1996). It is suggested that the predominant means of reproduction in both species is via vegetative means (Section 6.3). Although the percentage of *P. longifolia* seedlings found was only small relative to the number of new vegetative shoots, it is

suggested that there could still be a reasonable number of seedlings produced over a wide area even though these were not picked up by this sampling procedure. These seedlings may play a role in ensuring ongoing survival of the species in case the existing population was wiped out in some way and for the maintenance of genetic diversity. It was also presumed that seeds played some role in the dispersal of the weed, perhaps in water. Each seed was covered in short hairs that aided in the ability of it to float, at least for several minutes, as ascertained by personal observations. The mean seed weight of *P. longifolia* was 48.3 ± 0.5 mg, which was lighter than the equivalent volume of soil. Conceivably, the roundness of a seed which would help it to be rolled along by water over a short distance and the weight of a seed with the hairs covering the seed coat would help in long distance dispersal via irrigation water. However, since recruitment from seeds was not a major form of reproduction for *P. longifolia,* little further attention will be paid to seeds in this study.

5.3 The survival of *P. longifolia* seedlings in the field

5.3.1 Aim

This experiment aimed to determine the longevity of naturally emerged seedlings found in commercially managed fields and in an uncultivated area.

5.3.2 Methods

Seedlings were tagged in cultivated fields from December 1996 - February 1997 and November 1997 - January 1998 at Auscott, Moree, and November 1997 - February 1998 at Colly Farms, Collarenebri (Table 5.2). Seedlings were also tagged in an uncultivated area at Auscott during the period January - March 1999. Since seedlings were generally found at extremely low densities i.e. around 1% of all new shoots were seedlings (Section 5.2.3),

extensive searching around *P. longifolia* patches was needed. Finding seedlings was somewhat easier at Colly Farms in the 1997/98 season as application of the residual herbicide imazapyr in April 1997 had reduced stem density considerably (Section 9.6). All other management for these fields has been outlined in Appendix 4.

All seedlings were tagged between the two cotyledon and eight true leaf stage with 79% having fewer than three true leaves. From glasshouse observations, seedlings usually had three true leaves within two weeks of emergence and four true leaves within one month. Seedling survival was assessed at regular intervals after tagging. Since the sampling period varied, seedling survival has been recorded in Table 5.2 with the corresponding number of days after initial tagging. The final status of the seedling was denoted as dead, spray damaged or necrotic, or alive. The survival of 73 seedlings was assessed (Table 5.2).

5.3.3 Results and discussion

The proportion of seedlings that were dead after 50 days was 50% in normal non-sprayed areas but slightly higher in imazapyr-sprayed areas (64%) (Table 5.2). The application of imazapyr appeared to severely distort new seedling growth.

More seedlings were observed in the imazapyr sprayed areas than outside these areas. The greater number of seedlings may have been a result of superior production of seeds in this patch the previous season (Section 5.4.3) or that large bare gaps devoid of shoot growth early on in the season allowed greater seedling recruitment.

Only two seedlings survived to reach reproductive maturity (2.7% of those tagged). One of these seedlings died after herbicide application on Field 11, Auscott, 102 days after tagging while the other in the uncultivated area at Auscott survived until the final observation date, 98 days after tagging. The recruitment of seedlings into adult plants was likewise small in

Table 5.2 Seedling survival in cultivated fields at Auscott and Colly Farms and in a native plant community (uncultivated area) at Auscott. Seedling status was indicated by D (dead), N (with spray damaged or necrotic tissue) and A (alive).

Property and location	Season	Field	Tagging date	Number of seedlings[a]	Status after x days
Auscott (Moree)	1996/97	11	20/02/97	1	A (25)
			05/12/96	3	D (33)
			07/01/97	1	D (69)
			05/12/96	1	D (77)
			05/12/96	1	D (102)
Auscott (Moree)	1997/98	11	18/12/97	1	D (32)
		48	11/11/97	1	D (21)
			20/01/98	1	D (51)
Auscott (Moree)	1998/99	Uncultivated area	08/02/99	3	D (28)
			08/03/99	2	D (42)
			11/01/99	2	D (56)
			11/01/99	3	D (98)
			11/01/99	1	A (98)
Colly Farms (Collarenebri)	1997/98	12	18/02/98	2	D (22)
			26/11/97	1	D (57)
			12/01/98	1	D (57)
			04/11/97	1	D (78)
		27	04/11/97	14	D (22)
			12/01/98	12	D (38)
			26/11/97	2	D (47)
			12/01/98	3	D (57)
			04/11/97	2	D (69)
			18/02/98	1	N (20)
			12/01/98	9	N (57)
			19/02/98	1	A (19)
			12/01/98	3	A (57)
Total				**73**	

[a] Where more than one seedling has been noted, each seedling was similar in longevity.

other perennial species that commonly reproduced by vegetative means. For example, there was a 14% recruitment from seeds in *Chondrilla juncea* (Cullen and Groves 1977), 0% recruitment in *Haloragis aspera* (Osten *et al.* 1996) and 4% recruitment in *Reseda lutea* (Heap 1997).

The mortality of seedlings is likely to be high because rapid desiccation could occur without the vegetative support of a rhizome to supply water from lower in the soil profile or from which the plant could regrow if defoliation occurred (Forde 1966; Amor 1974; Cullen and Groves 1977). Desiccation appeared to be one of the major causes of mortality of *P. longifolia* seedlings, due either to competition from the surrounding weed biomass or from rapid drying of the soil.

Only small numbers of seedlings emerged between November and March in each season. As indicated in Section 5.2.3, seed germination and seedling emergence did not play a major role in the population biology of *P. longifolia*. The lack of seedling recruitment is in stark contrast to the mass of vegetative recruitment reported in Sections 5.2 and 5.4.

5.4 The phenological development of *P. longifolia*

5.4.1 Aim

These observations aimed to follow the timing of production of vegetative and reproductive stems, flowers and seeds by *P. longifolia* over the length of the cotton growing season.

5.4.2 Methods

Observations were made at two locations: Auscott, Moree and Colly Farms, Collarenebri. One field was chosen in each cotton growing season at each location. Descriptions for these fields and their management are given in Appendix 4. The fields were Field 11 on the Midkin Farm in the 1996/97 season and Field 4 on the Wilson's Farm in the 1997/98 season at Auscott. Field 27 was assessed in the 1996/97 season and Field 12 in the 1997/98 season at the Central Farm, Colly Farms. Two patches or sites were used in each field.

The observations were restricted to between cotton planting, when *P. longifolia* first emerged, and defoliation, after which the species disappeared. Failure of the weed to re-emerge after defoliation may have been related to low soil moisture after the cessation of irrigation. Six permanent quadrats, 0.5 metres x 1 metre, were set in the centre of each of the two patches in each field where there was a high density of *P. longifolia*. Each quadrat was located across a cotton hill and adjacent furrow. This accounted for the variability in plant emergence and plant size between the hills and furrows and for the furrow cultivation which occurred in some instances. The number of stems and whether they were vegetative or reproductive (with buds, flowers or seeds, Plate 5.2) was recorded along with the total number of flowers and seeds. Data from each patch were combined and presented with the standard error of the mean.

5.4.3 Results

5.4.3.1 Vegetative and reproductive stems

Total stem density generally increased over the growing season (Figure 5.1). There were exceptions to this trend. These exceptions were at 140 days after planting (DAP) at Colly Farms during the 1996/97 season with the reduction in stem density probably caused by soil water stress (Figure 5.1a). Cultivation damage reduced the stem number of *P. longifolia* at 64 DAP at Colly Farms during the 1997/98 season and 46 DAP at Auscott during 1997/98 season (Figure 5.1c and d respectively). Stem death was common after flowering and seed set, particularly towards the end of the season. Shooting from the base of these senescent stems or very nearby was a common occurrence.

The total stem density of *P. longifolia* was distinctly different in each graph (Figures 5.1a - d). The main reason for this was that different patches of *P. longifolia* were observed in

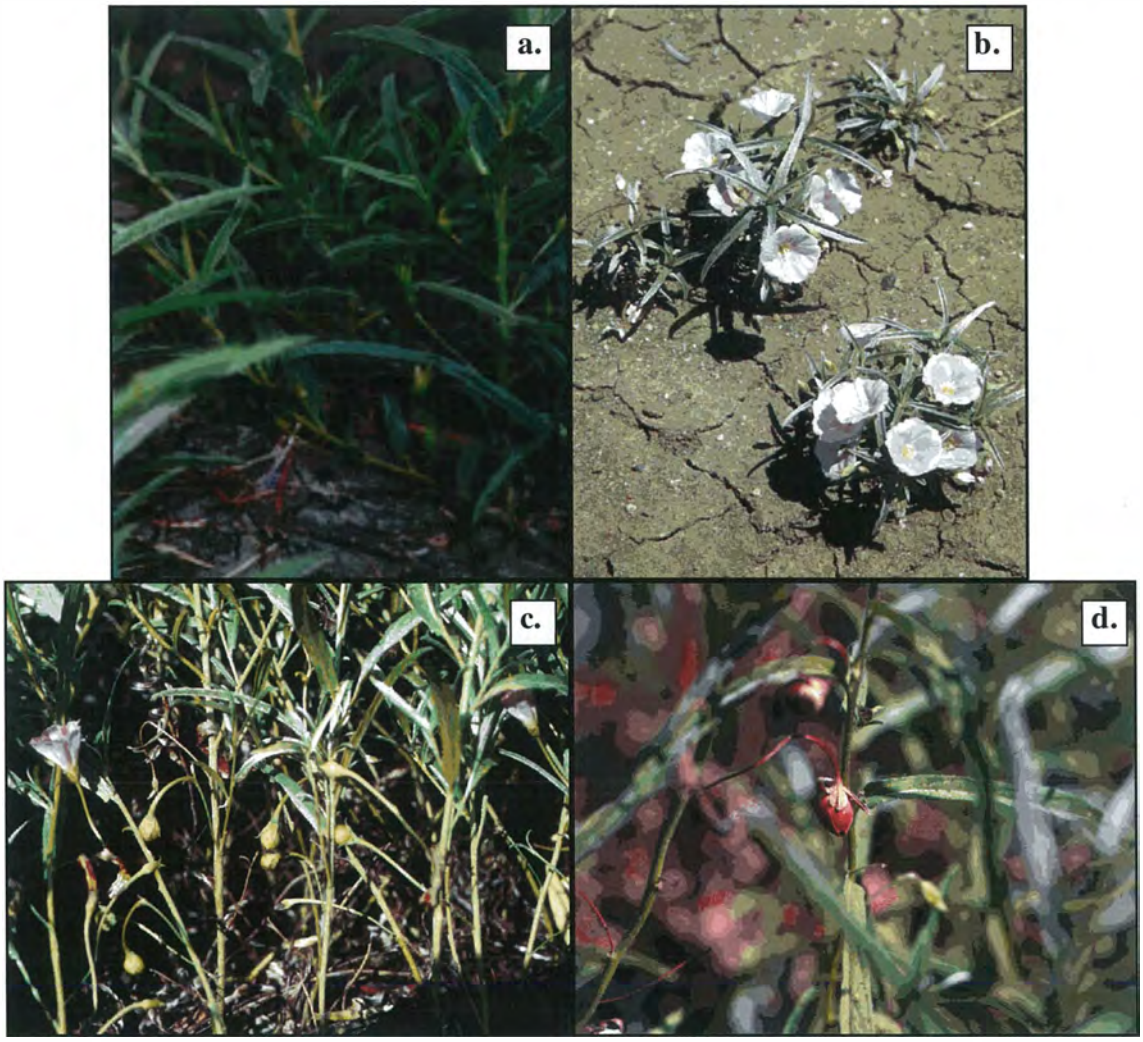


Plate 5.2 Stages of sexual reproduction in *P. longifolia.* Plate 5.2a shows emerging buds, 5.2b open flowers, 5.2c immature seed capsules and 5.2d a mature seed capsule immediately before shedding.

different fields during each season. A maximum of 220 stems per square metre was observed at Colly Farms during 1996/97 (Figure 5.1a). These patches were known to be 'old patches' that had been present for at least ten years. By comparison, only 149 stems per square metre were observed in the 1997/98 field in somewhat 'younger' patches. The maximum stem number in the 'old' established patches at Auscott in 1996/97 was only 62 stems per square metre (Figure 5.1b), while that in patches of unknown age in the 1997/98 season was 134 stems per square metre (Figure 5.1c), which was similar to that for Colly Farms in 1997/98 (Figure 5.1d). The maximum stem density observed in a quadrat in any patch was 279 stems per square metre at the end of the 1996/97 season at Colly Farms.

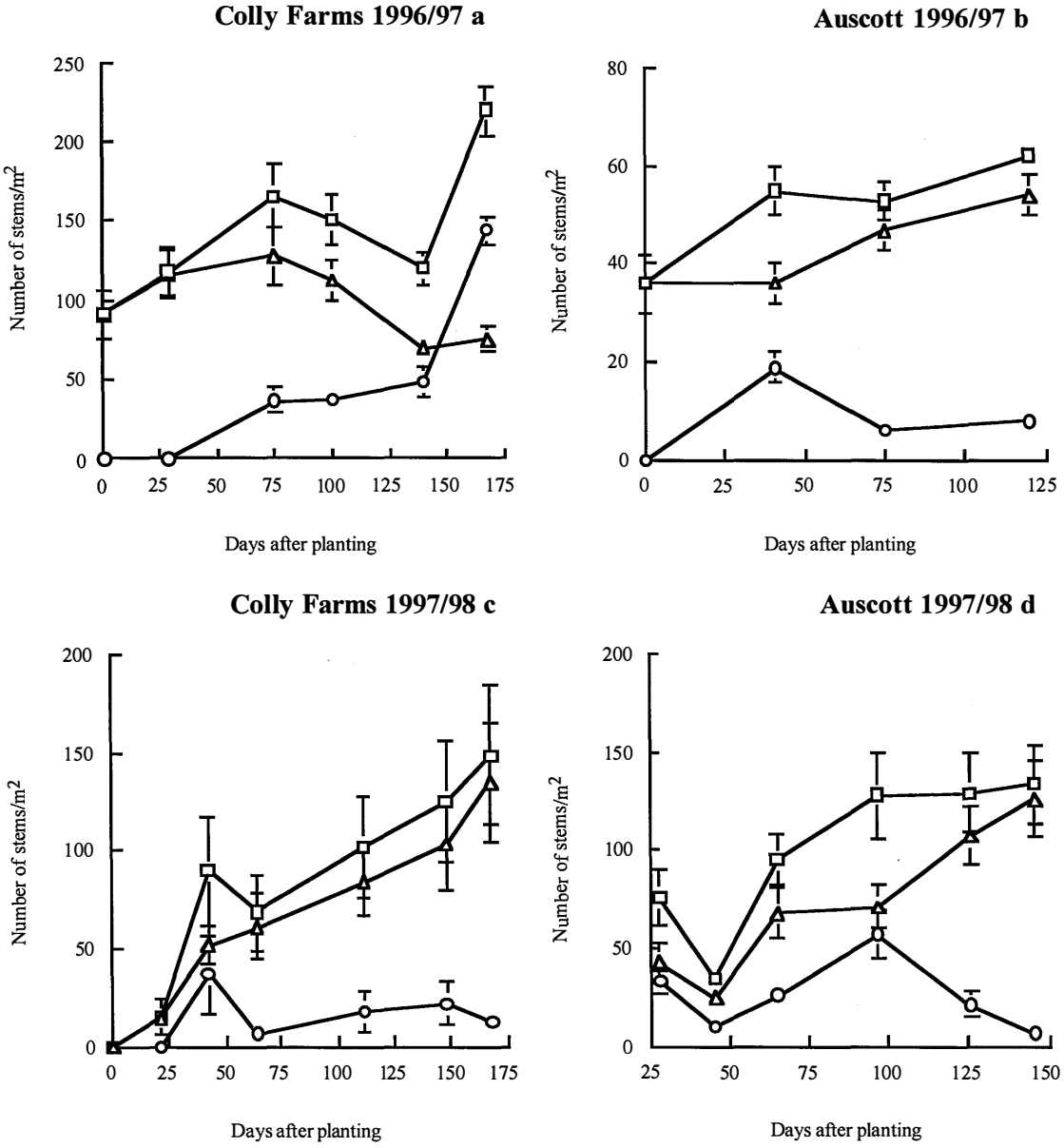


Figure 5.1 The vegetative (Δ), reproductive (O) and total (□) stem number of *P. longifolia*. These observations were taken during the 1996/97 and 1997/98 cotton growing seasons at Colly Farms, Collarenebri and Auscott, Moree. Each data point is the mean of two patches. The error bars represent the standard error of the mean.

There was generally a difference in density of 50 - 100 stems per square metre between the two patches at Colly Farms during both seasons and Auscott during the 1997/98 season. The difference was 20 - 40 stems per square metre at Auscott during the 1996/97 season.

These sites were separated by no more than 200 metres. These differences highlighted the importance of accounting for spatial variation in the field when assessing stem density.

The trend for the number of vegetative stems followed that for the total stem number (Figure 5.1). The trend in the number of reproductive stems was variable with an increase throughout the season at Colly Farms during the 1996/97 season (Figure 5.1a), an early season peak at Auscott during 1996/97 and Colly Farms during 1997/98 and a later season peak at Auscott during the 1997/98 season (Figures 5.1b - d).

5.4.3.2 Flower and seed production

A maximum of 67 flowers per square metre was observed at any one time at Colly Farms in 1996/97 (Figure 5.2a), 20 flowers per square metre and 35 flowers per square metre during 1997/98 at Colly Farms and Auscott respectively (Figures 5.2c and d) and only 5 flowers per square metre at Auscott during 1996/97 (Figure 5.2b). The maximum number of flowers on any one stem was nine, which was observed at Auscott during the 1996/97 season. Flower production often dropped below 10 flowers per square metre (Figures 5.2b - d).

Flower production increased with time at Colly Farms during the 1996/97 season (Figure 5.2a) and peaked at different times in each of the other areas. There was a maximum difference in the number of flowers produced between sites of 26 flowers per square metre at Colly Farms at 168 DAP in 1996/97, 23 flowers per square metre at 28 DAP and 38 flowers per square metre at 148 DAP at Auscott and Colly Farms respectively in 1997/98.

Because flowers remain open for only one day (personal observations), these data are limited to the day of sampling. Any extrapolation to determine the total number of flowers produced is likely to be very tentative given that flower production varies with time. What

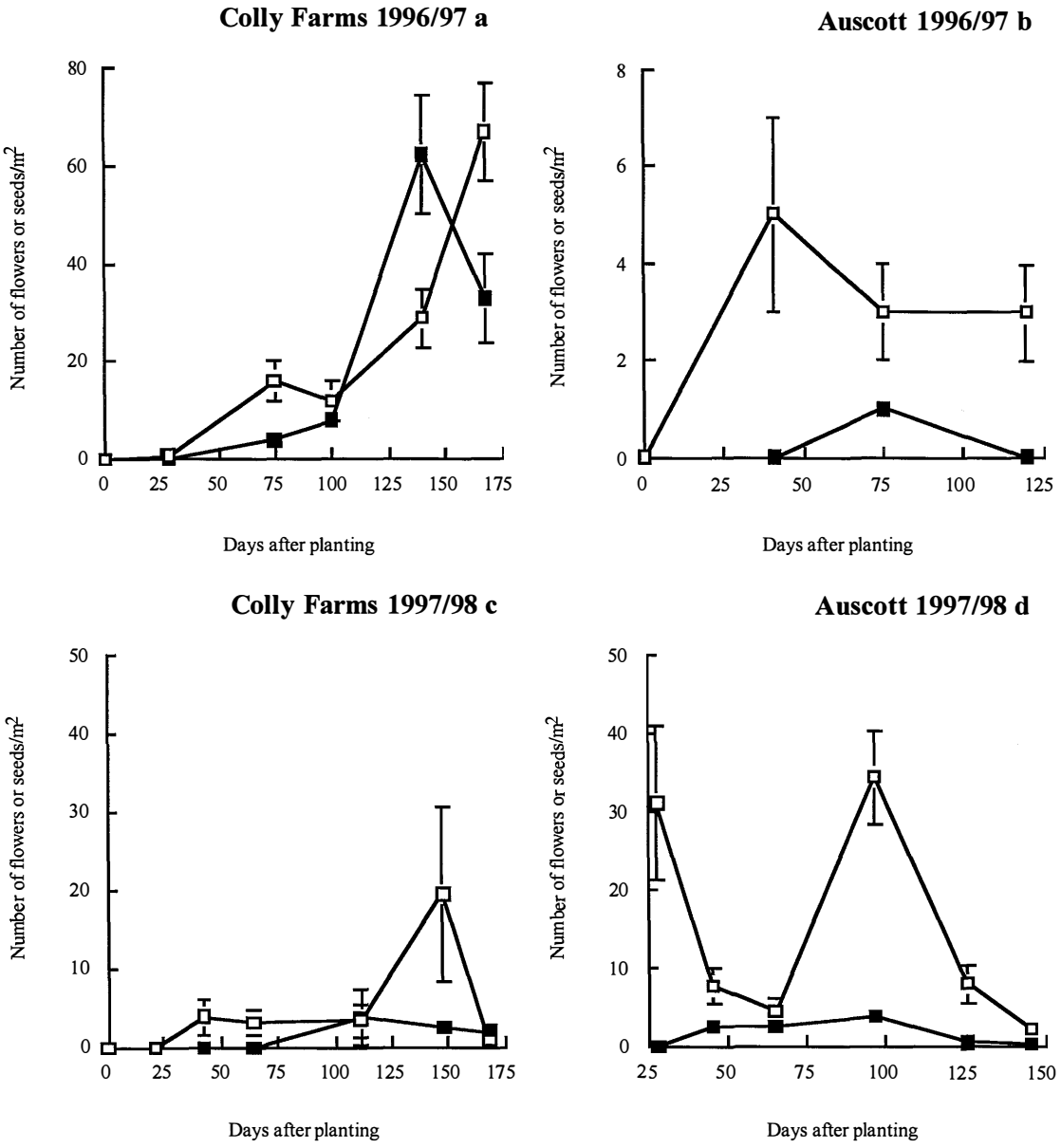


Figure 5.2 The number of flowers (□) and seeds (■) of *P. longifolia*. These observations were taken during the 1996/97 and 1997/98 cotton growing seasons at Colly Farms, Collarenebri and Auscott, Moree. All data were the mean of two patches.

this does indicate is that potentially there may be some hundreds, if not thousands, of flowers per square metre that open and close in a season.

Given the large number of flowers that were potentially produced each day, the production of seeds was low by comparison (Figure 5.2). This indicated that a very small proportion of flowers actually gave rise to seeds. Production of seeds did not exceed 62 seeds per square metre at Colly Farms during the 1996/97 season (Figure 5.2a). The maximum production of seeds in any quadrat was 142 seeds per square metre at 140 DAP and the maximum number of seeds observed on one stem was observed was 23, also at this date. By comparison, a maximum of only one seed per square metre was observed at Auscott in 1996/97 (Figure 5.2b). Less than five seeds per square metre were produced during the 1997/98 season at either Colly Farms or Auscott (Figures 5.2c and d).

The total number of seeds was the sum of all immature and mature seeds, with the maturity process taking approximately one month. At maturity a capsule turned brown and within two weeks dropped its seed which was not counted thereafter. Most capsules had only one seed, but those that formed two, or very rarely three seeds, had a compartmentalised capsule which was visible externally. The seed number values may be higher than actual seed numbers since an immature seed counted at one date may still have been retained by the capsule and observed at the next sampling date.

5.4.4 Discussion

5.4.4.1 Vegetative and reproductive stems

These results indicate that the maximum density of *P. longifolia* shoots occurs late in the cotton growing season and herbicide application at defoliation may be one effective way of achieving control assuming that the *P. longifolia* plants were not physiologically stressed, because stress may hamper herbicide translocation. Application of herbicide at defoliation would aim to reduce *P. longifolia* density and, by default, rhizome growth, without damaging the defoliated cotton crop. As the soil dried further after defoliation any herbicide

application would be less successful. Mechanical disturbance on this large shoot and possibly rhizome mass would not be possible until after the crop had been harvested. Mechanical disturbance could include some means of cultivation or deep ripping and is not as dependent on whether the *P. longifolia* is physiologically stressed or not.

These suggestions need further research. Firstly, an intensive growth and developmental study should be undertaken to determine the movement of photosynthetic products around the plant. It is highly likely that the early movement of carbohydrates in the plant go directly to the production of shoots with a shift to the storage of carbohydrates in perennial organs, rhizomes in the case of *P. longifolia*, sometime later in the growing season. The pattern of carbohydrate or dry weight allocation has been studied in a number of other species including *Convolvulus arvensis* (Wiese and Rea 1962), *Cyperus esculentus* and *C. rotundus* (Williams 1981), *Equisetum arvense* (Marshall 1986), and *Ipomoea pandurata* (Horak and Wax 1991) in an effort to enhance management. By depleting carbohydrate reserves by intensive defoliation earlier in the season in fallow fields (the time of early and rapid shoot production of *P. longifolia*) and achieving better herbicide translocation later in the season by understanding when maximum carbohydrate storage is occurring (Section 4.5.3.2), a more successful regime of management for *P. longifolia* may be achieved.

5.4.2.2 Flower and seed production

The fact that there were reproductive stems present throughout the season meant that the production of seeds could occur at any time and that the control of seeding would be difficult. However, the production of *P. longifolia* seeds was many times lower than production of seeds by annual weed species in the Australian cotton industry, e.g. *Xanthium spinosum* which produced 855 - 3842 seeds per square metre (Charles 1996b) and *Echinochloa crus-galli* which produced 20,000 - 1,000,000 seeds per square metre (Norris

1992), or by the perennial *Haloragis aspera* which annually produced 30,000 - 90,000 seeds per plant (Osten 1996).

Insect pollination probably occurred, given the bright colour of flowers and that insects were seen visiting flowers, although insecticide application to cotton may well reduce the potential number of pollinating insects. The insects that appeared to pollinate *P. longifolia* included the honey bee (*Apis mellifera*), which was commonly observed in fields in December and January and once observed to visit 15 opening flowers in 5.5 minutes. Small black *Carpophilus* spp. beetles, 3 - 4 mm in length, took shelter in open flowers early in the season from October - December. Although these beetles ate the corolla and sometimes did damage to the stamens and stigma, pollen may have been spread between flowers. Other species that were observed in flowers included transverse ladybirds (*Coccinella transversalis*), jewel beetles (Family Buprestidae) and small native bees with yellow and brown striped abdomens (Family Tipiidae).

5.5 Life histories of individual *P. longifolia* stems

5.5.1 Aim

This experiment aimed to determine the survival of individual stems of *P. longifolia* under cultivated field conditions.

5.5.2 Methods

Individual *P. longifolia* stems were observed at two locations: Colly Farms, Collarenebri and Auscott, Moree in the 1996/97 and 1997/98 seasons. At each location, one field was chosen in each growing season. Descriptions for these fields and their management are given

in Appendix 4. Data from two different patches permanently marked within each field have been combined.

Twelve individual stems of *P. longifolia* located in the centre of each patch, six of which were on hills and six in furrows, were randomly tagged just above ground level with brightly coloured plastic tape. Hills had very little disturbance from cultivation while furrows were cultivated twice before the end of December in each season. Tagging and observation of stems occurred only during the period January - March 1997 in the 1996/97 cotton growing season at both locations, but during the entire season from October 1997 - March 1998 the following season. The phenological status of each stem, that is whether it was vegetative or reproductive, was noted at regular monthly intervals. Reproductive stems had buds, flowers or seeds while vegetative stems did not. If stem death occurred another stem was tagged randomly to maintain the sample size.

5.5.3 Results and discussion

There was very little difference in the survival or biology of *P. longifolia* stems between the hills and furrows during either cotton growing season and for this reason the data were combined. There were various reasons for the lack of difference although the main one in the 1996/97 cotton growing season was that tagging commenced in January 1997 after cultivation had ceased. During the 1997/98 season limited furrow cultivation occurred at Auscott and again there was little difference between the survival or life histories of stems in the hills or furrows. There was one exception at Colly Farms during the 1997/98 season, however. Of the 15 stems that were tagged on the hills, 33% later died, while in the furrows, 72% of the 36 tagged stems later died. These differences highlighted that furrow cultivation was a major form of above-ground stem death.

Individual stem mortality was low in the 1996/97 cotton growing season at both Colly Farms and Auscott. For instance, only 38.2% and 12.5% of all stems tagged at Colly Farms and Auscott respectively were recorded as having died during the two month experimental period (Table 5.3). The reason why the mortality was higher at Colly Farms may have been related to the higher intra-specific competition of *P. longifolia* there, compared with that at Auscott. The density of stems during the experimental period at Colly Farms ranged between 50 - 200 stems per square metre while the density at Auscott was between 50 - 150 stems per square metre (Figure 5.1).

Stem mortality within the 1997/98 season was approximately 60% at both locations (Table 5.3). The largest number of stems that died were vegetative stems but, given that cultivation occurred when most *P. longifolia* shoots were in the vegetative phase, this trend was expected.

Around 25% of all *P. longifolia* stems that had been tagged in the reproductive phase had later changed back to the vegetative phase and they had no buds, flowers or seeds. The exception to this were the data from the 1997/98 season at Colly Farms. These results show that the lifecycle *P. longifolia* is indeterminate, i.e. it does not proceed regularly from seedling establishment to vegetative growth to reproduction and then to plant death. Instead, *P. longifolia* shoots can switch from the vegetative state to the reproductive state or *vice versa*, although this is probably dependent on environmental conditions. For example, rapid vegetative growth of *P. longifolia* occurs under high soil moisture conditions even if stems are in the reproductive phase. An indeterminate life cycle is essential in a perennial species so that, if suitable conditions for vegetative growth occur sometime after the initial vegetative growth phase, the plant can switch into vegetative growth again. Likewise, if conditions are suitable, flowering may occur at various times during the growing season. The plasticity of *P. longifolia* stems to switch between the vegetative and

Table 5.3 A summary of the life histories of tagged *P. longifolia* stems evaluated under cultivated field conditions at Colly Farms and Auscott over the 1996/97 and 1997/98 seasons. The life history description is what happened to the stems over the experimental period. Both the number of stems and percentage in each class have been presented.

Season	1996/97 (Jan. - Mar.)				1997/98 (Oct. - Mar.)			
Location	Colly Farms		Auscott		Colly Farms		Auscott	
Life history description	No.	%	No.	%	No.	%	No.	%
Vegetative	3	8.8	12	50.0	15	33.3	5	9.8
Reproductive	9	26.5	0	0	0	0	0	0
Veg. to Reprod.	1	2.9	3	12.5	0	0	1	2.0
Reprod. to Veg.	8	23.5	6	25.0	2	4.4	12	23.5
Veg. to Dead	8	23.5	3	12.5	21	46.7	14	27.5
Reprod. to Dead	4	11.8	0	0	4	8.9	13	25.5
Veg. to Reprod. to Dead	0	0	0	0	1	2.2	0	0
Reprod. to Veg. to Dead	1	2.9	0	0	1	2.2	4	7.8
Veg. to Reprod. to Veg.	0	0	0	0	1	2.2	2	3.9
Total	34	100	24	100	45	100	51	100

reproductive phases was not so clearly observed in the 1997/98 season because of the high cultivation-induced mortality.

Between 9 and 50% of all *P. longifolia* stems tagged during both seasons remained in the vegetative state. The function of these vegetative stems may have simply been to acquire plant resources.

In summary, individual stems of *P. longifolia* show a high degree of plasticity in moving between the vegetative and reproductive states. Significant stem mortality can occur as a result of cultivation damage but may also be tied to intra-specific competition.

5.6 Dry weight change of *P. longifolia*

5.6.1 Aim

This experiment was conducted to determine the dry weight changes of *P. longifolia* under cultivated cotton field conditions to ascertain when maximum biomass was achieved.

5.6.2 Methods

Dry weight production of *P. longifolia* populations was evaluated at Colly Farms, Collarenebri and Auscott, Moree. At each location, one field was chosen in each growing season i.e. 1996/97 and 1997/98. Descriptions of these fields and their management have been given in Appendix 4.

At several times throughout each season, *P. longifolia* stems in actively growing patches were counted in four randomly placed 1 metre x 1 metre quadrats and then harvested at ground level, dried at 70°C for 48 hours to constant weight and weighed. Previously harvested plots were tagged and not revisited on subsequent harvests. The three parameters evaluated were total density, total dry weight per unit area and dry weight per plant.

5.6.3 Results and discussion

The density of the *P. longifolia* stems was similar between the seasons and increased during the seasons (Figure 5.3a and b). The overall dry weight range of *P. longifolia* stems throughout the seasons was 11 - 486 grams per square metre, or 110 - 4,860 kilograms per hectare (Figure 5.3c and d). Total dry weight increased with time with two exceptions which were at 132 DAP at Auscott during the 1996/97 season (Figure 5.3c) when herbicide application on parts of the *P. longifolia* patch previously sampled were made, necessitating

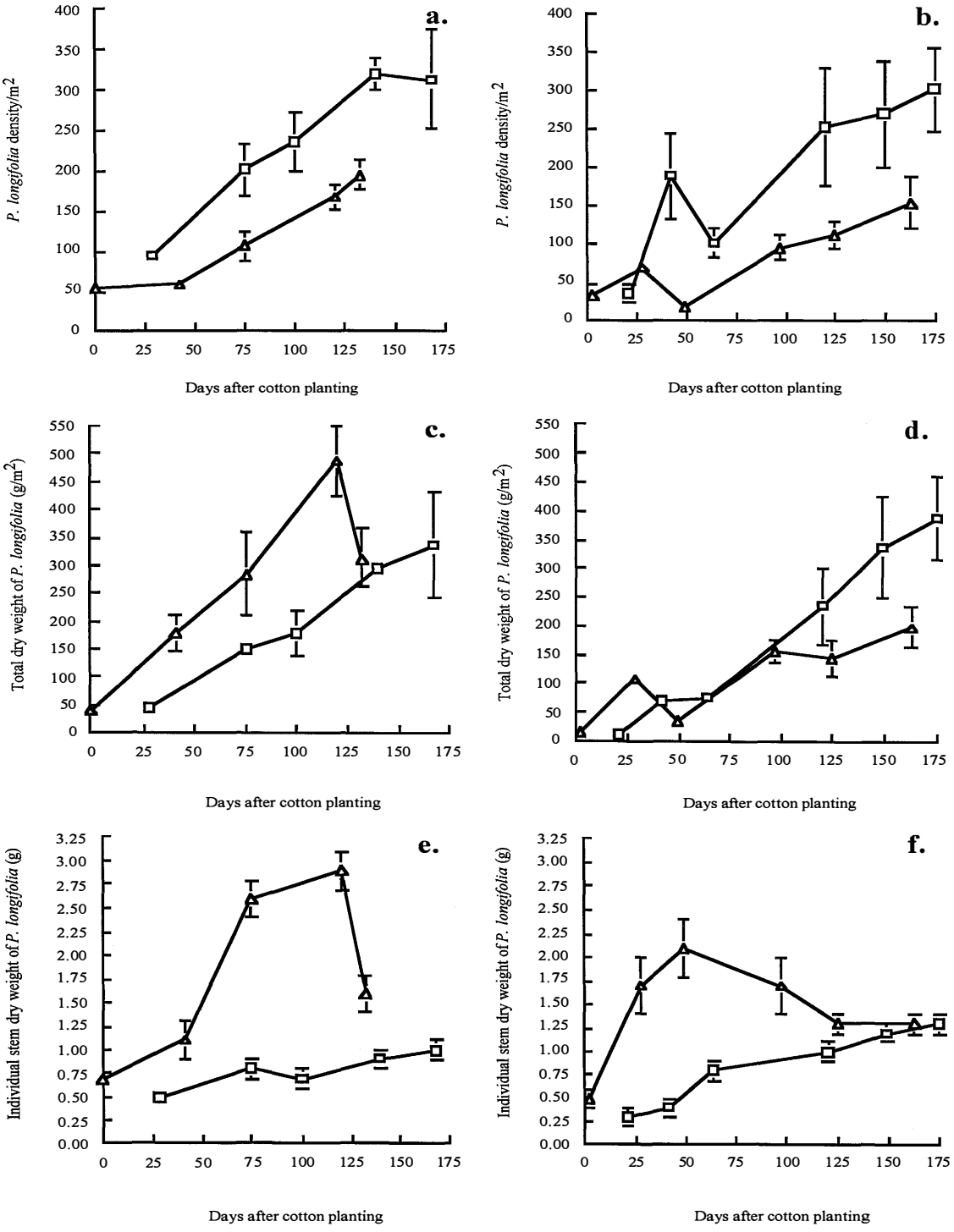


Figure 5.3 The density (Figures 5.3a and b), total dry weight/m^2 (5.3c and d) and individual dry weight/plant (5.3e and f) of *P. longifolia* stems during the 1996/97 (5.3a, c, and e) and 1997/98 (5.3b, d, and f) cotton growing seasons at Colly Farms, Collarenebri (□) and Auscott, Moree (Δ). The standard errors of the means have been presented as error bars. Where this error is small, the bars may not be visible.

the sampling of less dense patch areas, and at 49 DAP at Auscott during the 1997/98 season (Figure 5.3d.) when cultivation through the *P. longifolia* patch reduced stem density.

The total dry weight of *P. longifolia* quadrats was greater at Auscott than Colly Farms during the 1996/97 season (Figure 5.3c) but less so during the 1997/98 season (Figure 5.3d). These differences were probably due to the selection of four distinct patches of *P. longifolia* over the two seasons.

The individual plant dry weights of *P. longifolia* stems throughout the seasons partially reflect these differences. For example, the individual plant dry weights of *P. longifolia* during 1996/97 and 1997/98 at Colly Farms were 0.5 - 1 and 0.3 - 1.3 grams per stem and for Auscott, 0.7 - 2.9 and 0.5 - 2.1 grams per stem. Stems of *P. longifolia* were larger but also less dense at Auscott than at Colly Farms (Figures 5.3a, b, e and f).

The large above-ground dry weights of *P. longifolia* indicate that many plant resources are not being made available for cotton growth and that this contributes to poor cotton crops in the presence of *P. longifolia*.

5.7 The phenological development of *P. longifolia* in uncultivated areas

5.7.1 Aim

These observations were taken to compare the population biology of *P. longifolia* in uncultivated areas with that in cotton fields to see if *P. longifolia* is being favoured by cotton production systems.

5.7.2 Methods

The observations were taken at three locations, with each cultivated field having at least one adjacent uncultivated site: Field 36 at the Central Farm, Colly Farms, Collarenebri during 1997/98, Field 11 at the Midkin Farm, Auscott, Moree during 1997/98 and 1998/99 and Field 48 at the Top Box Farm, Auscott during the 1997/98 season. Only the uncultivated area of the latter location was examined during the 1998/99 season because the field was sown to wheat in winter and a management regime for *P. longifolia* implemented which prevented permanent location of quadrats.

Observations were made from six replicate 0.5 metre x 1 metre quadrats in each of the cultivated and uncultivated sites in a similar fashion to that already outlined (Section 5.4.2). Stems, flowers and seeds were counted and the state of each stem assessed i.e. whether reproductive with buds, flowers or seeds or simply vegetative at each time of sampling. The initial densities at the sites within each different location were comparable.

On the final harvest date at each site, *P. longifolia* shoot material was cut, dried at 70°C for 48 hours and weighed. At Colly Farms, harvest occurred at the end of the 1997/98 season, while for the two experiments at Auscott this harvest occurred at the end of the 1998/99 season.

The results were analysed using an analysis of variance and treatment means compared using the 5% least significant difference (l.s.d.). Only results which were different at this level will be discussed.

5.7.2.1 Colly Farms 1997/98 season

A basic description of Colly Farms and the experimental area is given in Appendix 4 and Table 5.4 respectively. Field 36 was managed in a similar way to Field 12 regarding planting, weed control, cultivation, irrigation, fertiliser and harvest operations (Appendix 4). Observations commenced on 14 October, which was 11 days after Field 36 had been planted to cotton. Observations were continued on 4 and 26 November (32 and 54 days after planting, DAP) and then on 21 January (wet weather prevented a December observation) and 18 February 1998 (110 and 138 DAP respectively). The trial was harvested on 10 March 1998 (158 DAP).

5.7.2.2 Auscott - Midkin 1997/98 and 1998/99 seasons

A basic description of the Midkin Farm, particularly the management of Field 11, is given in Appendix 4. The uncultivated area was located outside an earth bank which surrounded the farm and was split into three sites (Table 5.5). This was the closest *P. longifolia* infestation to a cultivated field. Field 11 was fallowed during the 1997/98 season after a winter crop of barley had been harvested. Observation dates have been included in Table 5.6.

The irregular fallow cultivations on the cultivated field meant that observations in permanent quadrats were only possible during the periods 0 - 63 and 400 - 525 days after initial observations (DAIO) (Table 5.6). During the first period of time, observations were based on a large patch nominally called site A. Control was so effective at reducing the *P. longifolia* population at site A that observations had to be transferred to another site, called site B, at 99 DAIO. The sites were named this way from observations that were made on them in the previous season (Section 5.4). Quadrats were randomly allocated around site B at each sampling date during the period 99 - 357 DAIO and then permanently

Table 5.4 Summary of the experimental area at Colly Farms.

Description	Uncultivated area	Cultivated field
Location	50 m north of Field 36.	Field 36
Previous history	Seldom used black soil road bounded by an irrigation channel and grassland (free of *P. longifolia*). Graded ca. 3 times/year before trial, not during experiment.	Cotton cropping
Other vegetation	Weeds, e.g. *Cucumis* spp. (paddy melons), *Tribulus* spp. (Yellow vine/Caltrop), *Hibiscus trionum* (bladder ketmia) and *Solanum nigrum* (blackberry nightshade). Quadrats mostly composed of *P. longifolia.*	Cotton
Size of patches	Small distinct patches ca. 1 - 2 m diameter.	1 patch ca. 20 m diameter

Table 5.5 Summary of the experimental area at Auscott - Midkin.

Description	Uncultivated area	Cultivated field
Location	3 km west of Field 11.	Field 11
Site names	There were three sites which were a graded bank site (1), a grassy undisturbed site (2) and a grassy grazed site (3).	Cultivated field
Site descriptions	**Site 1.** A graded earth bank wall sloped 40° to the west and a flatter area immediately below it. **Site 2.** 4 - 6 m west from farm wall but immediately inside an electric fence with no cultivation or grazing. **Site 3.** 9 - 12 m west from farm wall on grazed side of fence.	Cultivated field
Previous history	**Site 1.** Periodically graded twice/year prior to experiment, not during experiment.	Cotton
Other vegetation	**Site 1.** None. **Site 2.** Introduced grasses, e.g. *Panicum* spp. **Site 3.** As for site 2 with coolibah woodland (2 - 3 m west).	Cotton
Size of patches	Dispersed shoots.	20 - 80 m diameter

Table 5.6 Summary of the observation dates at Auscott - Midkin. All observations were calculated as the number of days after initial observation (DAIO).

Date of observation	Days after initial observation (DAIO)	Comments
15 October 1997	0	Initial observation
11 November 1997	27	
28 November 1997	44	
17 December 1997	63	
22 January 1998	99	
5 February 1998	113	Electric fence removed ca. 100 DAIO
6 March 1998	142	Grazing ceased sometime before this
1 April 1998	169	
30 April 1998	197	
2 June 1998	230	
7 October 1998	357	Site 1 sprayed ca. 300 DAIO
19 November 1998	400	Cotton planting on Field 11 between 357 and 400 DAIO
17 December 1998	428	
13 January 1999	455	
10 February 1999	483	
24 March 1999	525	Harvest

set from 400 DAIO which was after cotton planting had occurred. No *P. longifolia* could be found at 168 and 197 DAIO because of cultivation and laser levelling. Laser levelling is the cultivation of fields with very shallow grades for use in irrigated production using specially fitted laser guidance equipment.

Permanent quadrats were able to be set in the uncultivated sites because the management of the area was reasonably non-disruptive. The graded bank population was sprayed with a mixture of 2 L/ha MCPA and 2 L/ha glyphosate (both trade product rates) around 330

DAIO which resulted in progressive death of stems over the next 90 days and very little new plant recruitment. The grazed site was in a paddock where cattle were stocked at approximately one animal per hectare and, even so, no grazing damage on *P. longifolia* was observed throughout this trial.

5.7.2.3 Auscott - Top Box 1997/98 and 1998/99 (uncultivated area only) season

A basic description of the Top Box Farm, particularly Field 48, is given in Appendix 4. The uncultivated area examined in this experiment was located 100 - 150 metres south of the cultivated area and split into two sites (Table 5.7). No grazing damage was observed on the uncultivated populations of *P. longifolia* despite the presence of native and introduced fauna including kangaroos, emus and rabbits. Observation dates have been included in Table 5.8. On 14 November, a mixture of 2 L/ha of glyphosate and 1 L/ha of dicamba (trade product rates) was spot sprayed on the *P. longifolia* patches in the cultivated field. The herbicide application has been outlined further in Section 9.5.

During the 1997/98 season, stem heights and dry weights of *P. longifolia* stems were assessed in the graded roadside and undisturbed grassland sites. To assess these parameters, the height of five stems at four replicate sites was measured after which the stems for each replicate were bulked, dried and weighed as above. The stems were harvested from an area close to, but outside, the quadrat areas.

5.7.3 Results

5.7.3.1 Colly Farms

Total stem production was always greater in the cultivated field than in the uncultivated roadside with the exception of the first sampling date (Figure 5.4c). There was a large

Table 5.7 Summary of the experimental area at Auscott - Top Box.

Description	Uncultivated area	Cultivated field
Location	Up to 100m south of Field 48.	Field 48
Site names	There were two sites which were a graded roadside (1) and an undisturbed grassland site (2).	Cultivated field
Site descriptions	**Site 1.** Edge of a graded roadside in a slight drainage area. **Site 2.** 4 - 9 m south of graded roadside in a grassland area.	Cultivated field
Previous history	**Site 1.** Periodically graded four times/year prior to experiment, some grading during experiment.	Cotton
Other vegetation	**Site 1.** Very little, some introduced grasses, e.g. *Panicum* spp. **Site 2.** Native and introduced grasses, e.g. *Panicum* and *Chloris* species with *Acacia farnesiana* (mimosa bush) interspersed throughout area.	Cotton
Size of patches	Dispersed shoots.	Distinct patches, 1- 3 m in diameter

increase in the total density of *P. longifolia* stems in the cultivated field in contrast with the very modest increase at the uncultivated site. The range in stem density from the start of the trial to the end was 17 - 36 stems per square metre in the uncultivated site and 15 - 196 stems per square metre in the cultivated field. This was largely a result of the number of vegetative stems present, which was greater than 58% in the uncultivated roadside and 80% in the cultivated field (Figure 5.4a).

There was very little difference in the density of reproductive stems, flowers or seeds between the two sites except towards the end of the experimental period when the production of flowers and seeds in the cultivated field exceeded that in the uncultivated site (Figures 5.4b, d and e). The total dry weight of *P. longifolia* at harvest was far greater in the

Table 5.8 Summary of the observation dates at Auscott - Top Box. All observations were calculated as the number of days after initial observation (DAIO).

Date of observation	Days after initial observation (DAIO)	Comments
11 November 1997	0	Initial observation, ca. 1 month after cotton planting
2 December 1997	21	Patches on Field 48 sprayed 3 DAIO
17 December 1997	36	
20 January 1998	70	
5 February 1998	86	
12 March 1998	121	Seedbed preparation for wheat planting
1 April 1998	141	resulted in disappearance of patches in
30 April 1998	170	Field 48.
2 June 1998	203	
8 October 1998	331	
18 November 1998	372	
17 December 1998	401	
12 January 1999	427	
9 February 1999	455	
10 March 1999	484	Harvest

cultivated field than in the uncultivated roadside (Table 5.9). The individual dry weight of stems was about 50% greater.

5.7.3.2 Auscott - Midkin

The total density of *P. longifolia* stems in the cultivated field was far greater than the density in the uncultivated sites during the summer periods 0 - 99 and 400 - 525 DAIO (Figure 5.5). The maximum stem density for the 1997/98 season was 133 stems per square metre while that in the 1998/99 season was 139 stems per square metre and occurred during

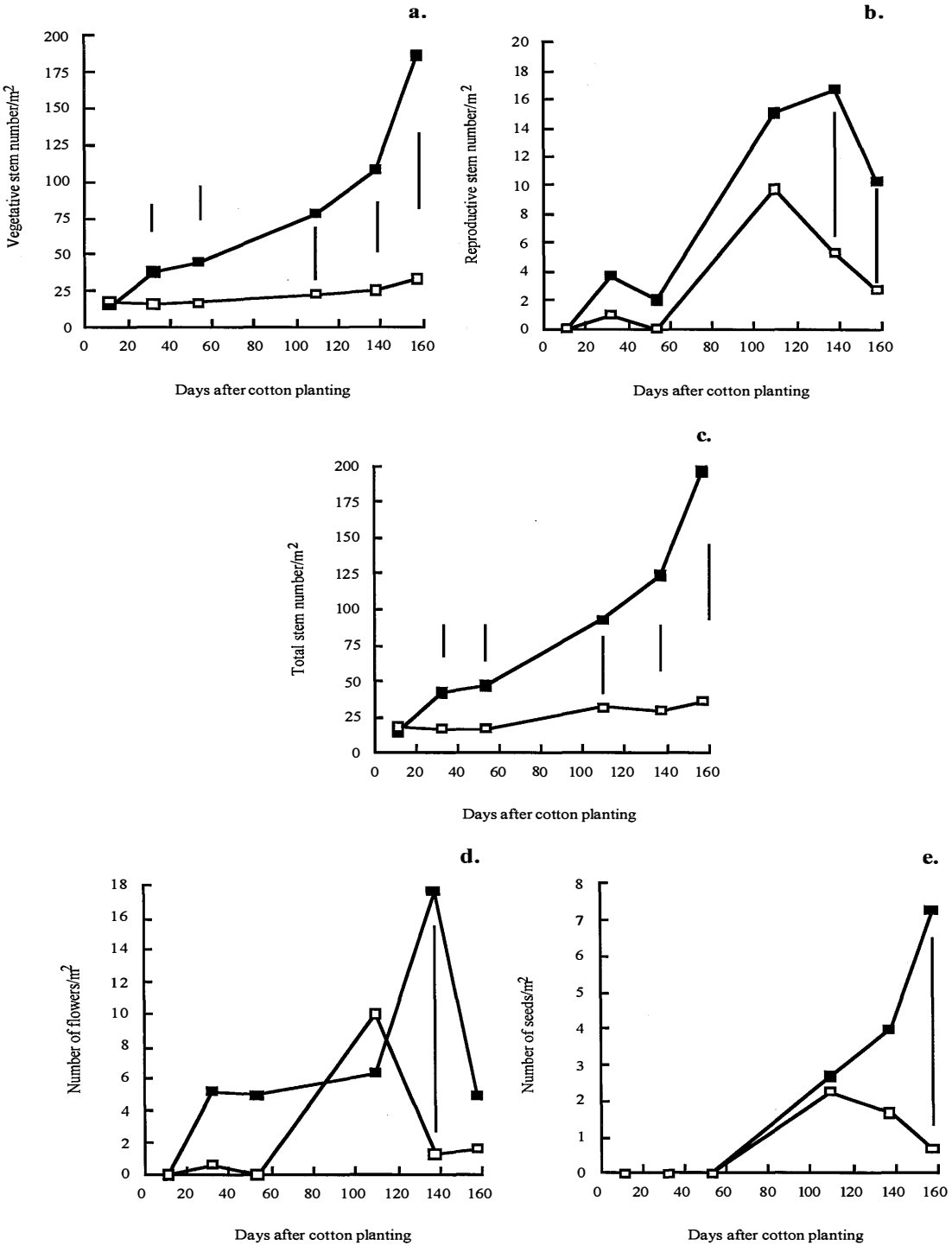


Figure 5.4 The biology of *P. longifolia* stems on the uncultivated roadside (□) and in the cultivated field (■) at Colly Farms. The number of vegetative stems is given in Figure 5.4a, reproductive stems in 5.4b, total stem number in 5.4c, and total flower and seeds number in 5.4d and 5.4e respectively. Vertical bars represent the 5% l.s.d. Where bars are not shown, the results were not significantly different at the 5% level.

Table 5.9 Summary of the *P. longifolia* harvest parameters at Field 36, Colly Farms.

Harvest parameter	Uncultivated site	In field	5% l.s.d.*
Density (stems/m^2)	36.0^a	196.3^b	50.2
Total dry weight (g/m^2)	36.3^a	298.8^b	85.3
Individual dry weight (g/plant)	1.0^a	1.5^b	0.4

* Means within a parameter marked with the different letter are significantly different ($P < 0.05$).

the later part of the cotton growing season during late summer - autumn. Stem density increased throughout each cotton growing season and then decreased in late autumn, e.g. there was a decrease in the stem density of *P. longifolia* after the first peak which was at 99 DAIO, until 197 DAIO in all sites. After this a small increase at all sites occurred and thereafter there was another decrease over the winter months until 357 DAIO. The rapid decrease in stem density in the cultivated field at 99 DAIO, January 1998, was due to herbicide application and cultivation damage while the smaller decrease after 428 DAIO (December 1998) was due to an inter-row cultivation event removing some stems.

There was very little variance in the total stem density of *P. longifolia* in the three uncultivated sites with time (Figure 5.5). For example, total stem density ranged from 5 - 25 stems per square metre for the graded bank, to 11 - 40 stems per square metre for the grassy undisturbed site and 7 - 33 stems per square metre for the grassy grazed site. For much of the 1997/98 season the density of stems in the grassy undisturbed site was greater than in the graded bank or grassy grazed sites which were not different from each other (0 - 197 DAIO). Following the application of herbicide to the graded bank population prior to 357 DAIO, the density of stems in the graded bank population decreased progressively through the 1998/99 season (357 - 525 DAIO). There was no difference in the total stem density of *P. longifolia* in the grassy undisturbed and grassy grazed sites during the 1998/99 season.

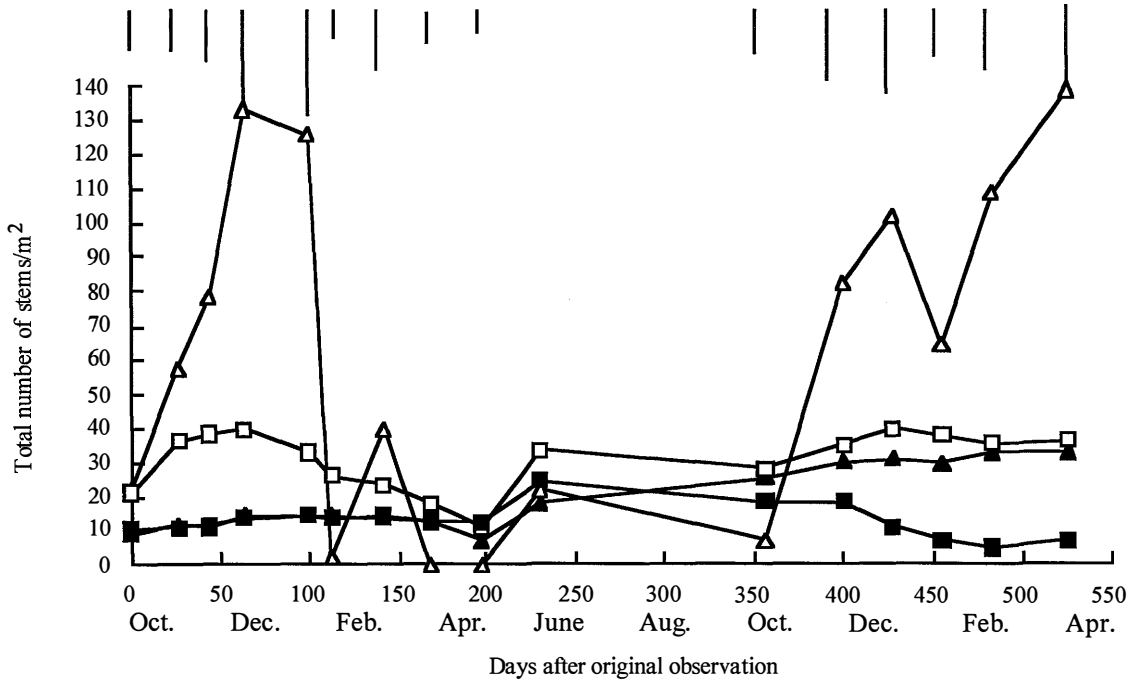


Figure 5.5 The total number of *P. longifolia* stems in the three uncultivated sites at the Midkin Farm, Auscott, Moree. These sites were the graded bank (■), the grassy undisturbed site (□) and the grassy grazed site (▲) as compared with the cultivated Field 11 (Δ). Vertical bars represent the 5% l.s.d. Where bars are not shown, the results were not significantly different at the 5% level. The trial was conducted from October 1997 through to March 1999. Note the nearly complete overlap of the graded bank and grassy grazed data on the left side of the figure.

Most of the stems were vegetative, with generally fewer than 11 stems per square metre being reproductive at any one time. There were essentially no differences in the trends for vegetative and reproductive stem number and total stem number. For this reason only the total stem numbers have been graphed (Figure 5.5).

Both flower and seeds production were low in all treatments with less than 12 flowers per square metre and one seed per square metre produced at any date (Table 5.10). Both the production of flowers and seeds was greater in the cultivated field than in the uncultivated sites which were not different to each other. No seeds were produced in the grassy grazed site. Total and individual dry weights were highest in the cultivated field, but also higher in the grassy undisturbed and grazed sites than in the graded bank (Table 5.11).

5.7.3.2 Auscott - Top Box

In contrast to the other two locations, the density of stems in the cultivated field at Top Box was less than in the uncultivated sites (Figure 5.6), however, this decline in stem density was caused by the application of a glyphosate/dicamba mixture shortly after initial observations commenced, as previously outlined (Section 5.7.2.3). No observations were made on the cultivated field after March 1998 (141 DAIO).

The maximum stem density for the cultivated field was 56 stems per square metre which occurred at the start of the experiment before the herbicide was applied (Figure 5.6). The stem density of *P. longifolia* peaked three times throughout the trial, these being during each summer and at 203 DAIO. After the initial summer peak at 36 DAIO, total stem density declined in both uncultivated sites. The large increase in total stem density at 203 DAIO was due to heavy rainfall which preceded this observation and continued until the next March. For example, a total of 906.8 mm of rainfall was recorded, six km away at the town of Garah and this rainfall was far in excess of the total rainfall for this period for the previous three years. For example, in the 1997/98 period, 352.6 mm fell, in the 1996/97 period, 747.4 mm fell and in the 1995/96 period, 568.0 mm fell (Bureau of Meteorology 1999). No long term averages were available. Although this rainfall occurred, there was still a decrease in the stem density of *P. longifolia* over the later winter and early spring months.

The range in total stem density for the graded roadside was 11 - 102 stems per square metre, while for the undisturbed grassland it was 11 - 67 stems per square metre. In many cases, total stem density in the graded roadside site significantly exceeded that in the undisturbed grassland. At 401 DAIO, the graded roadside site was graded with some plant loss occurring. There were essentially no differences in the trends for vegetative and reproductive stem number and total stem number. For this reason, only the total stem numbers have been graphed (Figure 5.6).

Table 5.10 The numbers of flowers and seeds per square metre at Midkin, Moree during the 1997/98 and 1998/99 cotton growing seasons. Only dates where flowers or seeds were observed have been included; a complete list of dates is given in Table 5.6.

Date and	DAIO	Graded bank	Grassy undist.	Grassy grazed	Cultivated field
Flowers					
11/11/97	27	0.7	5.0	0.7	0.0
28/11/97	44	0.3	1.7	0.7	3.7
17/12/97	63	3.7	3.0	0.0	1.3
22/01/98	99	6.7	0.0	0.0	5.7
05/02/98	113	0.3	0.0	0.0	0.0
06/03/98	142	1.0	0.0	0.0	0.0
02/06/98	230	2.7	2.0	0.7	0.0
19/11/98	400	0.0	1.3	0.3	0.0
17/12/98	428	0.0	0.0	0.0	2.7
10/02/99	483	0.3	0.0	0.3	11.3
24/03/99	525	0.0	1.0	0.0	4.7
Seeds					
17/12/97	63	0.0	0.0	0.0	1.0
22/01/98	99	0.3	0.3	0.0	0.3
05/02/98	113	0.3	0.0	0.0	0.0

Table 5.11 Summary of the *P. longifolia* harvest parameters at Midkin, Moree.

Harvest parameter	Graded bank	Grassy undist.	Grassy grazed	Cultivated field	5% l.s.d.*
Density (stems/m^2)	7.0^a	36.7^b	33.0^b	138.7^c	19.5
Total dry weight (g/m^2)	10.5^a	56.5^b	52.3^{ab}	286.6^c	42.6
Individual dry weight (g/plant)	1.7^a	2.9^b	3.3^{bc}	4.1^c	1.2

* Means within a parameter marked with a different letter are significantly different ($P < 0.05$). The letters n.s. indicate no significant difference at this level.

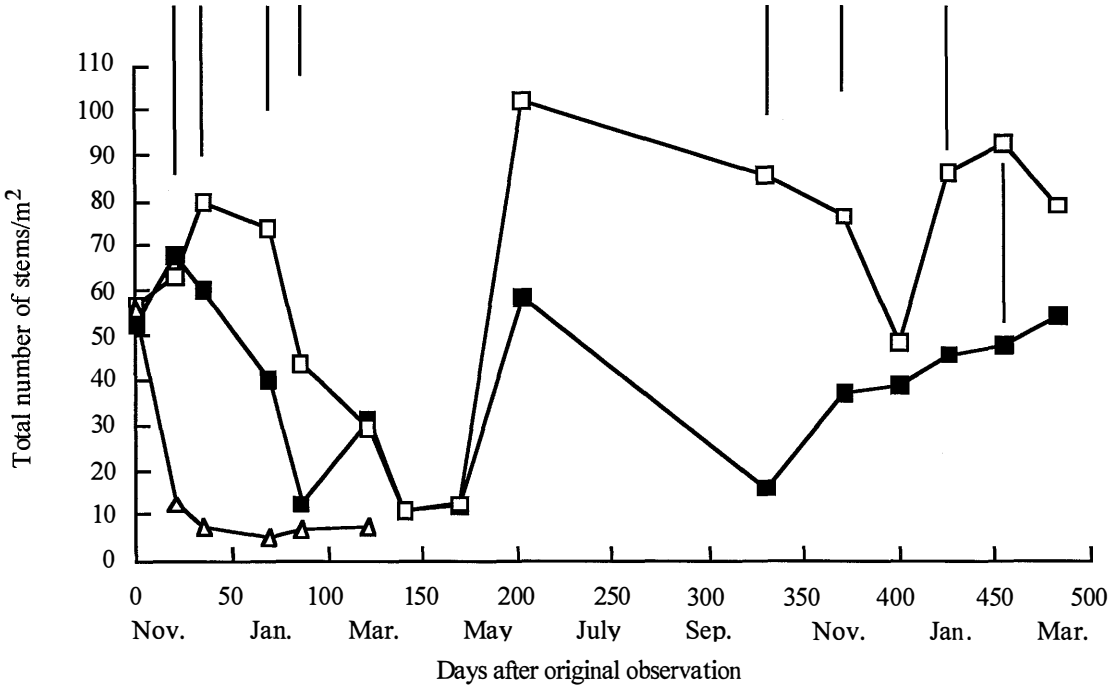


Figure 5.6 The total number of *P. longifolia* stems in the two uncultivated sites i.e. the graded roadside (□) and the undisturbed grassland (■) as compared with the cultivated Field 48 (Δ) at the Top Box, Auscott, Moree. Vertical bars represent the 5% l.s.d. Where bars are not shown, the results were not significantly different at the 5% level. The trial was conducted from November 1997 through to March 1999.

Except for the first three observation dates (0 - 36 DAIO), flower and seeds production was very low with less than five flowers and seven seeds per square metre produced at any date (Table 5.12). Maximum numbers of 104 flowers and 9.3 seeds per square metre were produced at 21 DAIO in the undisturbed grassland.

The dry weight of *P. longifolia* stems was higher in the graded roadside population than in the cultivated field and disturbed grassland areas, which were not different from each other (Figure 5.7b and Table 5.13). There was no difference in the stem heights (Figure 5.7a).

Table 5.12 The numbers of flowers and seeds per square metre at Top Box, Moree during the 1997/98 and 1998/99 cotton growing seasons. Only dates where flowers or seeds were observed have been included; a complete list of dates is given in Table 5.8.

Date and	DAIO	Graded roadside	Undisturbed grassland	Cultivated field
Flowers				
11/11/97	0	2.3	35.3	6.3
02/12/97	21	0.0	104.0	19.7
17/12/97	36	0.0	1.0	0.7
05/02/98	86	0.7	0.0	0.0
02/06/98	203	0.0	1.3	-
08/10/98	331	4.0	0.0	-
18/11/98	372	3.3	2.7	-
17/12/98	401	0.7	2.3	-
09/02/99	455	4.3	0.7	-
Seeds				
11/11/97	0	0.0	1.3	0.3
02/12/97	21	0.0	9.3	4.3
17/12/97	36	0.0	4.7	1.7
20/01/98	70	0.0	3.0	0.7
05/02/98	86	0.0	2.0	0.0
18/11/98	372	0.3	0.0	-
09/02/99	455	6.3	0.0	-
10/03/99	484	2.3	0.0	-

5.7.4 Discussion

Polymeria longifolia growing in cultivated cotton fields differed in a number of ways from more natural populations growing in uncultivated areas. Total stem density in the cultivated field populations always exceeded that in the uncultivated areas (Figures 5.4, 5.5

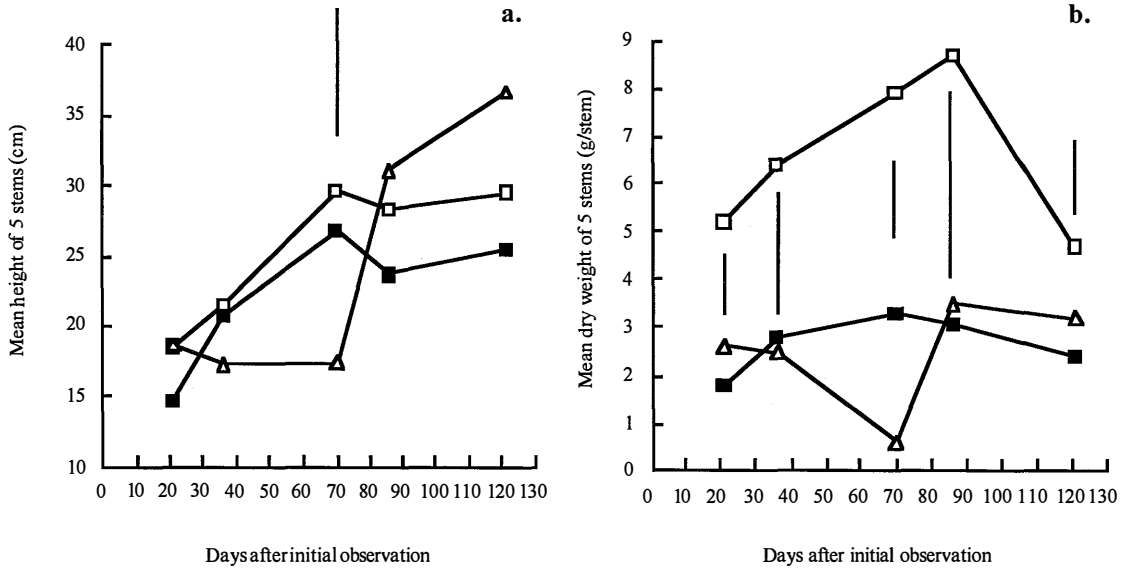


Figure 5.7 The mean height (Figure 5.7a) and dry weight (5.7b) of five *P. longifolia* stems in the two uncultivated sites i.e. the graded roadside site (□) and the undisturbed grassland site (■) as compared with the cultivated Field 48 (Δ) at the Top Box, Auscott, Moree. The vertical bars represent the 5% l.s.d.

Table 5.13 Summary of the *P. longifolia* harvest parameters at Top Box, Auscott, Moree.

Harvest parameter	Graded roadside	Undisturbed grassland	5% l.s.d.*
Density (stems/m^2)	75.3	54.3	n.s.
Total dry weight (g/m^2)	95.7^b	32.6^a	43.4
Individual dry weight (g/plant)	1.3^b	0.6^a	0.3

* Means within a parameter marked with a different letter are significantly different ($P < 0.05$). The letters n.s. indicate no significant difference at this level.

and Table 5.14). The obvious exceptions were in the Midkin and Top Box experiments when herbicide application or cultivation resulted in death of *P. longifolia* in the cotton fields (Figures 5.5 and 5.6). Likewise, the dry weight of *P. longifolia* at harvest was always greater in the cultivated fields than in the uncultivated areas (Tables 5.9, 5.11, 5.13).

The production of seeds is one mechanism by which the survival of a plant population may be ensured if vegetative reproduction fails. The greatest numbers of flowers and seeds on a unit area basis were produced in the cultivated fields (Table 5.14).

The fact that there was a greater density, dry weight and total flower and seeds production of *P. longifolia* on cultivated fields than in the uncultivated areas indicates that growth was favoured in the cultivated fields. The application of irrigation water and fertiliser combined with the infrequent and shallow cultivation events in cultivated fields may be responsible for the increase in density. Such increases may have resulted from a stimulation of dormant rhizome buds in the same way as previously outlined (Section 2.4.6). This is a relatively common means of regeneration after defoliation in other perennial rhizomatous species such as *Agropyron repens* (Vengris 1962), *Cynodon dactylon* (Horowitz 1972) and *Achillea millefolium* (Bourdot 1984).

It was also conceivable that competition from surrounding vegetation in the uncultivated grassland areas may have had a negative impact on the growth of *P. longifolia* and that the cotton crop may be less competitive than surrounding grassland in uncultivated areas. Further research would be required to determine this.

There were differences in the growth of *P. longifolia* among the uncultivated sites. For example, the reason why the density on the graded bank was lower than in the grassy undisturbed area at Midkin during the 1997/98 season was that the graded bank faced west and was subject to extremely high light intensity and desiccation which would have stunted plant growth (Figure 5.5, Plate 5.3). A reduction in dry weight at harvest was also recorded in this site (Table 5.12).

Table 5.14 A summary of the vegetative, reproductive and total stem density and total numbers of flower and seeds of *P. longifolia* in the three experiments. The experiments have been summarised by site types i.e. cultivated fields, graded and grassland sites.

Site and location	Description	Number of stems/m^2			Number/m^2		Harvest
		Vegetative (range)	Reproductive (range)	Total	Flowers	Seeds	dry weight (g/m^2)
Cultivated fields							
Colly Farms	Field 36	15 - 186	0 - 17	15 - 196	0 - 18	0 - 7	298.8
Midkin	Field 11	0 - 138	0 - 27	0 - 139	0 - 11	0 - 1	286.6
Graded sites							
Colly Farms	Road	16 - 33	0 - 10	17 - 36	0 - 10	0 - 2	36.6
Midkin	Bank	4 - 21	0 - 6	5 - 25	0 - 7	0 - 0.3	10.5
Top Box	Roadside	10 - 78	0 - 51	11 - 102	0 - 4	0 - 6	95.7
Grassland sites							
Midkin	Undisturbed	11 - 40	0 - 8	11 - 40	0 - 5	0 - 0.3	56.5
Midkin	Grazed	7 - 32	0 - 5	7 - 33	0 - 1	0	52.3
Top Box	Undisturbed	11 - 54	0 - 26	11 - 67	0 - 104	0 - 9	32.6

At Top Box, the density and dry weight of *P. longifolia* was higher in the graded roadside area rather than in the undisturbed grassland area (Figures 5.6, 5.7b and Table 5.13). This was possibly an effect of a lack of competition from surrounding grasses in the graded roadside site and a higher water potential in that site because of water pooled at the roadside edge.

These experiments also afforded the opportunity to trace the population biology of *P. longifolia* throughout the entire year instead of just through the cotton growing season as outlined in Section 5.4. *Polymeria longifolia* was not frosted off and did not disappear totally over winter, in contrast to observations made by G. Charles (Section 2.5.5). Those

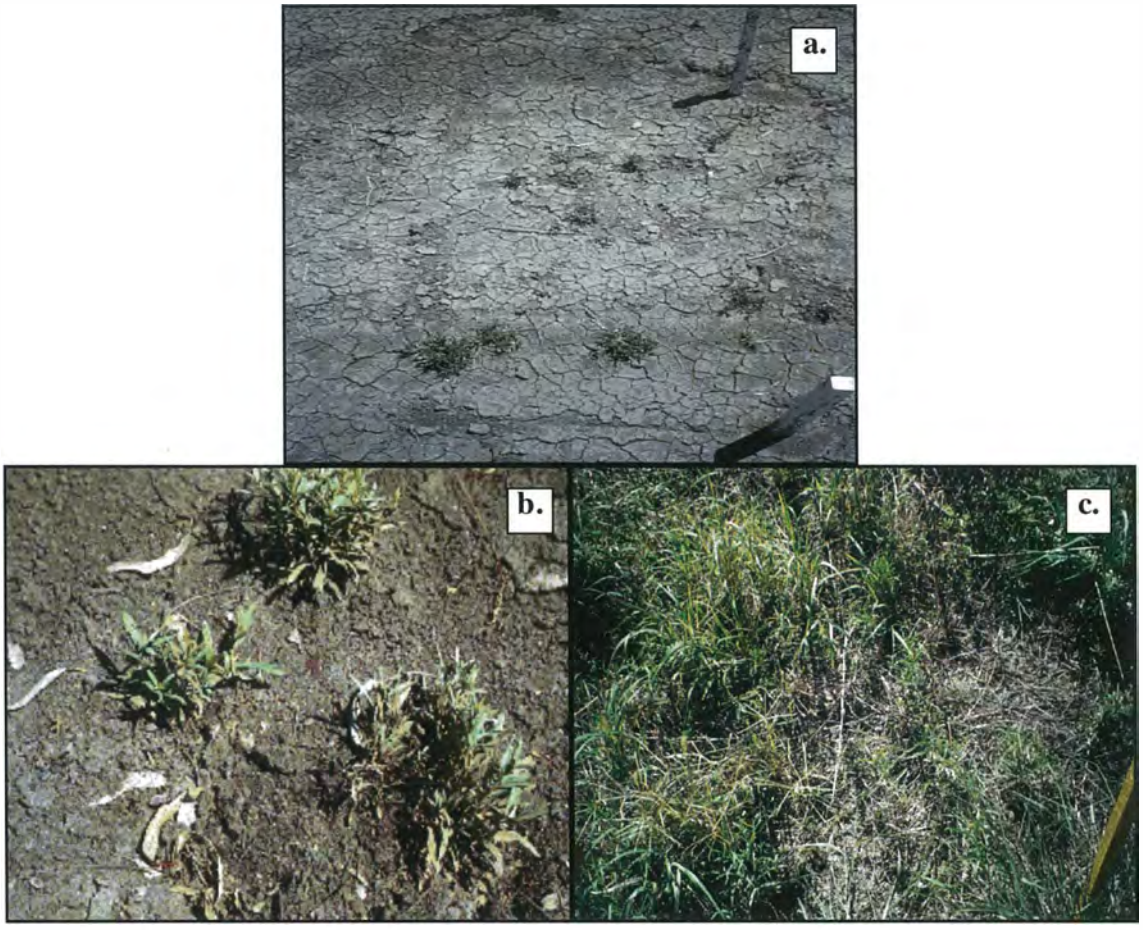


Plate 5.3 Plants of *P. longifolia* in uncultivated areas. Plate 5.3a shows plants in the graded roadside area at Colly Farms (approximately 10 cm high), 5.3b plants in the graded bank (approximately 10 cm high) and 5.3c in the grassy undisturbed area at Auscott Midkin (up to 25 cm high).

observations were probably based on field populations where the shoots had died back after irrigation had ceased and were ploughed in following cotton harvest. This was a common observation in cotton fields but ignored the fact that emergence occurred over the winter period (Figure 5.5). Plant death was often in response to the onset of rain (McMillan 1988a; Williams 1988), although peak emergence of the weed occurred at the time of cotton planting.

While *P. longifolia* grows throughout the year, stem death over winter certainly occurs (Figures 5.5 and 5.6). One implication of this slow down in growth is that herbicide application over the winter may result in a less than satisfactory result than at times of active growth. Herbicide application directly after harvest is a common management

method and it would be wise, once again, to recommend that herbicide be applied during periods when this plant is actively growing, particularly after irrigation or rainfall.

The slow rate of increase in stem density in populations of *P. longifolia* outside cropping fields and the very low rate of seed production indicates that these populations pose little threat as sources of re-infestation. Such a small threat assumes that cultivation or grading equipment does not move vegetative propagules from these existing patches. Patches in uncultivated areas may provide a problem if the areas in which they grow are brought into production. A particular problem could be experienced if laser levelling equipment, capable of moving large volumes of soil, moved soil infested with vegetative propagules of *P. longifolia*, as has previously happened at one farm (T. Haynes, pers. comm.).

5.9 Conclusions

Sexual reproduction has a relatively minor role in the population dynamics of *P. longifolia*. In contrast, vegetative recruitment is the predominant means of reproduction. Active shoot recruitment occurred throughout the cotton growing season, achieving maximum density (up to 279 stems per square metre) and dry weight at the season's end. Ideally, control should be aimed at depleting the carbohydrate reserves of the rhizome during active shoot recruitment either early in the season or later in the season when carbohydrate storage occurs (Wiese and Rea 1962; Williams 1981; Horak and Wax 1991). To actively deplete carbohydrate levels earlier in the season, both total shoot production during that season and potential carbohydrate storage later in the season should be reduced. Control treatments later in the season should enhance herbicide translocation in the translocation stream as carbohydrates are transported into the rhizomes and may also reduce shoot recruitment in the following growing season. Further work is needed to determine exactly when photosynthetic products are moved around the plant.

Both growth and sexual reproduction of *P. longifolia* are favoured by cotton farming practices. The application of irrigation water combined with shallow cultivation in cotton fields may stimulate meristematic activity in the rhizomes. These factors will be further examined in Chapter 10. Growth of *P. longifolia* will occur throughout the year but periods of active growth appear to be linked to the application of irrigation water or rainfall and herbicide applications should be done after these times. The slow rate of increase in stem density in populations of *P. longifolia* outside cropping fields and the very low rate of seeds production indicates that these populations pose a smaller threat as sources of re-infestation than populations in cultivated fields. Problems may arise if these areas are brought into production or earthmoving equipment moves vegetative propagules to uninfested areas.

These studies have revealed that *P. longifolia* is an extremely versatile plant, able to persist under conditions of high stress in uncultivated areas and to rapidly increase stem density under more luxuriant growth in cultivated fields. This flexibility will ensure the survival of *P. longifolia* infestations in native plant communities and aid in the rapid increase of populations in more favourable ecological niches such as cotton fields.

Polymeria longifolia along a roadside

Chapter 6

The reproduction and dispersal of *Polymeria longifolia*

"The regeneration of transplanted vegetative fragments, whether rhizomes, creeping roots, tubers or bulbs is an important mechanism resulting in the spread of weedy species"
(Swanton and Cavers 1988).

New clumps of Polymeria longifolia appear in infested and uninfested fields and original clumps increase in size (Chapter 3).

6.1 Introduction

An understanding of the reproductive biology and dispersal of weeds is essential in order to design effective weed management strategies. Very little is known about the reproductive and dispersal mechanisms of *Polymeria longifolia*. In the mail questionnaire reported in Chapter 3, most respondents suspected that *P. longifolia* spread by vegetative means, either naturally by roots or rhizomes (82.9%) or by shoot or root segments moved by cultivation (78%) (Table 3.11). Vegetative reproduction was thought to be responsible for

new clumps of *P. longifolia,* which appeared in both uninfested and infested fields, and increases in clump size (Table 3.9). By way of contrast, only 20% of respondents suspected that *P. longifolia* spread by seeds (Table 3.11).

These findings indicated that while vegetative reproduction appeared to be the predominant means of dispersal, all mechanisms of reproduction needed to be investigated. Two experiments assessed the effect of plant fragment size and placement on transplant success (Sections 6.3 and 6.4). A study was also conducted into the viability and dormancy of *P. longifolia* seeds planted in soil under glasshouse conditions (Section 6.5). Field patches of *P. longifolia* were examined to determine their expansion under conventional field management (Section 6.6). Finally, a preliminary study was undertaken into the movement of plant fragments by cultivation equipment (Section 6.7).

6.2 Brief review of literature: types and benefits of vegetative reproduction

There is a wide diversity in the reproductive mechanisms of plants. Sexual reproduction via seeds is common, but so too is asexual reproduction via vegetative means (Radosevich and Holt 1984). In terms of the reproductive success of a species, the existence of both sexual and asexual reproduction may be advantageous. For example, reproduction via a creeping root system and by seeds benefits problem weeds such as *Chondrilla juncea* (Cuthbertson 1972), *Haloragis apsera* (Osten *et al.* 1996) and *Reseda lutea* (Heap 1997).

Vegetative reproduction may take a variety of forms (Radosevich and Holt 1984). These may include:

- *stolons* or *runners,* which grow along the soil surface and produce adventitious roots and new shoots, e.g. *Fragaria* spp. (Hartman 1947), *Cynodon dactylon* (Horowitz 1972) and *Trifolium repens* (Turkington *et al.* 1979);

- *creeping roots* or *rhizomes,* which produce new underground shoot and root material, e.g. *Sorghum halepense* (Anderson *et al.* 1960), *C. juncea* (Cullen and Groves 1977), *H. aspera* (Osten *et al.* 1996) and *R. lutea* (Heap 1997);
- *tubers,* which are enlarged terminal sections of rhizomes containing storage tissue and buds, e.g. *C. rotundus* (Charles 1997b) and *Helianthus tuberosus* (Swanton and Cavers 1988);
- *bulbs,* which are underground buds with stem and scale leaf tissue, e.g. *Oxalis pes-caprae* (Peirce 1998);
- *corms,* which are enlarged vertical underground stems covered by leaf bases, e.g. *Solidago canadensis* (Raju *et al.* 1966; Hartnett and Bazzaz 1985) and *Arrhenatherum elatius* var. *bulbosum* (Tanphiphat and Appleby 1990).
- *stems,* which produce adventitious roots and new shoots at their tips, e.g. *Rubus* spp. (Heslop-Harrison 1959); and
- *fragmentation,* which is the spread and establishment of a species by excised leaves, stems or underground portions of the plant, e.g. *Portulaca oleracea* (Miyanishi and Cavers 1981) and *Taraxacum officinale* (Mann and Cavers 1979), again among many others.

There are many benefits that vegetative reproduction may confer on a species, for example:

- creeping roots and tubers may have large food reserves which can withstand defoliation and cultivation, e.g. *R. lutea* (Heap 1997) and *C. rotundus* (Charles 1997b);
- vegetative structures may allow the extension of the plant into areas of water and nutrient supply, e.g. *Convolvulus arvensis* (Kiltz 1930);
- plants may develop more quickly and have a higher probability of survival than seedlings because of the support of the parent plant, e.g. *C. dactylon* (Forde 1966) and *Rubus fruticosus* (Amor 1974);

- auxiliary buds and 'daughter' plants produced by a parent plant may provide a survival mechanism if the parent plant is destroyed, e.g. *C. juncea* (Cullen and Groves 1977), among others;
- 'daughter' plants can quickly capture plant resources and are not easily desiccated when exposed to adverse soil or micro-environmental conditions;
- regeneration can occur under a wide range of environmental conditions, given year-long vegetative reproduction;
- a plant may be brittle and not easily removed from the soil with often only part of it breaking away should removal be attempted, e.g. *P. oleracea* (Miyanishi and Cavers 1981);
- vegetative propagules are often easily dispersed by cultivation and harvesting machinery, farm vehicles and by other means, e.g. water, wind or animals;
- underground vegetative structures are often not killed by translocated herbicides, e.g. *H. aspera* (Osten *et al.* 1996); and
- some plants are able to produce shoots from deep within the soil, e.g. *C. arvensis* up to seven metres in depth (Degennaro and Weller 1984).

6.3 Reproductive potential of *P. longifolia* vegetative fragments and seeds

6.3.1 Aim

This experiment aimed to determine the potential for vegetative fragments and seeds of *P. longifolia* to produce new shoots and seedlings respectively.

6.3.2 Methods

The experiment was started on 13 January 1997 in a glasshouse at the University of New England, Armidale, maintained at 15 - 25°C. Black plastic pots (20 cm diameter and 18.5 cm deep) were filled to within two centimetres of the top with a mixture of sand, loam and peat (3:2:1 by volume) and were watered daily to maintain the pots close to field capacity.

Fragments used in this trial were exhumed from the centre of a small *P. longifolia* patch (ca. 10 m diameter) in Field 11 at the Midkin Farm of Auscott, Moree, two days prior to the planting of this trial. All fragment material was selected for uniformity in size (stem diameter, rhizome diameter and shoot height, where applicable). These fragments were stored in damp cloth at room temperature (20 - 25°C) until planting. Loose soil was shaken off the fragments before these were trimmed to size. Seeds were collected from plants in Field 27 at Colly Farms, Collarenebri, one week before planting.

There were ten treatments with five replicate pots for each treatment, with the exception of treatment 9, which had only three replicates (Table 6.1, Plate 6.1). Initial dry weights of fragments were calculated from fragments which were not planted by drying at 70°C for 48 hours to constant weight and weighing. Three fragments were planted in each pot at a depth of five centimetres. Five seeds were sown per pot at five centimetres depth in treatment 10. All rhizome material was buried horizontally on the surface of the soil and covered. Shoots were placed upright in the media, while the rhizomes in the rhizome/shoot combination treatments were placed horizontally at five centimetres depth in the soil and the attached shoots placed upright.

The emergence of seedlings, new shoots and the production of new leaves on old shoots were recorded daily, as was cumulative flower production. Leaf death occurred on all shoots after transplant and the emergence of new leaves indicated that these old shoots had

Table 6.1 The treatments used to examine vegetative reproduction in *P. longifolia*. The mean initial dry weight (g) is shown ± the standard error of the mean. The dry weights were determined from different numbers of fragments.

Fragment description	Number measured	Mean fragment dry weight (g)
1. 10-cm rhizome with 1 node	15	0.22 ± 0.03
2. 15-cm rhizome with 2 nodes	15	0.26 ± 0.04
3. 15-cm rhizome with 3 nodes	-	a
4. 15-cm rhizome with 4 nodes	-	a
5. 5-cm shoot-only	7	0.22 ± 0.07
6. 15-cm shoot-only	9	0.38 ± 0.13
7. 5-cm shoot and 5-cm rhizome[c]	10	0.33 ± 0.09
8. 15-cm shoot and 15-cm rhizome[d]	10	0.90 ± 0.31
9. Untrimmed shoot and 15+ cm rhizome[d]	-	b
10. Seed	-	0.03

[a] The dry weight for treatment 2 was used for treatments 3 and 4.
[b] The dry weight for treatment 8 was used for treatment 9.
[c] These fragments of rhizome originally had between 1 and 2 nodes.
[d] These fragments of rhizome originally had between 2 and 3 nodes.

survived. Plants were harvested 85 days after planting on 8 April 1997. This process involved a final count of all emerged, transplanted alive shoots, or seedlings, and the washing of media away from the plants, then counting of unemerged shoots. Shoots and rhizomes were separated for dry weight measurement by drying at 70°C for 48 hours to constant weight and weighing. The change in dry weight from planting to harvest was calculated by subtracting initial dry weight estimates from the total dry weight at harvest. The number of nodes on rhizomes was counted at harvest with the shoot number at harvest being expressed as a proportion of original and harvest node number. Nodes were identified as swollen sections on the rhizome where shoot, rhizome or root material arose. The standard error of the mean was calculated for all parameters measured and has been presented with the mean data.

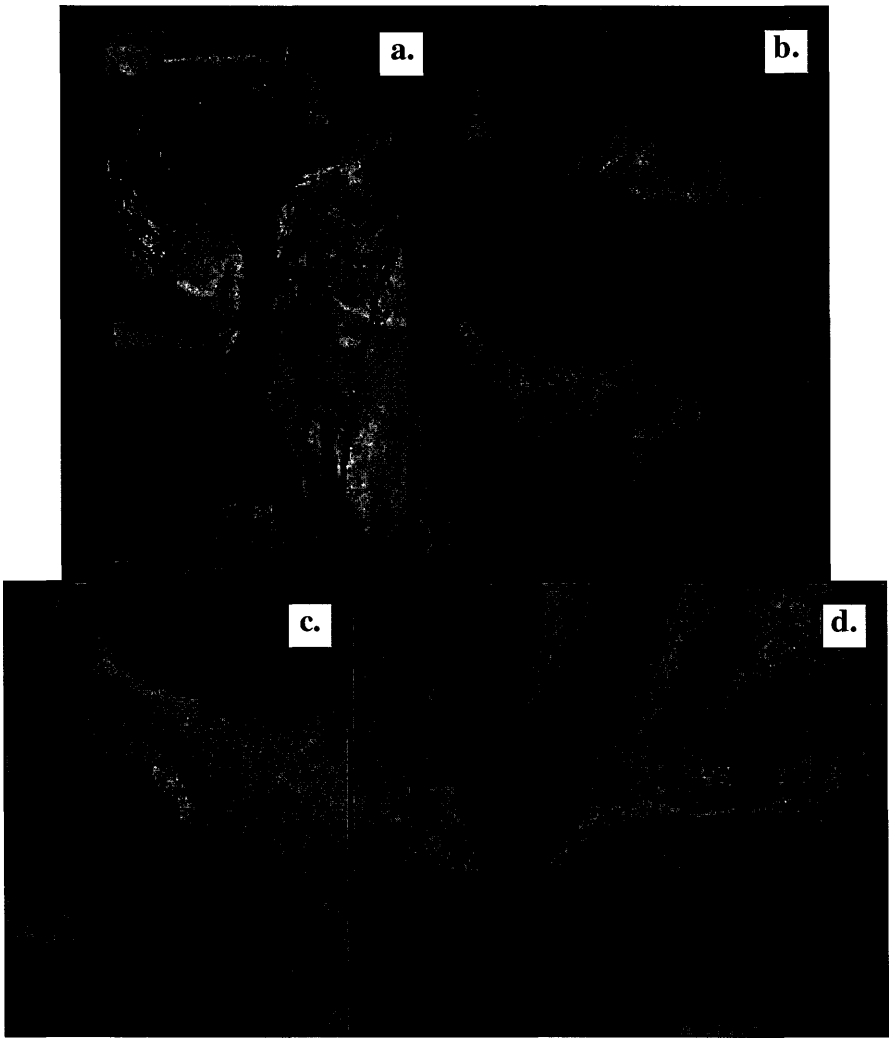


Plate 6.1 Some of the fragments of *P. longifolia* used in the transplant trial. Plate 6.1a illustrates the 15-cm shoot and rhizome treatment, 6.1b the 5-cm shoot and rhizome treatment, 6.1c the 5-cm shoot treatment and 6.1d the 4-node rhizome treatment.

Orthogonal contrasts separating total shoot number and dry weight at harvest for various vegetative treatment means were performed (treatments 1 - 8). Details of the comparisons made have been outlined with the levels of significance (Tables 6.4 and 6.7). For such comparisons to be made, the treatments needed to have the same number of replicates; since treatment 9 had only three replicates and not five, it was not considered in the comparison set. Only results that were significantly different will be discussed.

6.3.3 Results

In general, the more intact a plant fragment of *P. longifolia* was, the more shoots were produced at 20 days and at final harvest (Table 6.2). Rhizome treatments produced 0 - 4.4 shoots per pot at harvest while shoot-only treatments produced 0 - 3.4 shoots per pot. By way of contrast, the more intact shoot/rhizome fragments (treatments 7 - 9) produced more shoots at harvest i.e. 3.8 - 5.4 shoots per pot. This exceeded nearly all rhizome or shoot-only treatments. Individual pots in treatment 10 (the seeds treatment) had between one and three seedlings establish. One such seedling had begun to form rhizome material at harvest and unemerged shoots were recovered from the rhizome material. All seeds that had not germinated had rotted by the time of harvest.

While reshooting occurred in both shoot-only treatments initially, only the 15-cm shoots survived until harvest (Table 6.2). Small plant fragments i.e. 1-node rhizomes and 5-cm shoots, did not give rise to any new shoots at harvest. Shoot number was either the same, or had increased, from 20 days until harvest, with the exception of treatment 7 (5-cm shoot/rhizome) which had decreased by 1.4 shoots per pot (Table 6.2). There were very few unemerged shoots at harvest in any treatment.

The number of shoots produced increased with increasing number of nodes on rhizomes (Table 6.2, treatments 1 - 4). This increase was less distinct but still present when the average number of shoots produced per node (based on original and harvest node number) was considered (Table 6.3). The largest increase in node number per pot (87%) was observed in the 2-node rhizome treatment at harvest (Table 6.3). Rhizomes with three or four nodes on the original fragments did not increase node number to the same extent as the 2-node treatment, while rhizomes with only one node did not grow new nodes or shoots.

Table 6.2 The number of emerged and unemerged shoots, old but alive shoots or seedlings from transplanted *P. longifolia* fragments and seeds after 20 days and 85 days (harvest). The mean shoot number has been expressed ± the standard error of the mean.

Plant fragment or seed	Shoot or seedling number/pot			
	20 days	Harvest emerged	Harvest unemerged	Harvest total
1. Rhizome with 1 node	0 ± 0	0 ± 0	0 ± 0	0 ± 0
2. Rhizome with 2 nodes	0.8 ± 0.2	1.6 ± 0.4	0.2 ± 0.2	1.8 ± 0.6
3. Rhizome with 3 nodes	2.4 ± 0.9	2.4 ± 0.9	0 ± 0	2.4 ± 0.9
4. Rhizome with 4 nodes	4.2 ± 1.0	4.2 ± 1.0	0.2 ± 0.2	4.4 ± 1.0
5. 5-cm shoot-only	0.6 ± 0.2	0 ± 0	0 ± 0	0 ± 0
6. 15-cm shoot-only	3.0 ± 0.0	3.4 ± 0.5	0 ± 0	3.4 ± 0.5
7. 5-cm shoot and 5-cm rhizome	5.2 ± 0.9	3.8 ± 0.4	0 ± 0	3.8 ± 0.4
8. 15-cm shoot and 15-cm rhizome	3.6 ± 0.4	4.8 ± 0.5	0.6 ± 0.2	5.4 ± 0.7
9. Untrimmed shoot and 15+cm rhizome	4.0 ± 1.0	4.3 ± 0.9	0.7 ± 0.7	5.0 ± 0.6
10. Seed	1.2 ± 0.2	1.8 ± 0.4	0.4 ± 0.4	2.2 ± 0.7

Orthogonal contrasts of treatment means for total shoot number were evaluated (Table 6.4). There was no significant difference in the mean number of shoots produced from rhizome-only and shoot-only transplant material. There were more shoots produced by shoot/rhizome treatments than from rhizome-only or shoot-only treatments. The number of shoots produced by the 15-cm shoot-only treatment was significantly higher than the number of shoots from the 5-cm shoot-only treatment.

The cumulative number of flowers was used to give an indication of the reproductive capacity of the shoots produced (Table 6.5). As the size of *P. longifolia* fragments increased, the number of flowers increased. This trend was consistent across rhizome, shoot and shoot/rhizome treatments. The maximum flower number was produced in treatment 9 which was the most intact of all transplant treatments.

Table 6.3 The total number of nodes on original and harvested plant material and total number of shoots produced/node on rhizome-only treatments of transplanted *P. longifolia* material. Node and shoot number/node have been expressed ± the standard error of the mean.

Plant fragment	Node number/pot		Total shoot number/node	
	Original	Harvest	Original	Harvest
1. Rhizome with 1 node	3.0 ± 0.0	3.0 ± 0.0	0 ± 0	0 ± 0
2. Rhizome with 2 nodes	6.0 ± 0.0	11.2 ± 1.9	0.3 ± 0.1	0.2 ± 0.2
3. Rhizome with 3 nodes	9.0 ± 0.0	11.4 ± 1.2	0.3 ± 0.1	0.2 ± 0.1
4. Rhizome with 4 nodes	12.0 ± 0.0	13.0 ± 0.6	0.4 ± 0.1	0.3 ± 0.1

Table 6.4 Orthogonal contrasts for total shoot number/pot from vegetative transplant material of *P. longifolia.*

Treatment description of contrast	Treatments compared	Mean comparison		P[a]
Total shoot number				
Rhizome vs Shoot	(1+2+3+4) vs (5+6)	2.2	1.7	n.s.
Rhizome vs Shoot/rhizome	(1+2+3+4) vs (7+8)	2.2	4.6	P << 0.001
Shoot vs Shoot/rhizome	(5+6) vs (7+8)	1.7	4.6	P << 0.001
Shoot 5-cm vs Shoot 15-cm	5 vs 6	0	3.4	P << 0.001
Shoot/rhizome 5-cm vs Shoot/rhizome 15-cm	7 vs 8	3.8	5.4	n.s.

[a] P indicates the level of significance, while n.s. signifies no significance i.e. P > 0.05.

Table 6.5 The cumulative number of flowers produced on transplanted vegetative fragments and seedlings of *P. longifolia*. The flower number has been expressed ± the standard error of the mean.

Plant fragment or seed	Total flower number/pot
1. Rhizome with 1 node	0 ± 0
2. Rhizome with 2 nodes	0.2 ± 0.2
3. Rhizome with 3 nodes	1.2 ± 0.8
4. Rhizome with 4 nodes	2.2 ± 0.9
5. 5-cm shoot-only	0 ± 0
6. 15-cm shoot-only	0.6 ± 0.6
7. 5-cm shoot and 5-cm rhizome	2.0 ± 0.9
8. 15-cm shoot and 15-cm rhizome	2.4 ± 0.5
9. Untrimmed shoot and 15+cm rhizome	6.7 ± 1.5
10. Seed	0 ± 0

Total plant dry weight also increased with increasing size of rhizome, shoot and shoot/rhizome treatment (Table 6.6). Total plant dry weight changed little between rhizome-only treatments, with treatments 3 and 4 having similar total plant dry weights at harvest.

The change in total dry weight was calculated by subtracting the original fragment dry weight at planting from the total plant dry weight at harvest (Table 6.6). Dry weight increase was greatest in those treatments which were more intact initially, e.g. treatment 9. Treatments 1 and 5 which did not produce new shoots recorded a loss in dry weight. The total dry weight of rhizome-only treatments greatly exceeded that of shoot-only treatments (Table 6.7). In addition, the total dry weight produced by shoot/rhizome treatments was far greater than that produced by either shoot- or rhizome-only treatments (Table 6.7).

Table 6.6 Harvest dry weights of shoots, rhizomes and total plants, with the original fragment dry weight and dry weight change of vegetative fragments and seedlings of *P. longifolia*. The mean dry weights have been expressed ± the standard error of the mean.

Plant fragment or seed	Dry weight/pot (g)				
	Shoot	Rhizome	Total plant	Original fragment	Change
1. Rhizome with 1 node	0 ± 0	0.11 ± 0.01	0.11 ± 0.01	0.66	-0.55 ± 0.01
2. Rhizome with 2 nodes	0.19 ± 0.07	0.82 ± 0.21	1.01 ± 0.24	0.78	0.23 ± 0.24
3. Rhizome with 3 nodes	0.32 ± 0.15	1.38 ± 0.40	1.70 ± 0.54	0.78	0.92 ± 0.54
4. Rhizome with 4 nodes	0.46 ± 0.10	1.16 ± 0.11	1.62 ± 0.21	0.78	0.84 ± 0.21
5. 5-cm shoot-only	0.06 ± 0.01	0 ± 0	0.06 ± 0.01	0.66	-0.60 ± 0.01
6. 15-cm shoot-only	0.75 ± 0.15	0.47 ± 0.13	1.23 ± 0.28	1.14	0.09 ± 0.28
7. 5-cm shoot and 5-cm rhizome	0.51 ± 0.10	0.55 ± 0.12	1.06 ± 0.22	0.99	0.07 ± 0.22
8. 15-cm shoot and 15-cm rhizome	1.77 ± 0.13	1.48 ± 0.08	3.25 ± 0.17	2.70	0.55 ± 0.17
9. Untrimmed shoot and 15+cm rhizome	2.47 ± 0.25	2.25 ± 0.07	4.72 ± 0.29	2.70	2.02 ± 0.29
10. Seed	0.43 ± 0.12	0.34 ± 0.11	0.77 ± 0.22	0.15	0.62 ± 0.22

Table 6.7 Orthogonal contrasts for the total harvest dry weight (g/pot) of vegetative transplanted material of *P. longifolia*.

Treatment description of contrast	Treatments compared	Mean comparison		P[a]
Total dry weight				
Rhizome vs Shoot	(1+2+3+4) vs (5+6)	1.11	0.64	P < 0.05
Rhizome vs Shoot/rhizome	(1+2+3+4) vs (7+8)	1.11	2.16	P << 0.001
Shoot vs Shoot/rhizome	(5+6) vs (7+8)	0.64	2.16	P << 0.001
Shoot 5-cm vs Shoot 15-cm	5 vs 6	0.06	1.23	P < 0.01
Shoot/rhizome 5-cm vs Shoot/rhizome 15-cm	7 vs 8	1.06	3.25	P << 0.001

[a] P indicates the level of significance while << denotes 'far less than'.

6.3.4 Discussion

This study illustrates that *P. longifolia* is able to reproduce vegetatively, particularly in the glasshouse under a regime of daily watering and temperatures between 15 - 25°C. All vegetative fragments were able to give rise to new shoots with the exception of the smallest fragments which were rhizomes with one node and 5-cm shoots. This result is in general agreement with research for both *Cirsium arvense* (Hamdoun 1972) and *Solanum elaeagnifolium* (Richardson and McKenzie 1981), where all but the smallest fragments of these species were able to give rise to new shoots (Table 6.2).

These results contrast with those for other species. Stem fragments of *Portulaca oleracea* as small as 1.5 cm have been found to give rise to new shoots (Miyanishi and Cavers 1981). Root fragments, often smaller than 2.5 cm, have also been found to give rise to new shoots given suitable growing conditions, e.g. *Agropyron repens* (Vengris 1962); *Chondrilla juncea* (Cuthbertson 1972); *Taraxacum officinale*, (Mann and Cavers 1979); and *Reseda lutea* (Heap 1997). Furthermore, new shoots have been produced by root fragments containing

only one node in the case of *Cynodon dactylon* (Horowitz 1972) and *A. repens* (Leakey *et al.* 1977).

The number of new shoots produced increased significantly when the fragment was more intact. For example, shoot/rhizome treatments produced a significantly greater number of shoots at harvest than shoot or rhizome treatments alone. Increasing fragment size has been shown to have a significant effect on increasing plant regenerative potential (Kigel and Koller 1985). For example, increasing the fragment size of various species including *C. juncea* (Cuthbertson 1972), *C. arvense* (Hamdoun 1972), *Pennisetum macrourum* (Harradine 1980), *S. elaeagnifolium* (Richardson and McKenzie 1981; Boyd and Murray 1982), *Haloragis aspera* (Osten *et al.* 1996) and *R. lutea* (Heap 1997) resulted in increased shoot production (Table 6.2).

However, increasing fragment size does not always result in an increase in shoot number at harvest. For example, increasing both the length of rhizome fragments and the node number on the fragments of *Achillea millefolium* (Bourdot *et al.* 1982; Bourdot 1984) and *A. repens* (Vengris 1962; Turner 1968) resulted in a decrease in the number of new shoots per unit of rhizome length.

The apparent absence of the re-imposition of apical dominance after fragmentation and lack of regeneration of new shoots from small fragments has important implications on the regrowth of *P. longifolia* fragments under suitable field conditions. The more severely damaged a fragment of *P. longifolia* is, the less likely it is to establish and produce new shoots. Shoot material, with a rhizome attached, is more likely to be successfully transplanted than shoot or rhizome material alone.

Fragment size was an important determinant in the total dry weight of plants, the average number of shoots produced per node and the mean number of flowers produced per pot.

This research indicated that the larger initial fragments were, the larger plants were at harvest. This result has been found in other species including *A. repens* (Turner 1968), *S. elaeagnifolium* (Boyd and Murray 1982), *A. millefolium* (Bourdot 1984) and *R. lutea* (Heap 1997).

In order to prevent regrowth of *P. longifolia* fragments after they have been transplanted by cultivation the fragments need to be as small as possible, preferably rhizomes with only a single node or of no-more-than five centimetre long shoots. In addition, transplanted rhizome and shoot material should ideally be separated with shoots cut off from rhizomes to inhibit fragment survival.

This study illustrates that fresh seeds of *P. longifolia* can be quite viable. Seedling establishment from freshly harvested seeds was 34 ± 8% during the 85 day experimental period. This percentage is slightly higher than the germination percentage reported previously for untreated (20%) and nitric acid-scarified seeds (30%) (Charles 1996b) and considerably higher than recorded in Section 6.5.3 of this chapter. These differences may be explained by the fact that freshly harvested seeds were used in this experiment, while seeds had been stored for at least one month in Charles (1996b) and the experiment recorded in Section 6.5. The data set is, however, too small to make this conclusion definitive.

Although *P. longifolia* seedlings are rare, this study showed that seedlings may reach a stage of being able to vegetatively reproduce within three months of germination. Similar rapid rhizome production from seedlings has been recorded for *S. halepense* (Anderson *et al.* 1960; McWhorter 1961), *C. dactylon* (Horowitz 1972), *E. esula* and *C. arvense* (Kigel and Koller 1985).

6.4 Orientation of transplanted *P. longifolia* shoots and its effect on reproduction

6.4.1 Aim

This experiment was conducted to determine the potential of vegetative shoots to produce new shoots when placed both vertically and horizontally in the soil. This experiment separated out the influence of fragment orientation which was not investigated in Section 6.3.

6.4.2 Methods

This experiment was started on 24 February 1997 in a glasshouse at the University of New England, Armidale, maintained at 15 - 32°C. Twenty-centimetre diameter black plastic pots were filled to within two centimetres of the top with a mixture of sand, loam and peat (2:1:1 by volume) and were watered daily to maintain the pots close to field capacity.

The fragments for this trial were recovered from the same patch as previously outlined (Section 6.3.2) on 21 February 1997, which was three days prior to planting the trial. These fragments were stored in damp cloth at room temperature (20 - 25°C) until planting. There were four treatments in this trial each with five replicate pots. Initial dry weights of the treatments were estimated (Table 6.8). Three fragments were planted in each pot to a depth of five centimetres. Vertical treatments were planted upright so that the bottom five centimetres of the fragment were covered by the soil, that is the 5-cm vertical shoot was completely covered but the 15-cm shoot had ten centimetres exposed, while horizontal treatments were completely covered.

Plants were harvested 92 days after planting on 27 May 1997. Other details for this trial were similar to those outlined in Section 6.3.2.

Table 6.8 The treatments and dry weights of vegetative fragments of *P. longifolia*. These fragments were planted either vertically or horizontally to investigate the effect that orientation had on new shoot production. The mean initial dry weight has been recorded with a standard error of the mean.

Fragment description	Number measured	Mean fragment dry weight (g)
1. 5-cm shoot placed upright	12	0.10 ± 0.02
2. 15-cm shoot placed upright	12	0.41 ± 0.08
3. 5-cm shoot laid horizontally		a
4. 15-cm shoot laid horizontally		b

[a] The dry weight for treatment 3 was used for treatment 1.
[b] The dry weight for treatment 4 was used for treatment 2.

6.4.3 Results

The only transplant that produced new shoots or had old shoots that were alive at harvest were the vertical 15-cm shoot treatments with 3.6 shoots per pot (Table 6.9). The dry weights recorded at harvest for the 15-cm vertical shoot treatment were: 1.91 ± 0.19 grams (shoot dry weight), 1.03 ± 0.23 grams (root dry weight) and 2.94 ± 0.40 grams (total dry weight). The total original dry weight of these fragments was 1.23 grams and the dry weight change at harvest +1.71 ± 0.40 grams.

6.4.4 Discussion

This experiment indicated that excised shoots that have a vertical orientation and protrude from the soil may resprout or produce new shoots. On the other hand, shoots that were buried horizontally in the soil did not resprout or produce new shoots despite their length.

Table 6.9 The number of emerged and unemerged shoots, or old but alive shoots from transplanted *P. longifolia* shoot fragments planted either vertically or horizontally after 20 days and 92 days (harvest). The mean shoot number has been expressed ± the standard error of the mean.

Shoot fragment or seed	Shoot number/pot			
	20 days	Harvest emerged	Harvest unemerged	Total at harvest
1. 5-cm shoot placed horizontally	0 ± 0	0 ± 0	0 ± 0	0 ± 0
2. 5-cm shoot placed vertically	0 ± 0	0 ± 0	0 ± 0	0 ± 0
3. 15-cm shoot placed horizontally	0 ± 0	0 ± 0	0 ± 0	0 ± 0
4. 15-cm shoot placed vertically	2.2 ± 0.5	3.4 ± 1.0	0.2 ± 0.2	3.6 ± 0.9

A similar result has been found in *T. officinale*, with superior shoot regeneration from root fragments replanted in a 'normal' rather than horizontal position (Mann and Cavers 1979).

In this experiment, transplanted 5-cm shoots did not resprout or produce new shoots. This result is consistent with results from Section 6.3.3 and indicated again that transplanted shoots need to be larger to resprout.

The number of shoots produced at harvest by the 15-cm vertical shoot treatment in this experiment was similar to that produced in Section 6.3. Again, the original weight of the transplant here, 1.23 grams, was similar with that in Section 6.3.3 which was 1.14 grams, but the dry weights produced in this experiment (shoot, root, total and change) were larger. Plant growth conditions were similar, so either genetic differences in the plant material used in the two experiments may have been responsible or perhaps the fact that more carbohydrates were contained in the later harvested shoots. These explanations were not investigated in this research but have been investigated for other species elsewhere. For

example, new shoot recruitment from fragments was lowest when the plant was in a reproductive growth phase compared to a vegetative phase (Raju *et al.* 1964; Cuthbertson 1972; Swan and Chancellor 1976; Mann and Cavers 1979; Swanton and Cavers 1988). Similar research is therefore recommended for *P. longifolia*.

6.5 Dormancy and germination characteristics of *P. longifolia* seeds

6.5.1 Aim

This experiment aimed to determine the rate of reduction in the viability of *P. longifolia* seeds with time, the effect of depth of burial on seedling emergence and survival of seeds and whether post-harvest dormancy in seeds was broken over time.

6.5.2 Methods

This trial was conducted in a glasshouse at the University of New England, Armidale, with the air temperature maintained between 9 - 36°C during the experimental period. Ineffective heating and cooling in this glasshouse resulted in the wide temperature range.

The trial was planted in 20 cm diameter black plastic pots which contained 4100 ± 5 g (6.5% moisture) of air dried cracking clay soil (Ug 5.3, Northcote 1979). This soil had a $pH_{(1:5\ water)}$ of 8.6, a nitrate nitrogen level of 4 mg/kg, an organic carbon level of 0.7%, a Colwell phosphorus of 7 mg/kg and a maximum ped size of one centimetre. The soil was collected from the top ten centimetres depth of an area free of *P. longifolia* in Field 11 at Auscott, Moree on 29 May 1997. The soil had been cropped to cotton in the 1996/97 season and then ploughed (with cotton trash incorporation) in preparation for planting of barley. The soil was sieved using a one centimetre soil sieve and all cotton trash and roots

were removed by hand. After collection, the soil was stored in 40 litre sealed garbage bins.

Seeds which were ready to drop from the husks on adult *P. longifolia* plants were collected from Field 27 of Colly Farms, Collarenebri, on 23 April 1997. The outer papery husks were removed by rubbing the seeds between the fingers. Cleaned seeds were stored at room temperature (ca. 20°C) until planting.

Seeds were planted at three times: 2 June 1997 (T1, 40 days after the initial collection of seeds), 8 December 1997 (T2, 229 days after initial collection of seeds), and 4 June 1998 (T3, 407 days after initial collection of seeds). Twenty *P. longifolia* seeds per pot were planted at each of three depths at each time of planting: on the surface (slightly pressed into the soil to ensure soil/seed contact), and at 1 cm and 5 cm in depth (planted and then over-filled with soil). There were four replicates of each depth treatment, which resulted in 12 pots at each of the three planting times. In total, 240 seeds were sown at each time of planting. The different periods of laboratory storage before planting for each time treatment allowed an examination on whether post-harvest dormancy (found in trials by G. Charles) was broken with time.

All pots were watered initially and then every 28 days thereafter in an attempt to simulate either sporadic rainfall or irrigation events in the field. To ensure that the pots were watered to maximum capacity, the soil was initially wet by approximately 0.5 litres of water which allowed the soil to expand back to the edges of the pot and the soil cracks to close so that the water applied did not run straight through the pot. Watering then occurred every two to three hours by applying a similar amount of water (0.5 to 1 litre) to each pot over the period of one to two days until the small circular collector trays at the bottom of the pots were filled with water that had seeped through the soil. Watering was stopped when this occurred until the next time of watering 28 days later. In this way soil in pots remained moist for several days.

The date that seedlings emerged was recorded. The total seedling number has been presented to illustrate the low number of seedlings recruited. Mean percentage emergence and time of emergence relative to planting date was also determined. The experiment was terminated over a period of ten days from 30 March to 8 April 1999 after the following times had elapsed after initial collection of seeds: T1 after 102 weeks (712 days), T2 after 74 weeks (516 days) and T3 after 54 weeks (376 days). Harvest involved wet sieving the soil using a 2 mm soil sieve and recovering all seeds. All seeds not recovered were presumed to have decayed. Furthermore, all seeds were gently squeezed after harvest to determine those that were rotten.

The tetrazolium test was used to determine if the recovered seeds were still viable. This involved imbibing the seeds for 24 hours, dissecting the seeds longitudinally and exposing the embryos, then soaking the seeds face down in petri dishes filled with tetrazolium solution in a dark cupboard. The tetrazolium solution (500 mL of 0.1% tetrazolium solution in pH = 7 of phosphate buffer) was prepared by adding

(i) 2.269 g KH_2PO_4 to 250 mL distilled water,

(ii) 2.368 g Na_2HPO_4 (anhydrous) to 250 mL water, and

(iii) 0.25 g tetrazolium to 250 mL of a mixture of i and ii (i.e. 100 mL of i and 150 mL of ii).

The solution was then stored in a refrigerator in dark bottles and its pH adjusted to seven.

The seeds were examined after one and two hours to determine the presence of a red embryo. A red colour indicated that enzyme activity was occurring in the embryo and that the seed was still viable. Embryos with no colouration had questionable viability.

6.5.3 Results

Total seedling emergence was very limited in this trial with only 30 out of a possible 720 seeds emerging as seedlings (4.2% of all seeds, Table 6.10). This emergence came primarily

from those seeds buried at five centimetres (a total of 21 seedlings) while seven seedlings emerged from the one centimetre depth. Only two seedlings established from the zero centimetre depth, these seeds having fallen down cracks in the soil. Mean percentage emergence was very low, with a maximum of 11.3% at the five centimetre planting depth (Table 6.10).

The mean time to emergence was greater from the five centimetre than the one centimetre depth (Table 6.11). These data suggest that seedling emergence continued over a longer time at the five centimetre depth, but because of the small data set this result is tentative. The mean percentage viability of seeds appeared to decrease as the period of time in the soil increased (Table 6.12). There was little difference in the mean viability of seeds between the different depths when averaged over time. The mean percentage establishment and viability of seeds decreased when they were planted on the soil surface (zero centimetres) than at the one centimetre depth for the 102 and 74 week planting dates. There was a lack of rapid germination in either the T2 or T3 treatments after approximately six and 12 months of storage.

6.5.4 Discussion

The seeds of *P. longifolia* must be buried to ensure seedling emergence. No seedlings emerged from seeds that remained on the soil surface in this experiment. In the field, a large percentage of *P. longifolia* seeds (assuming zero insect predation) fell into the litter layer and onto the surface of the soil and from there they were eventually buried or fell down soil cracks. This experiment was designed to represent these depths by surface, one and five centimetre soil burial.

Germination and seedling emergence was superior from the five centimetre depth. This may have been a result of the watering regime which meant that seeds at this depth were in

Table 6.10 Total seedling emergence and mean percentage emergence of *P. longifolia*. Percentages are recorded ± the standard error of the mean.

Depth of planting (cm)	Total number of seedlings emerged Number of weeks of dry storage at 20°C before planting				Mean percentage emergence (%) Number of weeks of dry storage at 20°C before planting		
	102	74	54	Totals	102	74	54
0	0	1	1	**2**	0.0 ± 0.0	1.3 ± 1.3	1.3 ± 1.3
1	4	1	2	**7**	5.0 ± 2.0	1.3 ± 1.3	2.5 ± 1.4
5	9	9	3	**21**	11.3 ± 3.1	11.3 ± 3.1	3.8 ± 1.3
Totals	**13**	**11**	**6**	**30**	-	-	-

Table 6.11 The mean time of emergence of *P. longifolia* seedlings. Emergence data are recorded ± the standard error of the mean.

Depth of planting (cm)	Mean number of days to emergence Number of weeks of dry storage at 20°C before planting		
	102	74	54
0	0.0 ± 0.0	114.3 ± 114.3	65.3 ± 65.3
1	119.5 ± 62.4	108.5 ± 108.5	86.5 ± 72.0
5	242.6 ± 85.0	335.3 ± 90.8	106.5 ± 42.3

moist soil for longer as the soil dried out from above. Shallow cultivation may have an important role in burying seeds so that improved moisture conditions may be experienced by them.

Table 6.12 The mean percentage viability of *P. longifolia* seeds determined by the tetrazolium test. The viability of seeds are recorded ± the standard error of the mean. Seeds which produced seedlings were not included in these data.

Depth of planting (cm)	Mean percentage viability (%) Number of weeks of dry storage at 20°C before planting			
	102	**74**	**54**	**Mean**
0	18.8 ± 9.0	26.9 ± 8.7	43.3 ± 6.7	**29.6 ± 5.3**
1	29.1 ± 4.8	40.5 ± 2.1	29.7 ± 5.6	**33.1 ± 2.8**
5	14.3 ± 5.1	27.0 ± 2.1	37.8 ± 4.2	**26.3 ± 3.6**
Mean	**20.7 ± 3.9**	**31.5 ± 3.4**	**36.9 ± 3.4**	**29.7**

A move towards reduced tillage within *P. longifolia* patches may or may not reduce the burial of seeds. Seeds are less likely to be buried by cultivation but soils are likely to crack and move and so allow seeds to become buried at depth. Unfortunately, the depth of planting of *P. longifolia* seeds was not investigated below five centimetres and the effect that deep burial may have on seedling emergence is not known.

While percentage viability of remaining seeds declined as time of burial increased, seeds nevertheless retained 14 - 29% viability after having been buried for 102 weeks, or almost two years. In addition, post-harvest dormancy was not broken after six or 12 months storage which appears to indicate a high level of dormancy in this species.

Members of the Convolvulaceae are known to have hard seed coats and a corresponding high level of seed dormancy (Ballard 1973; Elmore *et al.* 1990). For example, viable *P. longifolia* seeds that were stored for at least one month had only 20% germination for untreated seeds or 30% for those treated with nitric acid scarification (Charles 1996b). On the other hand, seeds of *Ipomoea turbinata* had 98% viability while *I. lacunosa* seeds had

100% viability after five and a half years (Egley and Chandler 1983). Furthermore, seeds of *Convolvulus arvensis* can maintain viability from between 30 (Timmons 1949) and 50 years (Brown and Porter, 1942 in Degennaro and Weller, 1984). It would be reasonable to assume a high level of seed dormancy for *P. longifolia.*

This study showed that seedling emergence was low, indicating either that the conditions for germination and establishment were not met, that many seeds died in the soil or that seed dormancy was high. The air and surface soil temperatures in the glasshouse were probably less extreme than those commonly observed in the field and while watering is likely to have been more regular in the glasshouse it was limited in that long periods of soil drying or severe water inundation were not represented. The definitive reasons as to why low seedling emergence occurred will require future research.

6.6 The expansion of *P. longifolia* patches

6.6.1 Aim

This field trial was conducted to determine the extent of vegetative spread of *P. longifolia* from existing patches in cotton fields.

6.6.2 Methods

Patch size changes of *P. longifolia* were measured approximately monthly over the two seasons, 1996/97 and 1997/98. In each season, two locations were examined i.e. Colly Farms, Collarenebri and Auscott, Moree. One field was chosen at each location and patch size change was measured at two sites in each field. Each site was one *P. longifolia* patch with the words site and patch used interchangeably. The fields were Field 27 in 1996/97

and Field 12 in 1997/98 at Colly Farms and Field 11 in 1996/97 and Field Wilson's 4 (W4) in 1997/98 at Auscott. The sites were chosen after consultation with farm staff and represented a range of initial patch sizes, based on observations made in previous years.

The management of these fields has been described in Appendix 4. The patches of *P. longifolia* were inter-row cultivated twice during the cotton crop at Colly Farms in both seasons and at Auscott in the 1997/98 season only (Field W4). No patches at Auscott were cultivated in the 1996/97 season (Field 11).

Pegs were permanently placed in the cotton plant line on nine hills in the centre of each patch. From these points, a measuring wheel was used to record the extent of the patch in both directions on each hill. The total diameter of the patch was summed from these two directions for each row length. The patch was said to have ended at the base of a *P. longifolia* stem where no further *P. longifolia* stem was present for one metre along the row length. Only the half metre immediately either side of the plant line was assessed for the presence of *P. longifolia* plants. The length of the cotton row infested was measured to within ten centimetres accuracy as this was the accuracy of the tape measure originally used.

The only exceptions to the above protocols were at site 1 at Colly Farms in the 1997/98 season where only five replicates were measured throughout the season and a missed sampling date for site 2 at Colly Farms in 1997/98 at day 17.

6.6.3 Results and discussion

After a rapid increase in patch size in the 75 days following cotton planting, patch size tended to plateau (Figure 6.1). The assumption was made that until this time, plants at the

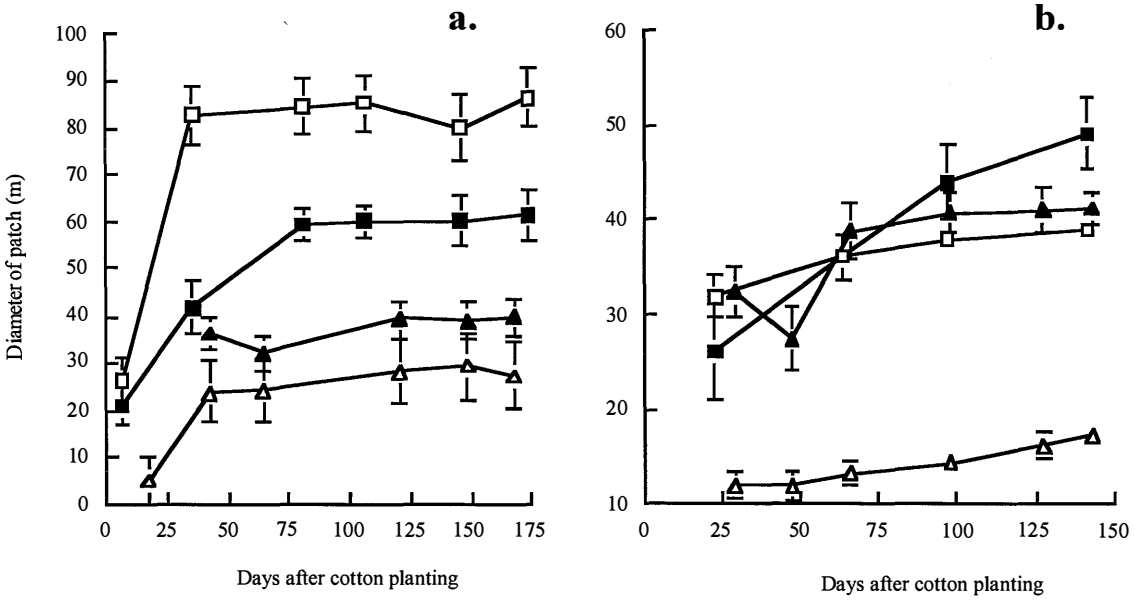


Figure 6.1 Row length diameter of *P. longifolia* patches during the 1996/97 and 1997/98 seasons at Colly Farms (6.1a) and Auscott Moree (6.1b). The diameter was measured on two patch sites in the one field in each season. These data are indicated on both sets of graphs as site 1 1996/97 season (□); site 2 1996/97 season (■); site 1 1997/98 season (Δ) and site 2 1997/98 season (▲). Standard errors of the means are shown at each measurement date.

edges of the patch (and indeed inside the patch) were still emerging and that, after this time, patch size changes were more likely to be the result of vegetative spread rather than continuing stem emergence. Stem emergence may still have been occurring after this time as shown by data in Section 5.4.3. The most rapid period of patch size increase immediately followed cotton planting (0 - 40 days after cotton planting). Cotton planting occurred at or after the soil temperature had reached a minimum of 14°C at ten centimetres depth on three consecutive days just after sunrise (Constable and Shaw 1988).

After patch size change initially started to plateau, patch size increased by an average of two to seven metres at Colly Farms (Figure 6.1a) and three to eleven metres at Auscott (Figure 6.1b), until the end of the season). It was assumed that these data may have represented vegetative spread in the patch. There appeared to be no difference in patch size

change when cultivation was not a factor at Auscott in 1996/97 and when it was in the 1997/98 season (Figure 6.1b).

Final patch size varied anywhere from 29 - 86 metres at Colly Farms and 17 - 49 metres at Auscott, at the time of cotton defoliation in March. The sudden decrease in patch size at site 2 at Auscott in the 1997/98 season, 47 days after planting (Figure 6.1b), was due to cultivation damage to *P. longifolia* plants. The maximum expansion of patches of *P. longifolia* in this study was 11 metres in diameter during a season under fully cultivated conditions. The only exception to this may have been at site 2 at Auscott in the 1996/97 season where the continuing increase in the patch size was a result of distinct small patches growing and coalescing into the main patch (Figure 6.1b).

It has long been recognised that *P. longifolia* tends to grow in patches which only gradually expand in size (McMillan 1988a, R. Johnson, pers. comm.). There are no published reports on the size of *P. longifolia* infestations or the rate of spread of this species. Estimates of the length of underground rhizomes of at least one metre or more have been made previously (Cunningham *et al.* 1981) and data from Section 4.2.3 support this assertion. Other observations have put estimates of patch spread at about two metres diameter per year (G. Charles, pers. comm.). These estimates are at the lower end of the measurements made in this experiment.

The rate of spread of *P. longifolia* is a composite of cultivation movement and natural rhizomatous expansion. Rhizomes of *P. longifolia* are able to produce new shoots and roots at intervals along the length thus aiding in spread (Cunningham *et al.* 1981; Auld and Medd 1987; McMillan 1988a; Charles 1991; Wilson *et al.* 1995; R. Johnson, pers. comm.). Natural spread of *P. longifolia* patches in the absence of cultivation may be only one to two metres per year but, because there was no opportunity to compare the non-cultivated patches at Auscott in the 1996/97 season with adjacent cultivated patches, this can only

remain an estimate. Spread of *P. longifolia* patches by up to 11 metres per year could be expected under cultivated conditions. This indicates that patches of *P. longifolia* are likely to have a limited potential for vegetative spread and without transplanting to clean areas of infested or uninfested fields will not pose a major problem from year to year.

There are a number of estimates of new plant recruitment from the horizontal spread of roots or rhizomes of other species. For example, roots of *Cirsium arvense* can extend up to 12 metres laterally (Rogers 1929, in Hamdoun 1972) and cover 25 square metres in a year (Manning 1965) while the spread of *Convolvulus arvensis* can approach 6.5 metres in nearly four years (Davison 1970). In addition, colony expansion rates of *S. elaeagnifolium* can approach between 2 - 3.9 metres per year (McKenzie 1980) while for *E. esula* the rate can be three metres per year (Morrow 1979). The expansion rate of *P. longifolia* outlined above lies within the rates reported for these other species.

Larger patches than the 86 metre patch seen in Figure 6.1a have been observed at Colly Farms, although the diameter of these patches perpendicular to the cotton rows was not as great. Several agronomists contacted during the survey process stated that *P. longifolia* appeared to be stretched out along rows and that this result was possibly due to cultivation. A number of patches observed by the author had oval or elliptic rather than circular shapes, suggesting that cultivation moved *P. longifolia* in the row direction. This result has been found in other weed species patches with the patch length parallel to the direction of cultivation being longer (Johnson *et al.* 1996; Mortensen and Dieleman 1998).

Since in-crop cultivation does not occur perpendicular to the row direction, patch size change was not measured in this direction. Research is needed to see if cultivation perpendicular to the normal row direction in fields in rotation is of any use in reducing the size of *P. longifolia* infestations or whether further spread would occur i.e. whether more damage would occur to the rhizomes that may grow parallel to the row direction. Murray *et*

al. (1992) indicated that an increase in the incidence of *Cyperus rotundus* was due to a reduction of cross-ploughing.

Anecdotal evidence indicates that even under continuous cultivation, clumps of *P. longifolia* failed to spread rapidly across an infested field (V. Osten, pers. comm.). The same can be said for *S. elaeagnifolium* (Moore *et al.* 1975), *H. aspera* (Osten *et al.* 1996) and *R. lutea* (Heap 1997) in cultivated fields, where the increase in size of existing patches was rather slow. New patches of *S. elaeagnifolium* did establish in otherwise uninfested areas, however (Moore *et al.* 1975). Further experimentation is needed to confirm whether or not there is mass translocation of *P. longifolia* with cultivation under a range of environmental and soil conditions. Pratley and Lemerle (1998) considered research into the dispersal mechanisms, the role of agronomy and machinery and temporal dynamics of patches, which is fundamental knowledge for the control of a patch-forming weedy species such as *P. longifolia.*

6.7 The movement of *P. longifolia* by cultivation equipment

6.7.1 Aim

The aim of this preliminary experiment was to determine the chance of survival of transplanted fragments of *P. longifolia* disturbed by one type of inter-row cultivation equipment in a commercial field.

6.7.2 Methods

This investigation was conducted in Field 11 at the Midkin Farm of Auscott, Moree in November 1998. The movement of *P. longifolia* within this field was examined by

recovering displaced plants after a 12-row cultivator had passed through a *P. longifolia* patch. The patch was approximately 25 metres in diameter with the soil surrounding the patch completely free of *P. longifolia.* The cultivation equipment had broad points, approximately 30 cm across and one per furrow, which were responsible for the cultivation of furrows, and curved vertical knives for hill sides. The shallow cultivation at a relatively constant speed of around 25 kilometres per hour disturbed only the top ten centimetres of the soil. This was the first inter-row cultivation of this field after planting and the surface soil was very dry. The type of cultivation equipment used is that used throughout the cotton industry for inter-row cultivation.

The initial stem density of *P. longifolia* was determined in a similar way to that outlined in Section 5.4.2. The density of six replicate 0.5 metre x 0.5 metre quadrats each located on the cotton hills and in adjacent furrows was assessed. The furrow area was later cultivated. The initial mean hill density was 36.7 stems per square metre, the mean furrow density 19.3 stems per square metre, with the overall mean density 28 stems per square metre.

To measure fragment size, all displaced plant fragments were collected along three replicate furrows within the 25 metre patch diameter and up to one metre outside the patch circumference as some displacement had occurred. In total, 194 plant fragments were collected and bulked. Rhizome length was measured from the severed end to where the stem chlorophyll turned purple or white which was ground level (Section 2.4.6). All rhizomes recovered were vertical and nearly always severed from any horizontal rhizome. Stem height was also measured from where the stem chlorophyll changed colour to the tip of the tallest leaf. Fragments were separated into different size classes for counting.

6.7.3 Results and discussion

Approximately 70% of the plant fragments recovered appeared to have been physically displaced from their point of origin by the cultivation equipment. However, displaced plant fragments were moved no more than one metre beyond the perimeter of the patch with this equipment. This indicated, at least in this case, that movement of plant fragments outside the patch was limited to a short distance. This may not always be the case as many survey respondents noted that the movement of plant fragments by cultivation equipment was probably responsible for new clumps of *P. longifolia* appearing in uninfested and infested fields, and original clumps that were increasing in size (Table 3.9).

At the time of recovery, all rhizomatous material and up to 75% of the shoot height of all fragments were buried in the soil, thereby aiding fragment survival and regeneration. Fragments which were totally buried would not have been recovered and that the data outlined here probably underestimated the total number of fragments produced. Further investigation is required to determine the effect that burial has on fragment survival. Such research is particularly important as crops are often irrigated immediately after inter-row cultivation of a field.

Rhizomes were most commonly (38%) 7.5 - 12.4 cm long (Table 6.13). Over 80% of all fragments recovered had a rhizome length less than 12.4 cm and nearly 20% of all fragments had no rhizome attached at all. Fragments of all sizes recovered have been shown to be able to regenerate into new plants given suitable conditions (Section 6.3.3 and Table 6.14). Both Hamdoun (1972) and Heap (1997) stated that cultivation of *C. arvense* and *R. lutea,* respectively, produced a large number of vegetative fragments able to regenerate given suitable conditions.

Table 6.13 Rhizome size class, mean rhizome and stem length, number of fragments recovered and estimated survival of plant fragments of *P. longifolia*.

Rhizome size class (cm length)	Mean length (cm)		Total recovered		Survival factor[a]	Estimated stem number
	Rhizome	Stem	Number	%		
0	0	18.1	38	19.6	1.1	41.8
0.6-2.4	1.8	20.6	9	4.6	1.2	10.8
2.5-7.4	5.6	18.5	42	21.6	1.3	54.6
7.5-12.4	10.1	17.5	73	37.6	1.5	109.5
12.5-17.4	14.2	17.6	29	15.0	1.8	52.2
17.4-18.5	18.1	18.6	3	1.6	1.7	5.1
Total	-	-	**194**	**100**	-	**274**

[a] The survival factor has been detailed in Table 6.14.

Table 6.14 Survival factor of the fragments of *P. longifolia* outlined in Table 6.13.

Rhizome size class (cm length)	Vegetative treatment (Table 6.1)	Total shoot number (Table 6.2)	Survival factor[a]
0	15-cm shoot-only	3.4	1.1
0.6-2.4	Mean of 15-cm shoot and 5-cm shoot/rhizome	3.6	1.2
2.5-7.4	5-cm shoot and 5-cm rhizome	3.8	1.3
7.5-12.4	Mean of 5-cm and 15-cm shoot/rhizomes	4.6	1.5
12.5-17.4	15-cm shoot and 15-cm rhizome	5.4	1.8
17.4-18.5	Untrimmed shoot and 15+ cm rhizome	5.0	1.7

[a] The survival factor is an estimate of the number of stems that would have emerged from a successful transplant of the fragment after 85 days. This factor was determined from the final shoot number from Table 6.2 divided by three, the number of vegetative fragments planted/pot.

There was very little variability in mean stem length in the six size classes mentioned (Table 6.13). Only three fragments had horizontal rhizomes attached to the vertical rhizome recovered (Section 4.2). This cultivation event did not expose a large number of the horizontal rhizomes of *P. longifolia* which, in the case of those recovered here, were an average of 19.5 cm underneath the soil surface or deeper. These horizontal rhizome segments were very short, having a mean length of 3.4 cm.

The survival factor is a projected shoot number assuming successful transplant conditions (Tables 6.13 and 6.14). In general, the larger the fragment transplanted the higher the survival factor. The survival factor is the number of stems that can be expected from the successful transplant of a plant fragment after 85 days in the glasshouse. If the estimated number of stems is summed, a further 80 *P. longifolia* shoots could be expected upon successful transplant of the 194 originally recovered, which is an increase of 41%.

The estimated final numbers of new stems or even fragments surviving out of fragment movement are likely to be higher than field conditions permit given the survival factor was derived from glasshouse data where soil temperature and moisture conditions were closer to the optimum. There is a considerable amount of experimental evidence to show that the recruitment of new shoots from fragments under optimal conditions does not accurately reflect survival and recruitment in the field (Hamdoun 1972; Bourdot 1984; Heap 1997) where fragments are more likely to become desiccated.

This preliminary study has indicated that fragments were not moved more than one metre beyond the perimeter of the patch by this type of inter-row cultivation equipment. The plant fragments were of a size, however, that would be able to establish if conditions were suitable. Personal observations indicate that the movement of plant fragments by this type of machinery does occur and that operators of cultivation machinery often stop after moving through a patch or at the end of the row to clean plant fragments from the points

and knives. The movement of *P. longifolia* fragments appears to occur more when cultivation equipment is moved through a dense patch, for example up to 200 plants per square metre (Section 5.4.3) compared with the light density of 28 stems per square metre in the patch examined in this experiment. Because of the preliminary nature of this experiment, the effect that density had on the movement of plant fragments was not examined. Other factors such as the speed of cultivation, the size of the patch, the moisture level of the soil and machinery type are also likely to affect the movement, survival and regeneration of *P. longifolia* fragments, and so require further investigation.

6.8 Conclusions

Polymeria longifolia is able to reproduce both by vegetative and sexual means (Figure 6.2). Stages involved in the sexual reproduction *P. longifolia* are shown on the left of Figure 2.2 and the stages involved in vegetative or asexual reproduction are at the bottom and to the right of Figure 2.2.

The larger and more intact vegetative fragments are those that are more likely to survive and from which subsequent shoot production will occur. These results indicated that intensive cultivation where *P. longifolia* plants are chopped into small fragments may reduce the survival of *P. longifolia* fragments moved during cultivation and reduce recruitment from existing populations. Intensive and repeated cultivation has been suggested for the control of similar weeds (Cullen and Groves 1977; Swanton and Cavers 1988; Osten *et al.* 1996), however, while discing or rotary hoeing *P. longifolia* infestations may reduce fragment transplant success, destruction of soil texture and increased expenditure are associated drawbacks.

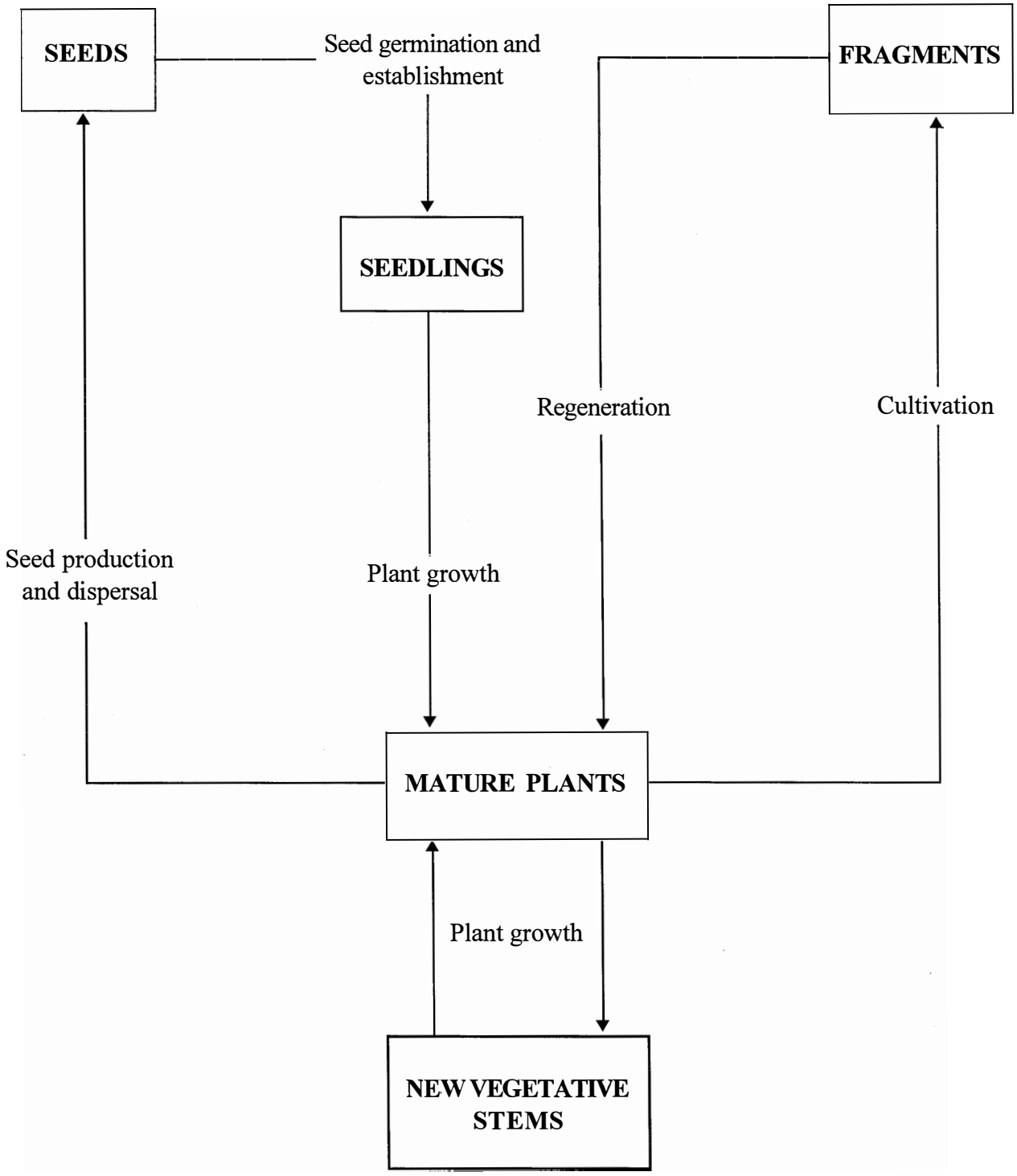


Figure 6.2 A schematic representation of the life cycle of *P. longifolia*.

While seeds appears to have a relatively minor role in the population dynamics of *P. longifolia* they cannot be dismissed completely as a concern because a freshly-harvested seed is able to germinate upon burial and maintain viability under conditions similar to those found in the field for at least two years. Many Convolvulaceae members have seeds with a strong dormancy mechanism (Ballard 1973; Elmore *et al.* 1990) and this indicates that successful recruitment of individuals may occur many years after eradication has occurred.

Patches of *P. longifolia* have a limited potential for vegetative spread and without transplanting will not pose a major problem from year to year. While the weed is persistent, it is not highly invasive. Nevertheless, transplanting does occur within fields to a limited extent. Research is needed to see if cultivation perpendicular to the normal row direction will reduce the size of *P. longifolia* infestations.

Competition between *Polymeria longifolia* and cotton

Chapter 7

The competitive impact of *Polymeria longifolia* on cotton

".....it is often impossible to clean the fields, and in midsummer you will see the cotton plants practically concealed under the grass and weeds waving above them"

(Hubbard 1923, in Murray et al. 1992).

7.1 Introduction

The competitive impact of *Polymeria longifolia* on cotton has not been examined in detail before. In the survey reported in Chapter 3 nearly 65% of cotton consultants stated that *P. longifolia* was a problem because of reductions in cotton yield. However, the level of yield loss was quite variable (Table 3.10). The aim of this experiment was to determine the competitive impact of *P. longifolia* on cotton, particularly as it is related to stem density.

It was not possible to artificially vary the density of *P. longifolia* because no consistent and effective control measure is currently available for this species. For this reason, naturally occurring areas which had different weed densities were sampled in a similar fashion to the research on *C. esculentus* (Patterson *et al.* 1980). This allowed the assessment of season-long competition by *P. longifolia* to be assessed.

7.2 Methods

This experiment was conducted at Auscott, Moree and Colly Farms, Collarenebri over the 1996/97 and 1997/98 cotton growing seasons (Table 7.1). A summary of these farms and the management of these fields is given in Appendix 4.

The experiment was conducted on one field at each location in each season (Table 7.1). Within this field at least two patches of *P. longifolia* were chosen. A varying number of permanent one metre x one metre quadrats were located on the centre of planted hills at various places inside and outside the *P. longifolia* patches. This variability in *P. longifolia* stem density appeared to be a function of distance from the dense patch centre. The square metre quadrats were at least two metres away from any other quadrat. Quadrats free of *P. longifolia,* and at least ten metres outside the patch, served as control quadrats.

The initial densities of *P. longifolia* and cotton were assessed before inter-row cultivation commenced at Auscott in the 1996/97 season and at Colly Farms during the 1997/98 season and six days after in the other cases (Table 7.1, Appendix 4). Because of the damage to *P. longifolia* shoots caused by inter-row cultivation, the initial densities measured after inter-row cultivation were probably lower than if cultivation had not occurred.

Plants were harvested soon after defoliation of the cotton crop (Table 7.1), the density of *P. longifolia* and cotton counted, and dry weight assessed after drying at 70°C for 48 hours to constant weight. In addition, the stem diameter of cotton plants at ground level and mean height of the cotton stem (to the base of the petiole of the youngest opened leaf of each cotton plant) were both measured. After dry weight measurement all bolls were removed and counted. The cotton lint and seeds were then removed by hand and ginned using a 20 saw gin at the Australian Cotton Research Institute, Narrabri, after which each component

Table 7.1 Summary of the experiments used to determine the competitive impact of *P. longifolia* on cotton during 1996/97 and 1997/98.

Cotton growing season	**1996/97**		**1997/98**	
Location	Moree	Collarenebri	Moree	Collarenebri
Field	11	27	Wilson's 4	12
Number of patches	2	2	4	3
Quadrats with *P. longifolia*	16	15	30	29
Quadrats with cotton only	6	6	6	7
Total quadrats	22	21	36	36
Cotton variety	Sicala V-2	Sicot 189	Sicala V-2i	Sicot 189
Dates of measurements				
Initial density	30/10/96	31/10/96	1-2/12/97	26-27/11/97
Final harvest	5-6/3/97	19-20/3/97	24-26/3/98	19-24/3/98

was weighed. A sub-sample of 100 ginned seeds was weighed for all samples collected in the 1997/98 season.

The data from this experiment were analysed using S-Plus 4.5 (S-Plus 1997) for treatment x time interactions. The effects of time were modelled as splines with the curves fitted to the data using the program ASREML. The 95% confidence intervals have been illustrated on all figures. When S-Plus is combined with the graphing capabilities of ASREML (from NSW Agriculture), these tools are highly effective in the analysis and presentation of data from competitive impact studies (Charles 1998b). Unfortunately, it was not possible to remove the waves in the fitted curves and the irregularly shaped data points on some of the figures upon importing them into the word processing program used to prepare this text. Unless otherwise stated all data were estimated from the fitted curves.

7.3 Results

There was little change in cotton density between the beginning and end of each season (Table 7.2). The density of *P. longifolia* stems, however, increased considerably in each season and, in general, was greater at Colly Farms than at Auscott.

There was a slight, almost linear reduction in the final density of cotton as the density of *P. longifolia* increased (Figure 7.1). Season and location did not appear to influence this trend. By way of contrast, there was a large, almost linear reduction in the final cotton dry weight (total vegetative and reproductive yield) as the density of *P. longifolia* increased (Figure 7.2). A similar trend was obtained for each cotton yield parameter measured (Section 7.2). For this reason only stem height and lint and seeds dry weights are presented (Figures 7.3 and 7.4). There was a 50% reduction in the final cotton dry weight when the final density of *P. longifolia* was 110 stems per square metre (1996/97) and 145 stems per square metre (1997/98) at Auscott and 245 stems per square metre (1996/97) and 260 stems per square metre (1997/98) at Colly Farms (Figure 7.2).

The reduction in mean cotton stem height was not linear with increasing *P. longifolia* density (Figure 7.3, Plate 7.1). The combined lint and seeds yield of cotton outside the patch areas was 400 and 485 grams per square metre at Auscott and 430 and 612 grams per square metre at Colly Farms in the 1996/97 and 1997/98 seasons, respectively (Figure 7.4). These figures equated to 4,000, 4,850, 4,300 and 6,120 kilograms per hectare. Cotton lint and seeds yields would be reduced to zero when the density of *P. longifolia* stems reached the 'theoretical' thresholds of 217 and 257 stems per square metre (Auscott 1996/97 and 1997/98) and 457 and 428 stems per square metre (Colly Farms 1996/97 and 1997/98). These thresholds were determined by extrapolating the spline until it intersected the x axis. The addition of each new *P. longifolia* stem per square metre reduced cotton lint and seeds yield in *P. longifolia* patches by 1.84 and 1.89 grams per square metre (18.4 and 18.9

Table 7.2 Cotton and *P. longifolia* densities (average and range) used to determine the competitive impact of *P. longifolia* on cotton during 1996/97 and 1997/98.

Cotton growing season	1996/97		1997/98	
Location	Moree	Collarenebri	Moree	Collarenebri
Initial density				
Average cotton density (plants/m^2)	13.7	11.3	10.7	8.1
Cotton density range (plants/m^2)	9-17	5-17	3-15	3-16
Average *P. longifolia* density (shoots/m^2)	23.8	44.1	17.6	31.4
P. longifolia density range (shoots/m^2)	0-100	0-199	0-69	0-188
Final density				
Average cotton density (plants/m^2)	12.5	10.1	11.1	7.8
Cotton density range (plants/m^2)	4-16	1-17	3-16	3-16
Average *P. longifolia* density (shoots/m^2)	88.5	169	75.4	87.5
P. longifolia density range (shoots/m^2)	0-244	0-495	0-268	0-419

kilograms per hectare) at Auscott in 1996/1997 and 1997/98, and by 0.94 and 1.43 grams per square metre (9.4 and 14.3 kilograms per hectare) at Colly Farms in 1996/97 and 1997/98. Moderate densities of *P. longifolia* were required for a lint and seeds yield reduction of 25% i.e. between 70 and 115 stems per square metre (Figure 7.4). Densities from 110 - 220 stems per square metre caused a 50% reduction.

There was a slight reduction in the weight of 100 cotton seeds as the final density of *P. longifolia* increased (Figure 7.5). The final dry weight of *P. longifolia* stems was closely correlated with the final density of *P. longifolia* at harvest (Figure 7.6). A typical patch density of 100 *P. longifolia* stems per square metre resulted in a final weed dry weight of 75 and 130 grams per square metre at Colly Farms and 205 and 190 grams per square metre in the 1996/97 and 1997/98 seasons, respectively.

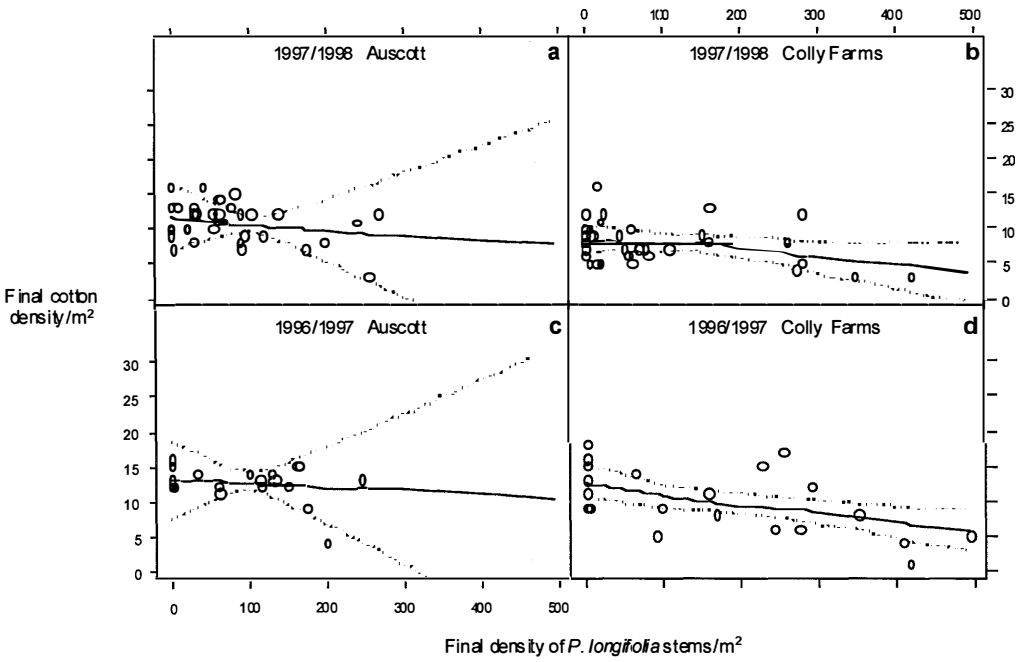


Figure 7.1 Cotton density as a function of *P. longifolia* stem density at harvest. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

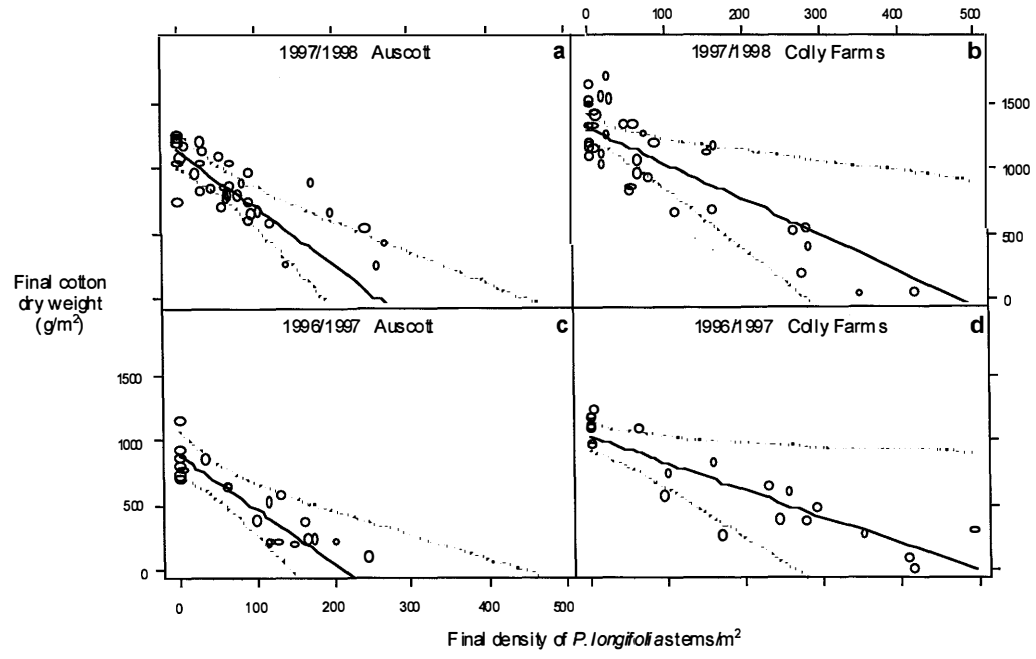


Figure 7.2 Cotton dry weight as a function of *P. longifolia* stem density at harvest. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

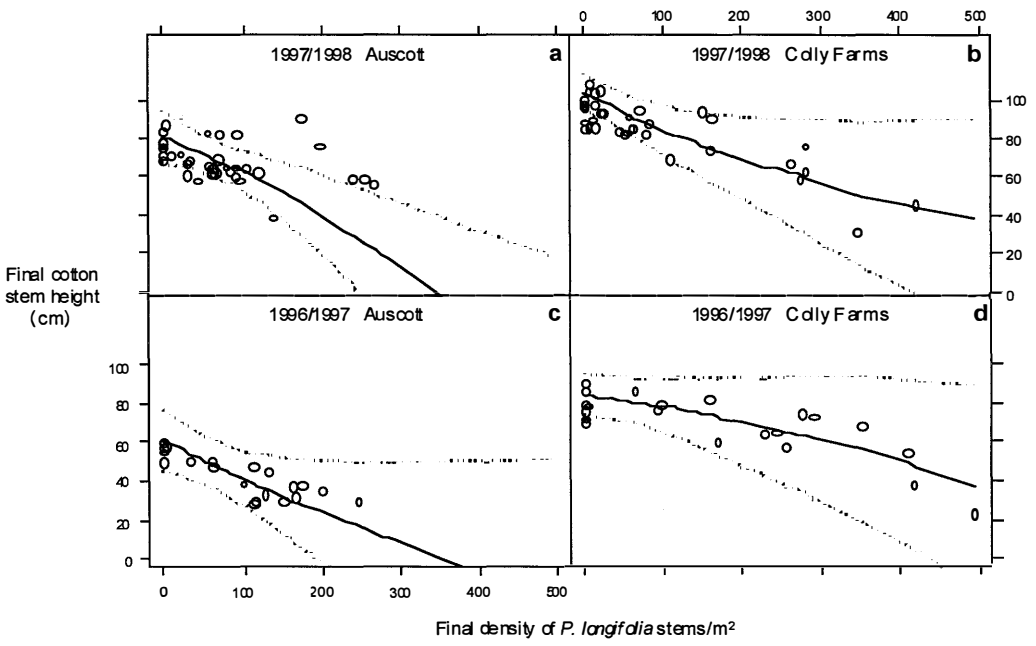


Figure 7.3 Cotton stem height as a function of *P. longifolia* stem density at harvest. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

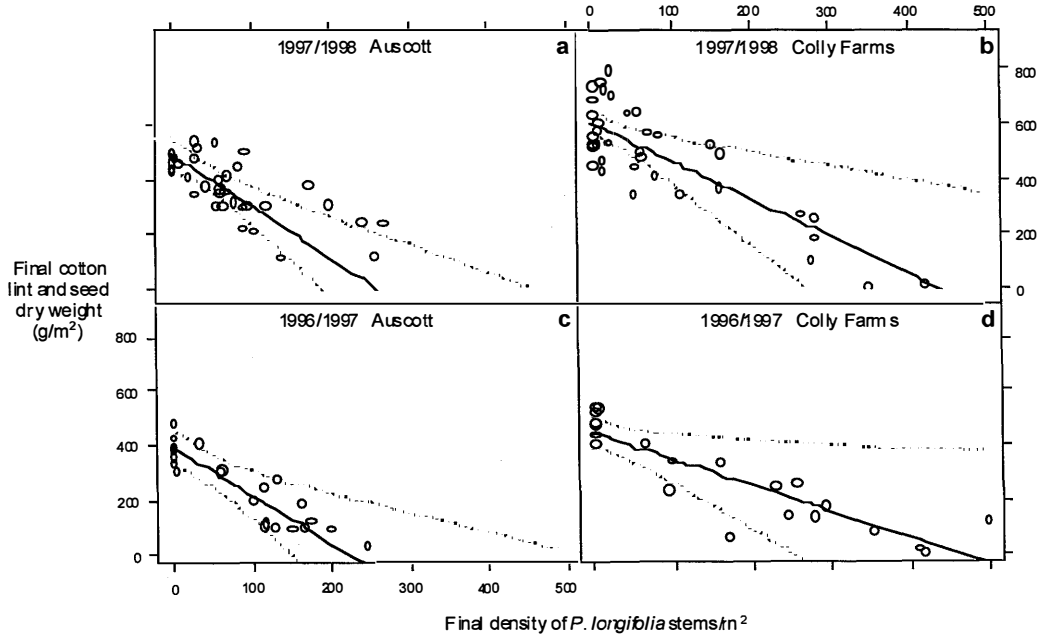


Figure 7.4 Final lint and seeds dry weight of cotton as a function of *P. longifolia* stem density at harvest. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

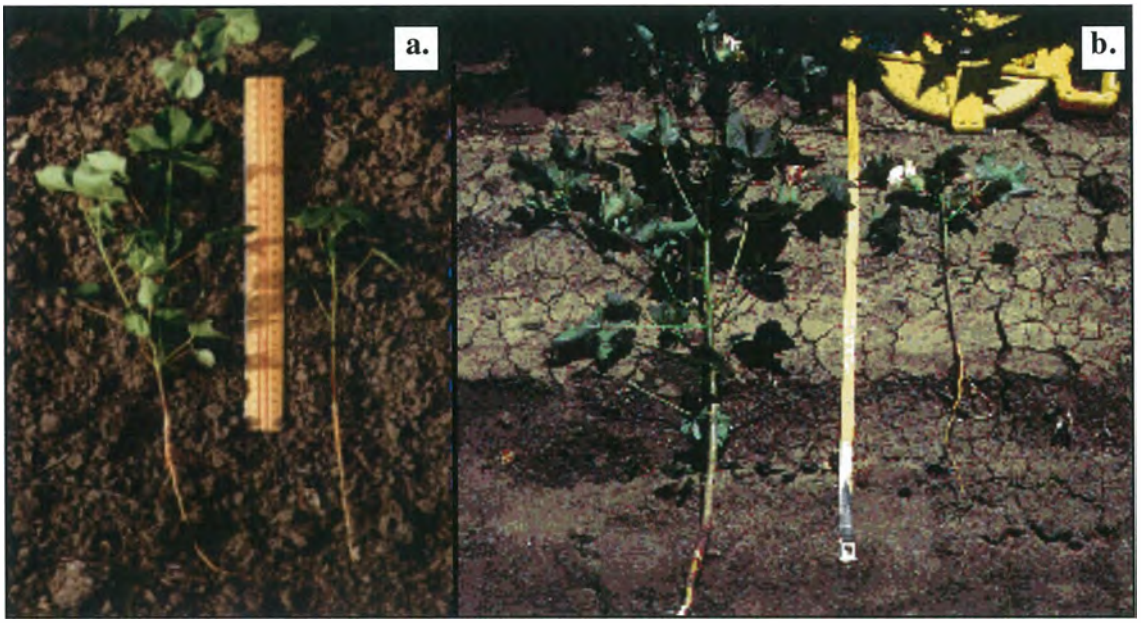


Plate 7.1 Early (7.1a) and mid season (7.1b) competition between *P. longifolia* and cotton, in November and January respectively. The plants on the left of each plate were removed from outside the patch areas and were 30 and 80 cm tall (from ground level) while those on the right of each plate were from the centre of patches and were 20 cm and 35 cm tall.

The relationship between final and initial density of *P. longifolia* was nearly linear (Figure 7.7). Based on the initial mean stem densities of *P. longifolia* (Table 7.3), the final density increased by 520% and 215% (Colly Farms 1996/97 and 1997/98) and 465% and 590% (Auscott 1996/97 and 1997/98). The relationship between combined cotton lint and seeds dry weight and the initial density of *P. longifolia* showed that a 50% reduction in yield could be expected when the initial density of *P. longifolia* was between 45 stems per square metre and 95 stems per square metre depending on location and season (Figure 7.8). These initial densities were evaluated 17 and 28 days after planting in the 1996/97 season at Colly Farms and Auscott respectively and after 65 days in the 1997/98 season at both locations.

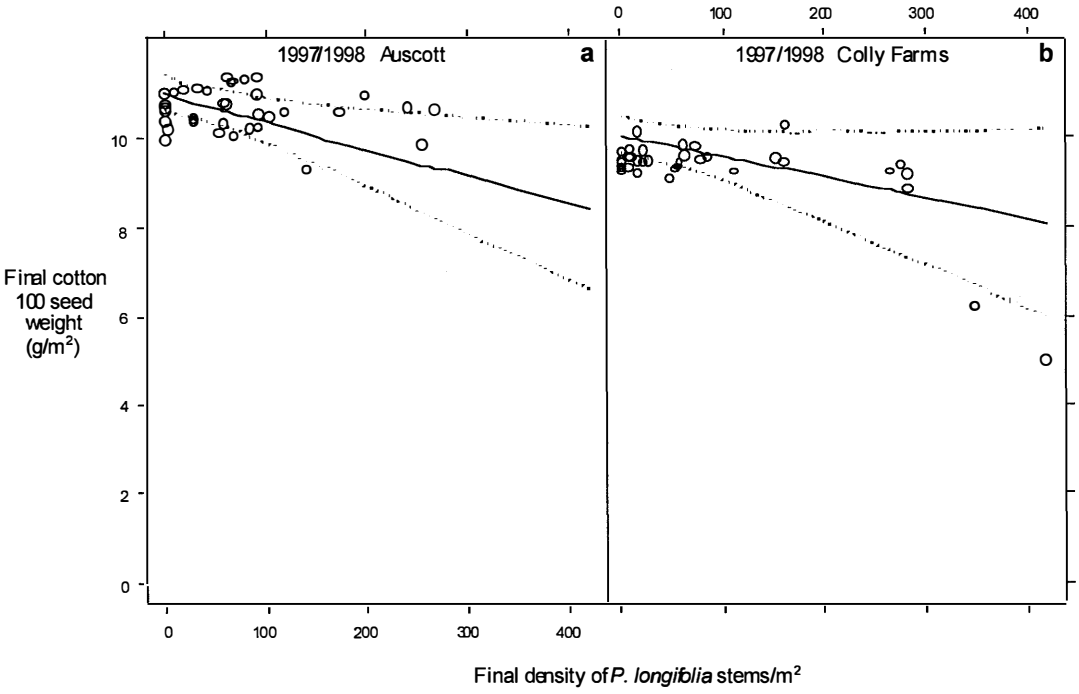


Figure 7.5 Weight of 100 cotton seeds as a function of *P. longifolia* stem density at harvest (1997/98 only). The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

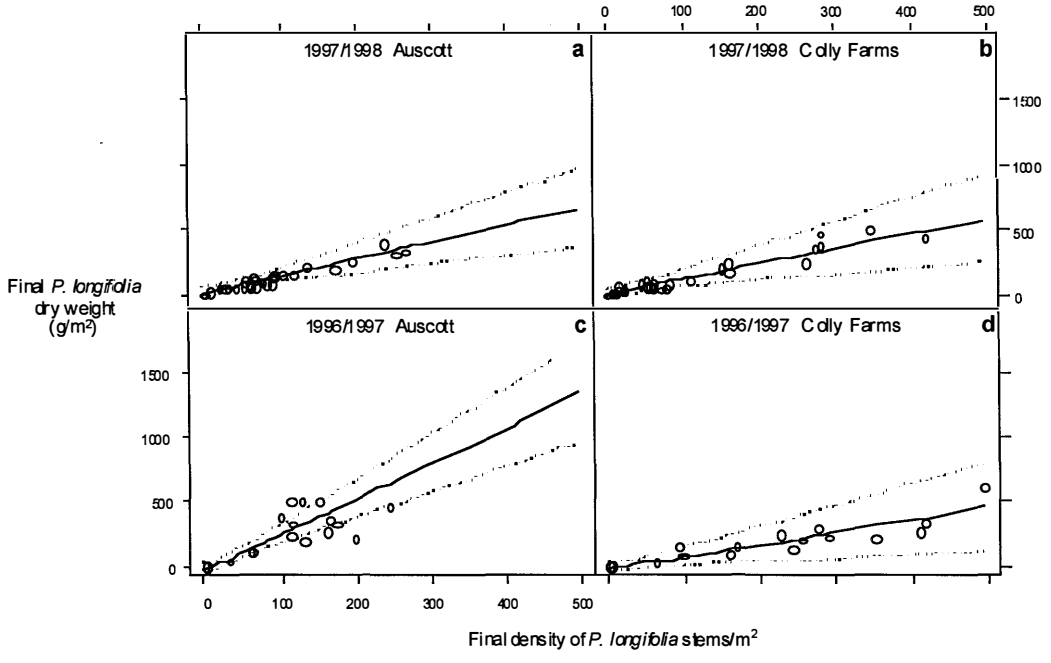


Figure 7.6 Final dry weight of *P. longifolia* as a function of *P. longifolia* stem density at harvest. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

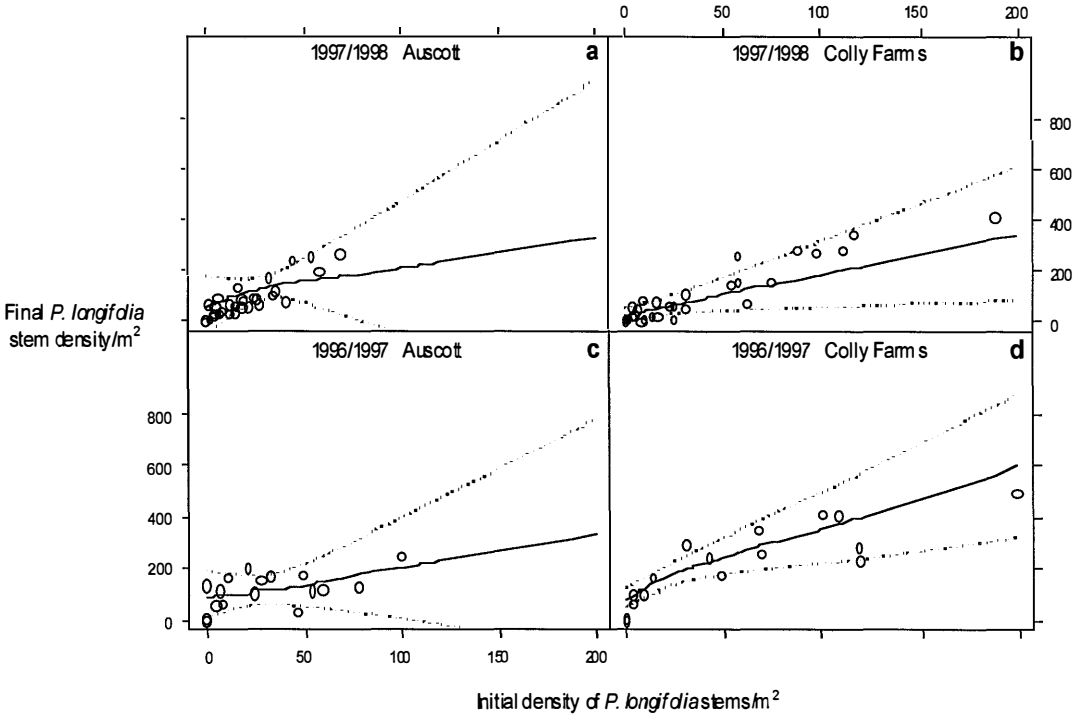


Figure 7.7 Final harvest density of *P. longifolia* as a function of initial density. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

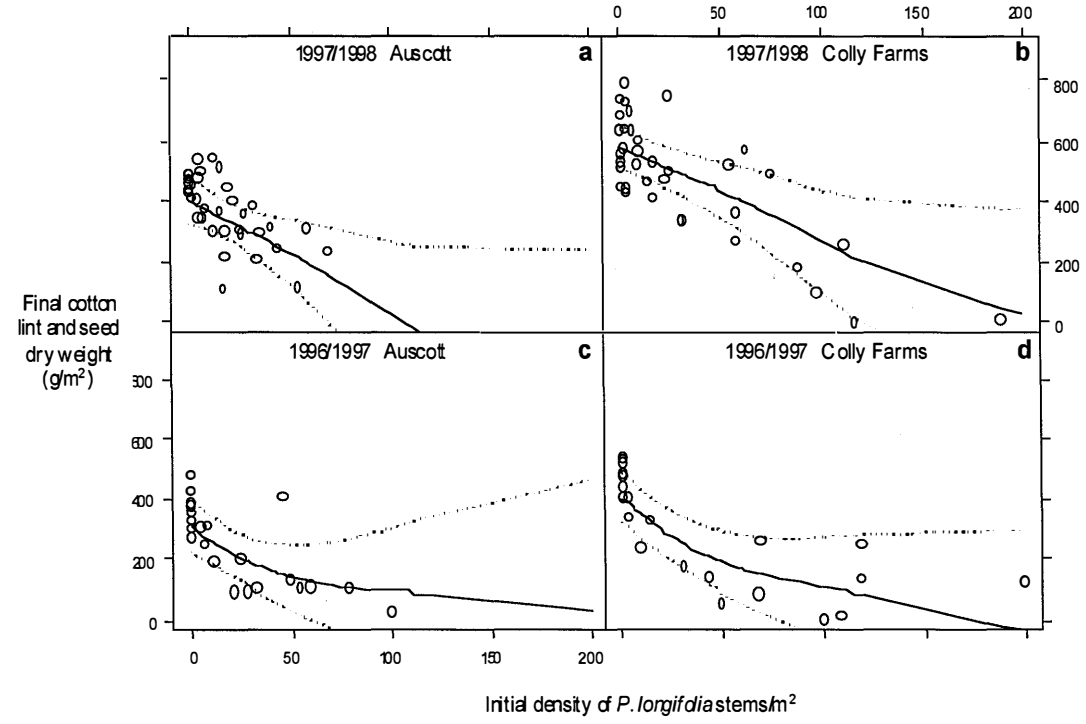


Figure 7.8 Final lint and seeds dry weight of cotton as a function of initial *P. longifolia* stem density. The solid line represents the curve fitted to the data while the dashed lines represent the 95% confidence intervals.

7.4 Discussion

Each stem of *P. longifolia* in the patch reduced the cotton lint and seeds yield within that patch by 9.4 - 18.9 kilograms per hectare. A reduction of between 17.5 - 17.9 kilograms per hectare has been reported for the perennial *C. esculentus* (Patterson *et al.* 1980) and 26.2 kilograms per hectare for the much larger perennial *S. halepense* (Keeley and Thullen 1981). This appears to indicate that *P. longifolia* is not as competitive as these two species and such differences are likely to be related in part to size differences between the species. For instance, *C. esculentus* is of similar size to *P. longifolia* while *S. halepense* may be up to three metres tall and is likely to have a much larger root system (Auld and Medd 1987). However it is difficult to make valid comparisons under potentially very different experimental conditions. Another problem with these comparisons is that the number of distinct *P. longifolia* plants could not be determined because of the deep rhizomatous connections. It is highly likely that the number of distinct *P. longifolia* plants represented is actually much smaller than the stem number (Section 4.4).

A 25% reduction in lint and seeds yield could be expected for cotton growing with *P. longifolia* if the final stem density was between 70 - 115 stems per square metre while a 50% reduction in yield could be expected from a stem density of 110 - 220 stems per square metre. Such densities are often exceeded both in the centre of patches (Figure 5.1) and further towards the perimeter (Section 5.7.3 and Figure 5.4). Commercially, cotton within most dense *P. longifolia* patches is not picked because very little cotton is produced and the risk of lint contamination by weed trash is increased. Unfortunately, there is no threshold density above which picking does not occur, but from personal observations a density over 100 stems per square metre in the patch centre seems likely.

Comparisons between annual and perennial vine species suggest that annual species interfere with crops more than an equivalent biomass of the perennial species (Elmore *et al.*

1990). This is understandable given that annual species rapidly acquire the resources they need for growth to produce seeds. A more gradual acquisition may occur in perennial species like *P. longifolia,* however, such interference may occur at any time rather than just during periods of rapid growth.

Buchanan and Burns (1971) stated that the competitiveness of a weed was more strongly expressed in the reproductive characteristics rather than the vegetative characteristics of cotton. For example, seed cotton yield was reduced far more significantly than stem height and diameter as the density of *I. purpurea*, an annual, increased. This was certainly the case with the cotton stem heights and final cotton density observed from *P. longifolia* (Figures 7.3 and 7.1). The same trend was also observed in *C. esculentus*, *S. elaeagnifolium* and *S. halepense* (Keeley and Thullen 1975; Patterson *et al.* 1980; Green *et al.* 1987; Keeley and Thullen 1989). By way of contrast, the reduction in cotton dry weight by *P. longifolia* was similar to that in lint and seeds dry weight (c.f. Figures 7.2 and 7.4). This suggests that the final total dry weight of cotton plants may be as equally valid a predictor of *P. longifolia* competition as yield parameters such as total boll number per square metre, total lint and seeds total dry weight, whether combined or separate.

There was a reduction in the dry weight of 100 cotton seeds as the density of *P. longifolia* increased, similar to that found with *I. purpurea* (Buchanan and Burns 1971). Reproductively, the most plastic responses to competition are found, in decreasing order, in the number of fruiting sites, the size of fruit, the number of seeds per fruit and seed weight (Harper 1977). The interference from *P. longifolia* must have been severe and season-long to have caused such a reduction in cotton seed weights and it is possible that similar reductions will be found in other perennial species that compete for cotton resources over the entire season like *Cyperus* spp.

Understanding the relationship between the initial density of *P. longifolia* and cotton yield may allow early season yield predictions to be made. For example, these results indicate that if the density of *P. longifolia* stems exceeds 45 - 95 stems per square metre, one to two months after planting, irrespective of cultivation, then a yield loss of greater than 50% can be expected at harvest (Figure 7.8). Knowing this relationship enables a decision to be made to implement a potential means of control or not, particularly if the decrease in cotton lint yield is likely to be high. McMillan (1988a) indicated that more successful control of *P. longifolia* will be achieved when the weed is growing actively. There is some potential to do this within a cotton crop without greatly compromising cotton yield by means of herbicide delivered through shielded spray units.

The spatial variability in density found in patches of *P. longifolia* and reported in this chapter may be a factor for consideration in the application of any management strategy. Observations by at least one agronomist indicate that while control around the edges of *P. longifolia* patches is possible, the more dense patch centres resist eradication (T. Haynes, pers. comm and see plate on page 193). Repeated attempts at eradication may achieve the desired goal.

7.5 Conclusions

Polymeria longifolia competes strongly with the cotton crop reducing yields and warranting attempted control. Competitive relationships are affected by a number of environmental and management factors including crop and weed genotype, time of emergence, soil type, climate, plant nutrition and irrigation management. These experiments were conducted at different locations in two distinctly different seasons in an effort to account for some of this variability (Appendix 4). In addition, the cotton varieties chosen were distinctly different in terms of growth habit and yield even though direct varietal comparisons were not

conducted. For example, Sicala V-2 and Sicala V-2i (with the Ingard® gene inserted) is the most widely grown variety in Australia, being short and compact in growth habit with high yields under a wide range of conditions, while Sicot 189 is vigorous, tall and commonly grown on fields that are cropped every summer (Cotton Seed Distributors 1999).

Control of *P. longifolia* is usually not based on stem density but on other factors such as the perceived potential for spread and re-infestation in clean field areas, and the chance that lint contamination may occur at harvest. This means that control is often attempted at densities far below the density perceived to result in cotton yield loss. The relationship between the density of *P. longifolia* stems at the beginning of the growing season and the final lint yield at harvest may have some part to play in attempted control. For example, early predictions of yield loss may result in in-crop control measures during the early growth of *P. longifolia*. An effective and consistent means of controlling this weed has yet to be devised, although work indicating control with glyphosate at rates exceeding four litres per hectare (trade product rates) is promising (G. Charles, pers. comm.).

A patch of *Polymeria longifolia* growing in a cultivated cotton field. Control measures, including the application of herbicides may reduce the problem on the edges of patches but the more resistant patch centres resist eradication. Control measures may also reduce cotton growth.

Chapter 8

Does Polymeria take all?

"Nitrogen and water were two of the most essential materials competed for by plants" (Kurtz et al. 1952).

8.1 Introduction

The consultant survey of Chapter 3 showed that 75% of respondents regarded *Polymeria longifolia* as a problem because it removed moisture from the soil. Consultants were not asked specifically about the extraction of nutrients by this plant in the survey, however, one respondent indicated that nutrient removal was a problem. Since *P. longifolia* is commonly known as Polymeria 'take-all', this chapter aims to answer the question concerning to what degree patches of *P. longifolia* exploit available soil water and nutrient resources.

8.2 Methods

The experiments outlined in this chapter were conducted at Field 4 of the Wilson's Farm, Auscott, Moree during the 1997/98 cotton growing season. A description of this field and its management is provided in Appendix 4.

Three separate sets of measurements were taken. These measurements were made on the same experimental areas so that a comparison between the different measurements could be made. Three well established patches of *P. longifolia* with a minimum diameter of 10 - 20 metres were selected as replicates for the measurements. Within each replicate, three treatment sites along the same cotton hill were selected. These evenly spaced sites were in the centre of the patch, on the edge of the patch and outside the patch. Each site was permanently marked with a wooden peg.

8.2.1 Soil water extraction

Soil water extraction was measured using a neutron probe meter (model number 503 DR). Aluminium neutron probe access tubes (50 millimetres diameter and 1.5 metre length) were installed by hand auguring a vertical hole with a diameter slightly less than 50 millimetres to a depth of 135 cm and then inserting the access tube to ensure a close fit with the soil. One tube was inserted at each treatment site (centre, edge and outside patch) for each replicate on 29 January 1998.

The soil around these tubes was allowed to settle prior to the first irrigation event on 7 February. The first measurement was taken on 9 February. The time of measurement was 48 hours after the irrigation and this point was taken as the time when the soil could hold the maximum amount of water i.e. field capacity.

Approximately 75 mm of rainfall fell on the field on 9 and 10 February after field capacity measurements. Probe measurements were subsequently taken on 16 and 20 February. The measurements on 20 February were taken as the refill point i.e. the driest point the soil would be allowed to reach before economic yield loss would be incurred. The final crop irrigation was on 21 February with the measurements between 9 and 20 February being part of the first measured drying cycle. Probe measurements were used to trace the drying of the

soil profile for a second time after this irrigation on 23 (field capacity) and 26 February and on 2, 5, 9 and 12 March, at which time the probe tubes were removed.

The measurements taken using the neutron probe meter were neutron counts. These counts were taken at 10 cm intervals down to 90 cm and then at 20 cm intervals to 130 cm using a count time of 16 seconds. The profile moisture content of the soil was determined by multiplying the volumetric soil water at each layer by the depth of the layer in millimetres. The change in profile moisture content was determined by subtracting the profile moisture content at each depth at the refill point or end date from the profile moisture content at field capacity. The results were analysed statistically using an analysis of variance with treatment means within each soil depth (Figures 8.1, 8.2, 8.3 and 8.5) or time (Figure 8.4) compared using a 5% l.s.d. No repeated measure analyses were performed. Only those differences which were significantly different will be discussed. The nutrient extraction and dry weight data were analysed and discussed in a similar fashion.

8.2.2 Soil nutrient extraction

Soil nutrient levels were measured for the top 25 cm of the soil profile. This involved random sampling of 10 x 50 mm diameter soil cores over six square metre area and bulking these samples together for each treatment site. The cores were air dried, mixed and sub-sampled twice for analysis. The mean of the two sub-samples was used for data analysis.

Soil samples were sent for nutrient analysis to Incitec, Port Kembla, New South Wales (NSW). The following parameters were measured :- pH (1:5 water and 1:5 $CaCl_2$), organic carbon, nitrate nitrogen, sulfate sulfur (mono calcium phosphate, MCP), phosphorus (Colwell), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), electrical conductivity, copper (diethylenetriaminepenta-acetic acid, DPTA), zinc (DPTA), manganese (DPTA), iron (DPTA), and boron (hot water). Three calculations were derived

from these data, which were the cation exchange capacity (CEC, the sum of K, Ca, Mg and Na ions), the calcium/magnesium ratio and the sodium ESP (exchangeable sodium percentage), which was the percentage of Na ions/CEC. In addition, soil texture was assessed. There were two times that soil cores were taken - 4 December 1997, mid season, and 4 February 1998, near harvest.

8.2.3 Densities and dry weight

Total cotton and *P. longifolia* densities and dry weights were determined on 16 February and 26 March 1998. The total density of all *P. longifolia* and cotton plants was determined in one metre x one metre plots at each experimental area. All above-ground plant material was harvested with a pair of secateurs before drying at 70°C for 48 hours and weighing.

8.3 Results

8.3.1 Soil water extraction

The main differences in volumetric water content between the treatments were in the surface 10 cm of the soil profile throughout the trial period and at 70 cm from 5 March (Figures 8.2d - f). In both the 10 cm and 70 cm profiles, the volumetric water content was significantly lower in the centre and on the edge of the *P. longifolia* patch rather than outside (Figures 8.2 d and e). The centre and edge, however, were not significantly different from one another. There were no other significant differences between the treatments within each soil layer even though there was a definite trend towards greater soil water extraction in the centre of the patch in the 50 - 80 cm soil profile as time progressed (Figures 8.2 d - f). Because of the lack of differences, the 5% l.s.d. statistics have not been presented (Figures 8.1 and 8.2).

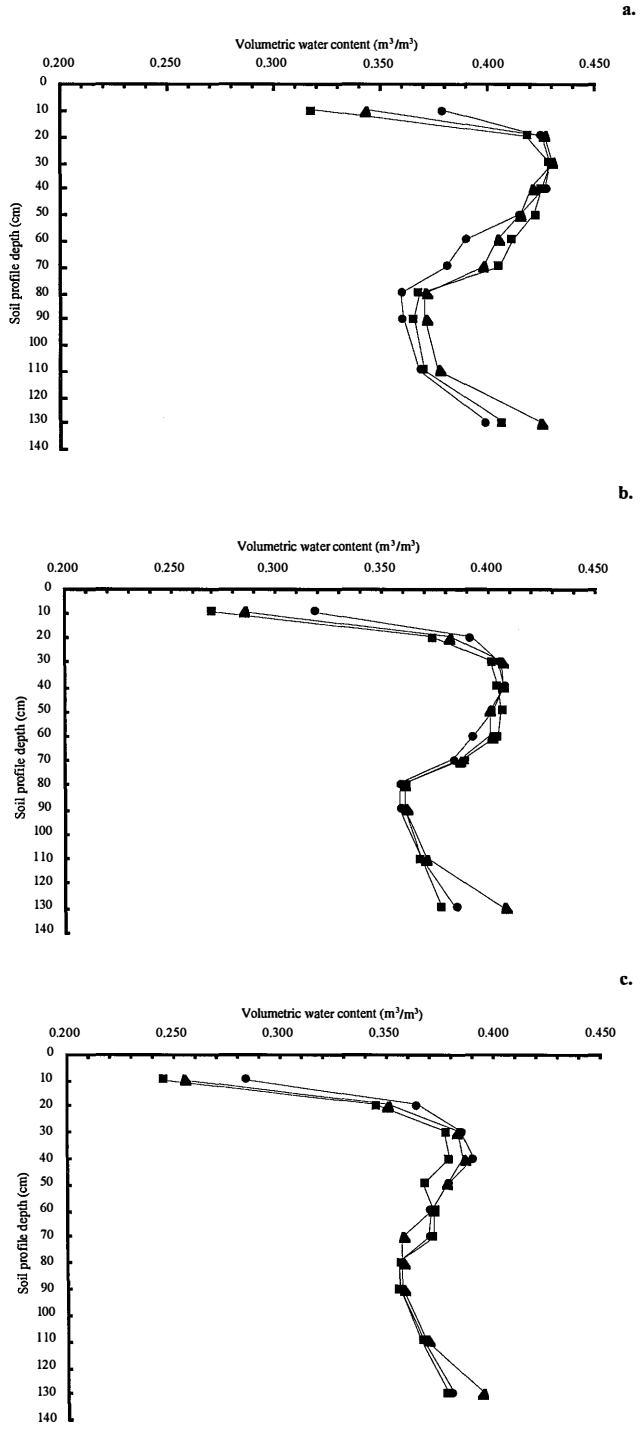


Figure 8.1 Volumetric water content of soil profile layers inside (■), on the edge of (▲) and outside (●) *P. longifolia* patches. These measurements were taken during the first drying cycle from the full point or field capacity of the soil, 48 hours after irrigation on 9 February (8.1a), 16 February (8.1b) and to the refill point on 20 February 1998 (8.1c).

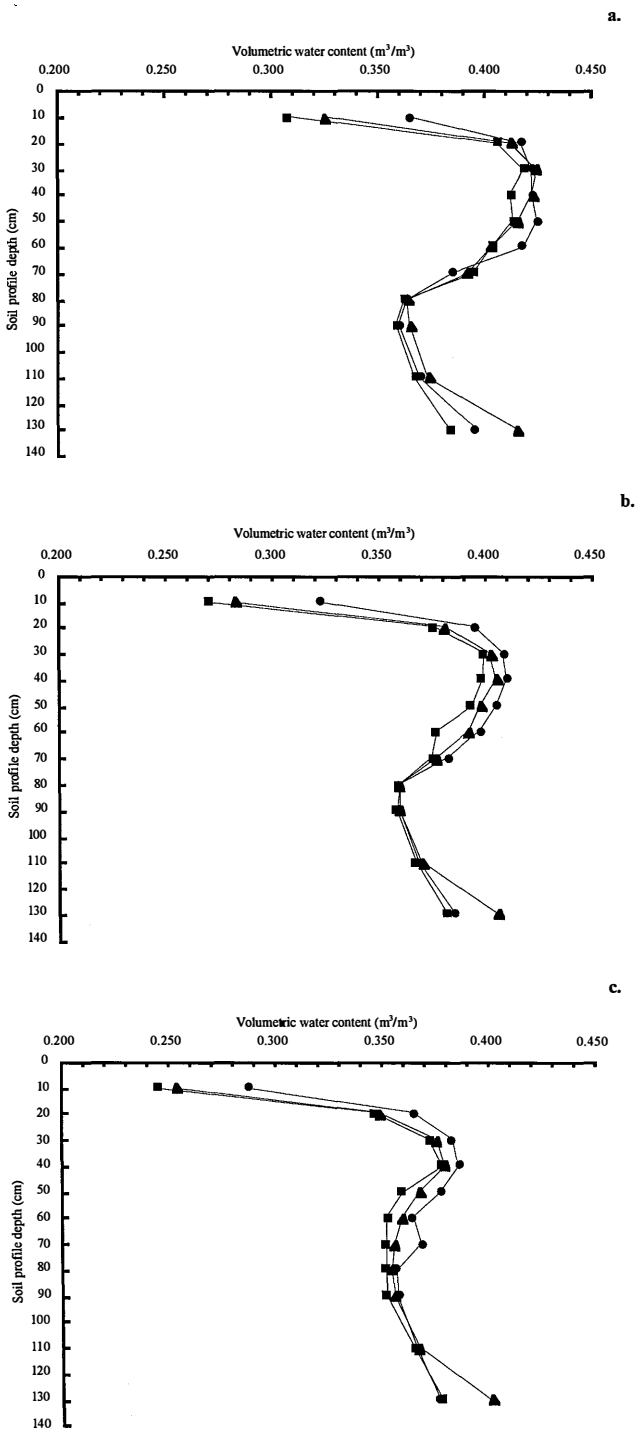


Figure 8.2 Volumetric water content of soil profile layers inside (■), on the edge (▲) and outside (●) *P. longifolia* patches. These measurements were taken during the early part of the second drying cycle from the full point or field capacity of the soil, 48 hours after the irrigation on 23 February (8.2a), 26 February (8.2b) and 2 March 1998 (8.2c). (Continued overleaf).

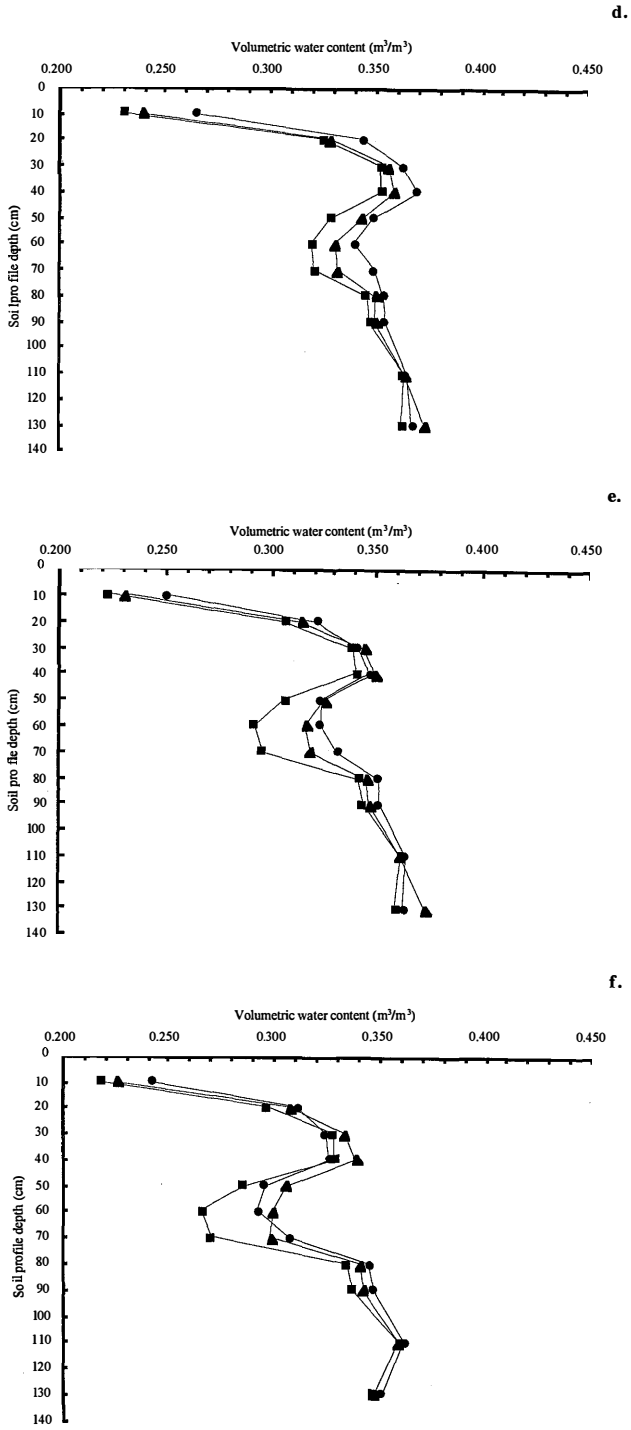


Figure 8.2 (From previous page). Volumetric water content of soil profile layers inside (■), on the edge of (▲) and outside (●) *P. longifolia* patches. These measurements were taken during the later part of the second drying cycle from 5 March (8.2d), 9 March (8.2e) and at 12 March 1998 (8.2f).

There was a reverse sigmoidal trend in volumetric water content over all treatments with low water content in the surface 10 cm increasing to 30 cm and then decreasing again from 40 - 70 cm (Figures 8.1 and 8.2). The volumetric water content below 80 cm then appeared to increase again.

Soil moisture decreased at each successive measurement date at depths above 80 cm due to the extraction of water from the soil profile by both cotton and *P. longifolia* and from other losses such as evaporation (Figure 8.3). Very little water was extracted over time in any treatment below 80 cm with the exception of 130 cm. It was not known why this exception occurred.

Total profile moisture content decreased with time as both cotton and *P. longifolia* extracted water from the profile (Figure 8.4). The sudden increase after day 11 (20 February) was due to the irrigation event the next day filling the soil profile. This irrigation event took place when the total profile moisture content outside the *P. longifolia* patch treatments had reached 475 mm of water. This was taken as the refill point in this experiment.

There were no differences in total profile moisture content in the soil between the centre, edge and outside the *P. longifolia* patch when the soil profile was comparatively full (Figure 8.4). However, as the soil profile dried below the refill point on day 21, the soil within the *P. longifolia* patch became significantly drier than the soil outside the patch. The total profile moisture content of the edge treatment was intermediate between the centre and outside the *P. longifolia* patch.

The change in profile moisture content from 48 hours after irrigation (field capacity) until either the refill point was reached (Figures 8.5a and b) or until the end of measurements (Figure 8.5c) was determined. As with the actual moisture contents, there were essentially no significant differences in the change in profile moisture content between the centre, edge

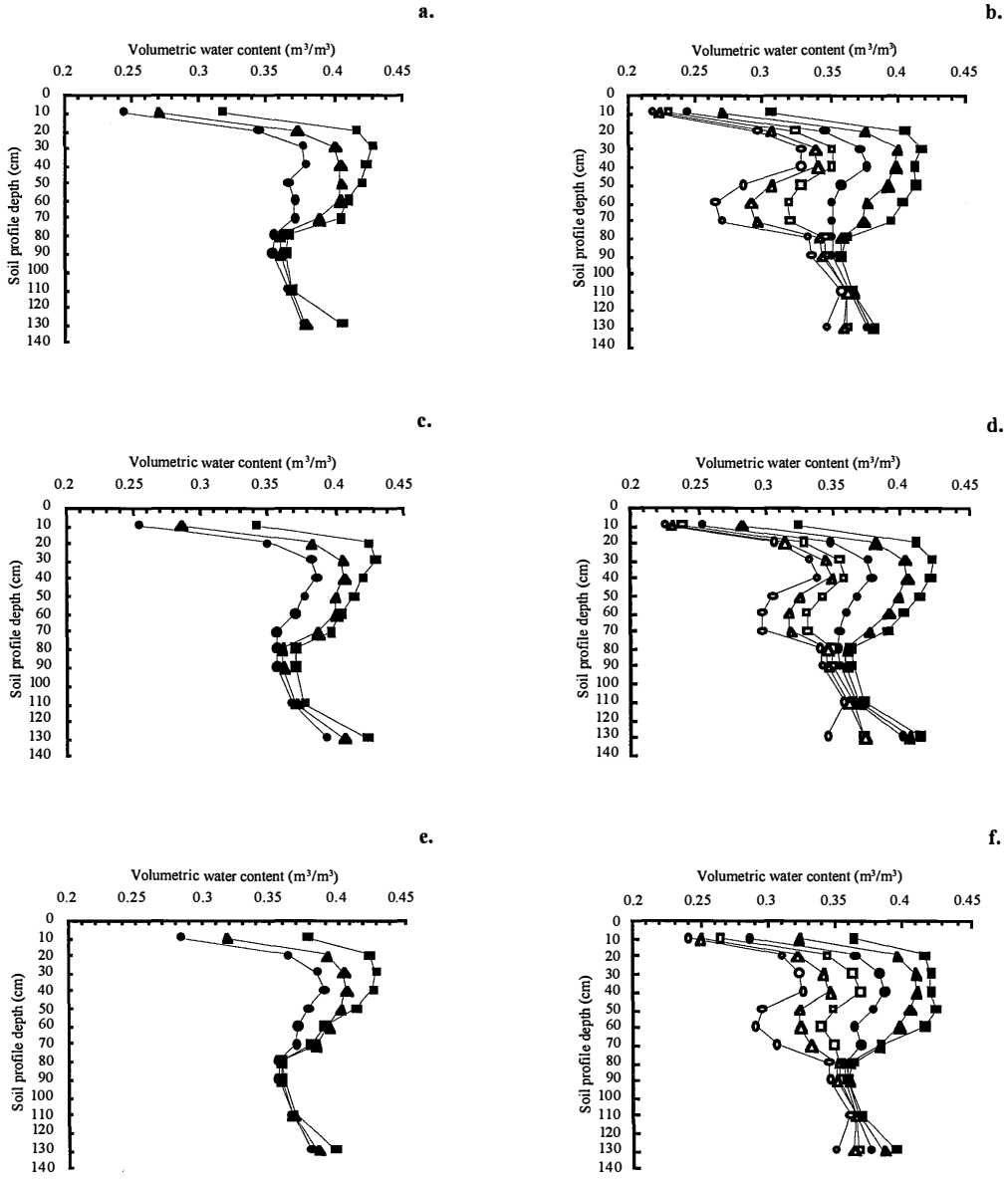


Figure 8.3 Volumetric water content of soil profile layers in the centre (8.3a and b), edge (8.3.c and d) and outside (8.3e and f) *P. longifolia* patches. The change in volumetric water content has been illustrated through the first (8.3 a, c and e) and second drying cycle (8.3 b, d and f). The observation dates in the first drying cycle are 9 February at field capacity, (■), 16 February (▲) and 20 February 1998 (●). For the second drying cycle they are 23 February at field capacity (■), 26 February (▲), 2 March (●), 5 March (□), 9 March (Δ) and 12 March 1998 (○). The 5% l.s.d. statistics can be used to compare all depth x time data within each set of graphs and were as follows, 0.032 (8.3a), 0.029 (8.3b), 0.023 (8.3c), 0.023 (8.3d), 0.016 (8.3e) and 0.019 (8.3f).

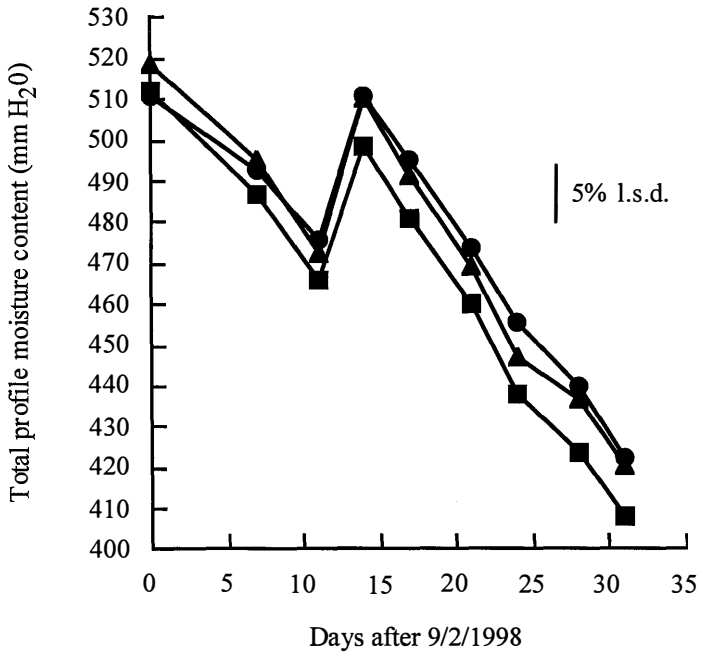


Figure 8.4 Total profile (130 cm) moisture content in the centre (■), edge (▲) and outside (●) *P. longifolia* patches. The initial measurements were taken on 9 February 1998 (Section 8.2.1).

or outside the *P. longifolia* patch within any given depth with several exceptions. These were at 10 cm where the change in profile moisture content was greatest outside the patch compared with the patch centre and at 70 cm where the moisture content change was greatest in the centre and on the edge of the patch compared with outside the patch.

When summed over the whole 130 cm soil profile, there was no significant difference in the total amount of soil profile moisture extracted in the centre, on the edge or outside the *P. longifolia* patch. The mean amount of water extraction across all treatments in the first cycle was 42.3 mm of water while in the second cycle, 89.4 mm of water was extracted.

8.3.2 Soil nutrient extraction

Analyses of soil parameters at each sampling time revealed very few differences between the centre, edge and outside of *P. longifolia* patches. The differences that were determined are shown in Table 8.1. The iron concentration was lower in the centre of the *P. longifolia*

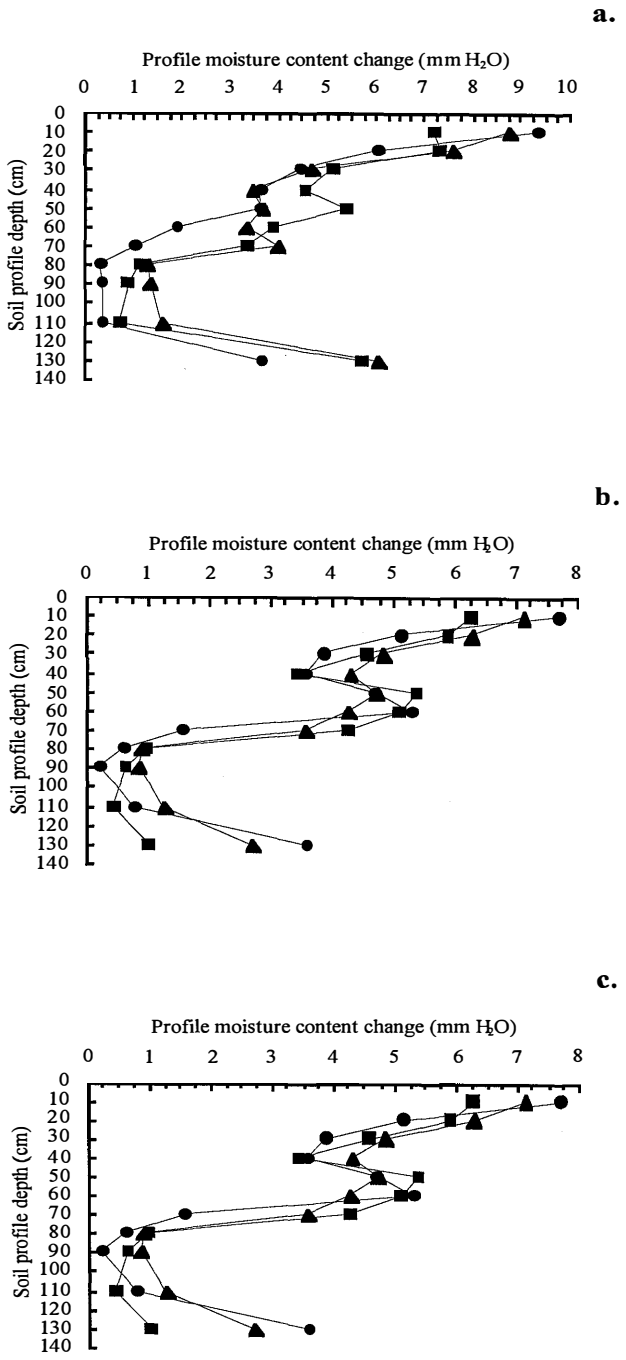


Figure 8.5 Change in profile moisture content from field capacity to either refill point in the first (8.5a) or second cycle (8.5b) or from field capacity to the end of measurements in the second cycle (8.5c). The treatments have been illustrated as in the centre (■), on the edge of (▲) or outside (●) the *P. longifolia* patches. The 5% l.s.d. statistics can be used to compare all treatment x depth data within each set of graphs and were as follows, 2.11 (8.5a), 1.96 (8.5b) and 3.31 (8.5c).

Table 8.1 Soil parameters that showed differences between treatments at each sampling date.

Time of sampling and parameter	Parameter mean in each treatment			5% l.s.d.*
	Centre	Edge	Outside	
December				
Iron (mg/kg)	9.00[a]	9.83[b]	10.33[b]	0.76
February				
Magnesium (meq/100g)	9.07[a]	8.98[a]	9.42[b]	0.19
Iron (mg/kg)	10.50[a]	9.67[a]	12.17[b]	0.89

* Means within a parameter marked with the same letter were not significantly different ($P > 0.05$).

patch compared with the weed free area at the December and February sampling dates. The magnesium concentration in February was also lower in or at the edge of the patch compared with the area beyond the patch.

When the soil nutrient data were combined and averaged over the two sampling dates, several differences became apparent (Table 8.2). The levels of iron and magnesium were greater outside the plot area than on the edge or in the centre. The opposite trend appeared in the Ca/Mg ratio with a higher ratio in the centre of the patches to that outside the patch areas. When the data were combined and averaged over treatment sites there were significant decreases in electrical conductivity, cation exchange capacity, nitrate nitrogen, magnesium and chloride levels and a significant increase in iron levels from the December to the February sampling time.

Table 8.2 Soil parameters that showed significant differences between treatments when data from sampling dates were combined.

Parameter	Parameter mean at each treatment site			5% l.s.d.*
	Centre	Edge	Outside	
Iron (mg/kg)	9.75[a]	9.75[a]	11.25[b]	1.11
Magnesium (meq/100g)	9.08[a]	9.17[a]	9.42[b]	0.15
Ca/Mg ratio	2.90[b]	2.74[ab]	2.66[a]	0.17

* Means within a parameter marked with the same letter were not significantly different (P > 0.05).

8.3.3 Dry weight

The total dry weight of cotton was less in the centre of the *P. longifolia* patch than on the edge or outside the patch area (Table 8.3). Cotton dry weight in the centre of the patch increased very little between the February and March sampling dates in contrast with the cotton on the edge and outside the patch. Cotton density did not vary between treatments at either date.

The total dry weight and density of *P. longifolia* stems was highest in the centre of the patch and decreased on the edge and outside the patch area (Table 8.3). There was a decrease in *P. longifolia* dry weight and density for the edge treatment between February and March, which was probably related to sampling less dense *P. longifolia* quadrats. There was no treatment x time interaction and, for this reason, the data have been averaged over the two sampling dates (Table 8.3). The same trends were evident for these combined data.

Table 8.3 The dry weight and density of cotton and *P. longifolia* in the centre, on the edge and outside *P. longifolia* patches. A total cotton and *P. longifolia* plant dry weight has been included for comparison.

Time of sampling and parameter	Parameter mean at each treatment site			5% l.s.d.*
	Centre	Edge	Outside	
February				
Cotton dry weight (g/m^2)	500.8^a	831.2^b	886.9^b	207.4
Cotton density ($stems/m^2$)	9.3	11.0	8.7	n.s.
P. longifolia dry weight (g/m^2)	166.1^b	55.7^a	0^a	73.0
P. longifolia density/m^2	122.7^b	43.3^a	0^a	49.1
Total plant dry weight(g/m^2)	666.9	886.9	886.9	-
March				
Cotton dry weight (g/m^2)	506.8^a	1064.4^b	1167.1^b	384.0
Cotton density ($stems/m^2$)	7.7	10.0	11.7	n.s.
P. longifolia dry weight (g/m^2)	172.3^b	16.5^b	0^a	159.2
P. longifolia density/m^2	150.0^b	11.0^a	0^a	124.8
Total plant dry weight(g/m^2)	679.1	1080.9	1167.1	-
Averaged over time				
Cotton dry weight (g/m^2)	503.8^a	947.8^b	1027.0^b	195.0
Cotton density ($stems/m^2$)	8.5	10.5	10.2	n.s.
P. longifolia dry weight (g/m^2)	169.2^b	36.1^a	0^a	65.8
P. longifolia density/m^2	136.3^b	27.2^a	0^a	48.8
Total plant dry weight(g/m^2)	673.0	983.9	1027.0	

* Means within a parameter marked with the same letter were not significantly different ($P > 0.05$). The letters n.s. indicate no significant difference at this level.

8.4 Discussion

8.4.1 Water extraction

There were few detectable differences in the extraction of soil water between the cotton only (outside) and the cotton plus *P. longifolia* treatments (edge and centre) at any depth and at any time. One notable difference was when the water in the soil profile had dropped below the refill point after irrigation had ceased on 23 February. Below this point, more soil water was extracted in the centre of the *P. longifolia* patches (where *P. longifolia* and cotton were growing together) than outside the patch where cotton was growing alone. This final irrigation was timed to ensure adequate soil moisture to mature the cotton crop and to reduce soil compaction at harvest. Water extraction in the centre of *P. longifolia* patches also tended to be greater than on the edge and outside the patches as the refill point was approached, particularly in the second drying cycle and to a lesser extent in the first drying cycle. The differences were not as pronounced in the first drying cycle because of the additional 75 mm of rainfall on 9 and 10 February 1998.

Another difference was between the 50 - 70 cm soil depths where more water was extracted in the centre and on the edge of *P. longifolia* patches rather than outside the patch areas. This was not expected as over 80% of rhizomes and 65% of roots of *P. longifolia* were found in the top 40 cm of soil (Table 4.2). The water extraction at this depth did not preclude the possibility that fine roots which were not necessarily visible resulted in this water extraction.

The volumetric water content in these depths appeared to decrease more rapidly than in the other soil layers and to some degree was independent of treatment (Figures 8.2d - f and Figures 8.3b, d and f). A lighter, sandier, soil layer has been identified at varying depths throughout this field and it is likely that this layer has a lower water holding capacity as

previous probe data have shown (R. Webb, pers. comm.). Therefore, any differences between the ability of *P. longifolia* and cotton to extract water from the profile are likely to have been highlighted here. This soil layer was identified when excavating probe tube holes. A third difference was identified in the top 10 cm of the soil profile which was always drier inside the *P. longifolia* patch area than outside the patch (Figures 8.1 and 8.2). By way of contrast, the extraction of water over the drying cycles was greater outside the patch area than in the centre of the patch (Figure 8.5). In explanation, it appeared that *P. longifolia* had already extracted water in this surface layer after an irrigation event and before the initial probe measurements occurred. This is plausible given that around 18% of all rhizome and root material in the top metre of soil occurred in the top 10 cm of the soil (Table 4.2). This extraction before measurements commenced resulted in a lower initial water level in this layer and therefore a 'reduced' amount of extraction within the centre of the patch (Figure 8.5). Other factors such as the shading of the soil by *P. longifolia* may have reduced evaporation from the soil surface within the patch.

The most severe interference between weeds and crops is for available soil moisture (Pavlychenko 1940, in Radosevich and Holt 1984). This chapter has shown that *P. longifolia* does compete with cotton for water. The point at which interference for available soil moisture started in this experiment was not determined, but *P. longifolia* was clearly depleting the soil profile of moisture as the refill point was approached. To determine the point at which interference started, a water-use experiment should be conducted where the level of soil water could be varied under controlled conditions.

Thus far, this discussion has centred on irrigated cotton production. Dryland production accounted for 18% of the area sown to cotton in the 1997/98 season (Dowling 1998b). The soil moisture levels in dryland crops would be below the refill point for longer than in irrigated crops and hence competition from *P. longifolia* for soil water may be more severe. Irrigated cotton crops may also experience more severe water stress if the final irrigation/s

are missed due to inadequate water supply in a drought season. Under dryland or drought conditions, *P. longifolia* would be competing with cotton for water and differential extraction would be occurring in more of the soil profile than that observed here.

8.4.2 Nutrient extraction

There was no measurable increase in the extraction of major plant nutrients including nitrogen, phosphorus and potassium down to 25 cm in *P. longifolia* patches over cotton alone. Iron and magnesium levels, however, were lower in the centre of the patches compared with outside the patches (Tables 8.1 and 8.2). Steenhagen and Zimdahl (1979) similarly compared soil samples to 20 cm depth in areas of low, moderate and high stem density of *Euphorbia esula*, another hard-to-control perennial species, and found no difference in phosphorus, potassium, nitrate, zinc, iron and organic matter. They concluded that this weed's principal interference mechanism may have been allelopathy.

The absence of depletion of major nutrients was in direct contrast to other studies on the nutrient use of weeds. For example, Robinson (1976) found that cotton height was reduced by up to 75% and cotton yield by up to 88% when a number of weeds such as *Ipomoea* spp., *Amaranthus retroflexus*, *Digitaria sanguinalis*, *Abutilon theophrasti* and *Anoda cristata* were growing with the crop. They reversed the effect of this interference by applying nitrogen fertiliser which, they suggested, was the major limiting nutrient to cotton growth. Although cotton dry weight was reduced in the centre of *P. longifolia* patches, it is less likely that growth was limited by nitrogen supply as no differences between the nitrogen levels inside compared with outside the patch area were observed in the top 25 cm of the soil profile.

There are several explanations as to why differential extraction of nutrients was not detected in the presence of *P. longifolia.* Firstly, the extraction of soil nutrients by the

cotton with or without the *P. longifolia* may have been so small that it was not detectable by these measurements. This explanation is unlikely given that changes in several soil parameters were measured over time. Secondly, the combined nutrient extraction of *P. longifolia* with a weakened cotton crop may have been similar to the more vigorous cotton alone. Thirdly, differential extraction between the two species may have been occurring further down the profile and this was not detected by the relatively shallow soil cores. This explanation seems likely given that more than 30 and 40% of *P. longifolia* rhizomes and roots respectively were detected lower than 30 cm in the soil profile (Table 4.2) and that extraction of soil water appeared to be occurring down to 80 cm. Kapur and Sekhon (1985) indicated that cotton roots were more concentrated in the top 45 cm, which was an area of high fertility. It is probable that nutrient extraction for *P. longifolia* occurs at around the same depth as water extraction occurs and that this was not sampled thoroughly by the shallow soil cores used in this chapter.

8.4.3 Dry weights

Some form of interference between *P. longifolia* and cotton clearly occurred in this experiment as measured by a reduction in cotton dry weight in the patch (Table 8.3). In addition, there was a negligible increase in the dry weight of cotton plants in the centre of the patch between the two sampling dates compared with the increase outside the *P. longifolia* patches. The total plant dry weight, a combination of the shoot dry weights of cotton and *P. longifolia*, also indicated interference in the weed patch and again one explanation may be that the weakened nature of the crop with the weed may have reduced water and nutrient depletion below what may have been expected. These comparisons do not make any allowance for below-ground competition.

8.4.4 The when and where of competition between P. longifolia and cotton

The measurements taken in this experiment were all in the latter half of the growth phase of the cotton crop. Competition early in a crop's growth can result in yield reductions later in the season, particularly in cotton where slow seedling growth provides ample opportunity for the establishment of weeds. For this reason, cotton should be maintained weed free for at least the first six to ten weeks of growth, but possibly up to 14 weeks to avoid yield loss (Buchanan and Burns 1970; Rogers *et al.* 1976; McMillan 1988b).

Weeds compete for a number of resources early in crop growth. These include water, nutrients and light and a deficit of any one of these resources may result in crop yield reductions (Donald 1963, Plate 8.1). It is highly likely that the early capture of soil water by *P. longifolia* occurs during cotton emergence (Radosevich and Holt 1984) and that, shortly after, competition for light occurs if the *P. longifolia* canopy shades out the seedling cotton. Donald (1963) stated that competition for light occurred in almost all cropping situations, while Radosevich and Holt (1984) stated that if a weed species could produce a canopy over a crop at a critical stage in its development, for example in seedling growth, then a considerable competitive advantage could be gained. To illustrate this point Oliver *et al.* (1976) demonstrated that competition for light between soybean and *Ipomoea purpurea* after the first six to eight weeks of growth resulted in a reduction in seed yields of 43 - 66%.

Early season competition has not been proven by the research contained in this chapter but anecdotal evidence suggests that it does occur. If so, it would be desirable to keep crops of cotton free from *P. longifolia* for the first ten weeks of growth. This is currently impossible even though the use of residual herbicides and cultivation at planting currently practised in cotton farming systems aims to control a wide variety of weeds including *P. longifolia.* The reason for this is that the large rhizome and root mass of *P. longifolia* results in rapid and early production of weed shoots either before, or at the very least concurrent with, cotton

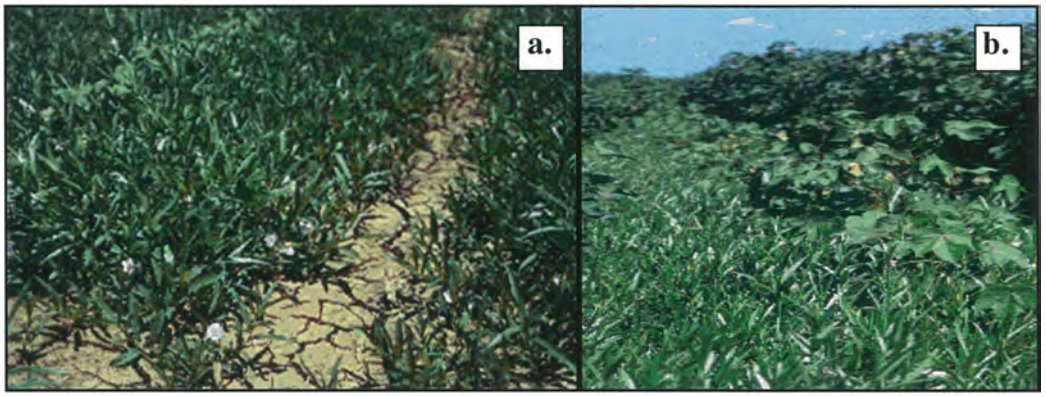


Plate 8.1 Early season competition between *P. longifolia* and cotton (8.1a) may involve the weed interfering with water, nutrient and light capture by the cotton crop. Later season competition (8.1b) may involve the weed interfering with water and nutrient capture by cotton but, in contrast, cotton interfering with the capture of light by *P. longifolia* as it is increasingly shaded out in the rows.

planting. Continuing recruitment of the shoots then occurs throughout the season (Section 5.4.3).

8.4.5 Another form of interference ?

It was conceivable that *P. longifolia* produces allelochemicals that affect the growth of cotton. This was suggested by the crystallised compounds found in the rhizomes of *P. longifolia* (Section 4.5.3) and the fact that allelopathy has been demonstrated in several other Convolvulaceae species, e.g. *Convolvulus sepium* (Quinn 1974), *Ipomoea batatas* (Peterson and Harrison 1991a, b among others) and *Ipomoea tricolor* (Anaya *et al.* 1995) and in other aggressive perennial weed species that form monocultures (Putnam 1985). From their own observations, several cotton agronomists have suggested that *P. longifolia* may possess allelopathic properties (G. Charles and T. Haynes, pers. comm.). An investigation into the possible production of allelochemicals by *P. longifolia* is needed. Suppression of cotton may result from competitive and allelopathic effects and the interaction of various factors should be considered in further experimentation because realistic weed management cannot be achieved unless the limiting resources and interactions are defined (Radosevich and Holt 1984).

8.4.6 How to improve the experimentation

In all cases of research there are a number of sources of variation which can prevent treatment differences from being observed. In this research, the use of 32 second neutron probe counts instead of 16 second counts and the insertion of more than one probe tube in each treatment may have reduced variation within the neutron probe measurements. The natural variability inherent in soil nutrient studies in the field places a further restriction on finding differences between treatments. Among the many sources of variation, natural in-field variation and in-sample variation existed, but sampling within blocks and sub-sampling within the bulk soil collected for the nutrient samples accounted for some of this.

8.5 Conclusions

There were limited differences in the extraction of water or nutrients between cotton only areas and those containing *P. longifolia* and cotton, however, this does not prove that competition was not occurring between the two species. Interference between *P. longifolia* and cotton occurred throughout the trial period as reductions in crop dry weight showed. Allelopathy, common in a number of perennial weeds which also form monocultures like *P. longifolia* (Putnam 1985), may also have been acting. This mechanism, although suggested in the anatomical studies outlined in Chapter 4, requires further research, initially in glasshouse or laboratory culture where environmental factors can be controlled.

Competition between *Polymeria longifolia* and native vegetation

Chapter 9

How do control measures affect *Polymeria longifolia*?

"Present control measures for Polymeria longifolia are far from satisfactory, and progress towards improved control systems have been slow due to a lack of research effort. Polymeria longifolia is largely resistant to chemical and cultural control" (McMillan 1988a).

9.1 Introduction

At present, management methods used for *Polymeria longifolia* are still not satisfactory with little changing in the 12 years since the statement above was made. Some 83% of survey respondents in Chapter 3 had attempted control at a cost of $36.20 per hectare per year (Section 3.4.10). Herbicide application was the most successful means of control with 37% of respondents indicating a decrease in the occurrence of the weed using this technique (Table 3.12). However, registered in-crop herbicides were not generally regarded as being successful (Table 3.13) and the effect of many other herbicides was variable. Similarly, cultivation was not successful in reducing *P. longifolia* infestations (Table 3.12). Hand chipping had little effect on the incidence of the weed in 80% of cases. Nevertheless hand chipping, cultivation and herbicide application were the three most common means of attempting to manage *P. longifolia* infestations in the field.

The experimental effects of chipping are examined in Section 9.2 of this chapter and the use of several herbicides in Sections 9.3 - 9.5. The reader is referred to Chapter 6 for some information on the effect of cultivation on *P. longifolia.*

9.2 Hand chipping and pulling effects on *P. longifolia*

9.2.1 Aims

This experiment was conducted to determine whether hand chipping and pulling had any impact on *P. longifolia* growth and cotton yields.

9.2.2 Methods

This experiment was conducted at two locations which were Field 11 at the Midkin Farm, Auscott, Moree and Field 27 at the Central Farm, Colly Farms, Collarenebri in the 1996/97 cotton growing season. A basic description of these farms with the management of these fields is given in Appendix 4.

The trials were set up in well established patches of *P. longifolia.* The same six treatments were used at each location and were an unchipped control, chipping every one, two, or three months, and chipping or hand pulling at the start of the trial only. Hand chipping and chipping are synomymous in the following text. There was no control external to the patch area. These treatments were randomly allocated to plots in each of four adjacent blocks (replicates). Each plot was one metre x one metre and was centred on the cotton plant line.

The initial densities of *P. longifolia* shoots and cotton plants in each plot were counted on 30 October 1996 at Auscott and 31 October at Colly Farms (Table 9.1). All shoot material

of *P. longifolia* was removed prior to chipping by cutting just below ground level. This material was dried at 70°C for 48 hours to constant weight and weighed. Hand chipping was then carried out with a hoe to a depth of 5 - 10 cm. Each plot was hoed for an equal amount of time within any hoeing date. In practice, a hoe would cut shoots off somewhere below ground level and disturb the soil all in one event, but to avoid further damage to the shoots by the hoe, and to aid in shoot collection, it was decided that cutting the shoots off initially was a reasonable compromise. Hand chipping does very little damage to the underground system aside from removing a small length of the vertical shoot-bearing rhizome with the shoot. In the hand pulled plots, all shoots were gently pulled up so that vertical shoot-bearing rhizomes did not break and retained as much rhizome attached as possible, generally between 10 and 15 cm. Only the shoots from this treatment were weighed and the plots were not disturbed in any other way.

The density of *P. longifolia* in each treatment plot was assessed immediately before each chipping event and the shoot material weighed (Table 9.1). There were two inter-row cultivations performed at Colly Farms on 26 October (six days preceding the initial assessment of density) and approximately one week after the 16 December sampling. These cultivation events reduced the shoot density present. There were no inter-row cultivations at Auscott.

The cotton and *P. longifolia* plants were harvested on 6 March 1997 at Auscott and 18 March 1997 at Colly Farms (Table 9.1). The density and dry weight of both *P. longifolia* and cotton were assessed. In addition, stem diameter of cotton plants was measured at ground level and mean height of the cotton stem to the base of the petiole of the youngest opened leaf was measured. Following dry weight assessments, all cotton bolls were removed and counted. The cotton lint and seeds were then removed by hand and ginned using a 20 saw gin at the Australian Cotton Research Institute (ACRI), Narrabri, after which each component was weighed.

Table 9.1 Assessment dates and days after initial assessment in the chipping experiment.

Assessment time	Auscott		Colly Farms	
	Date	Days after initial assessment	Date	Days after initial assessment
Initial	30/10/1996	0	31/10/1996	0
1 month	06/12/1996	37	16/12/1996	46
2 months	07/01/1997	69	09/01/1997	70
3 months	21/02/1997	114	18/02/1997	110
Harvest	06/03/1997	127	18/03/1997	138

The results were analysed using an analysis of variance and differences were assessed using the 5% least significant difference (l.s.d.). Only results that were different at this level will be discussed in general. The statistical procedure and discussion of results were the same for the experiments outlined in Sections 9.3.2, 9.4.2 and 9.5.2.

9.2.3 Results and discussion

The density of *P. longifolia* shoots generally increased throughout the season both in chipped and unchipped plots (Figures 9.1a and b). This result was similar to the density increase found in Section 5.4. However, there were no significant treatment differences between *P. longifolia* densities at harvest (Table 9.2).

The initial chipping of the one, two and three month plots increased the dry weight of *P. longifolia* over the initial dry weight (Figures 9.1c and d). Cumulative dry weight at harvest was also higher in these plots than the dry weight in control plots (Table 9.2). The cumulative dry weight of *P. longifolia* was generally maximised as the intensity of chipping increased i.e. in the one month treatment, although the differences among the one, two and

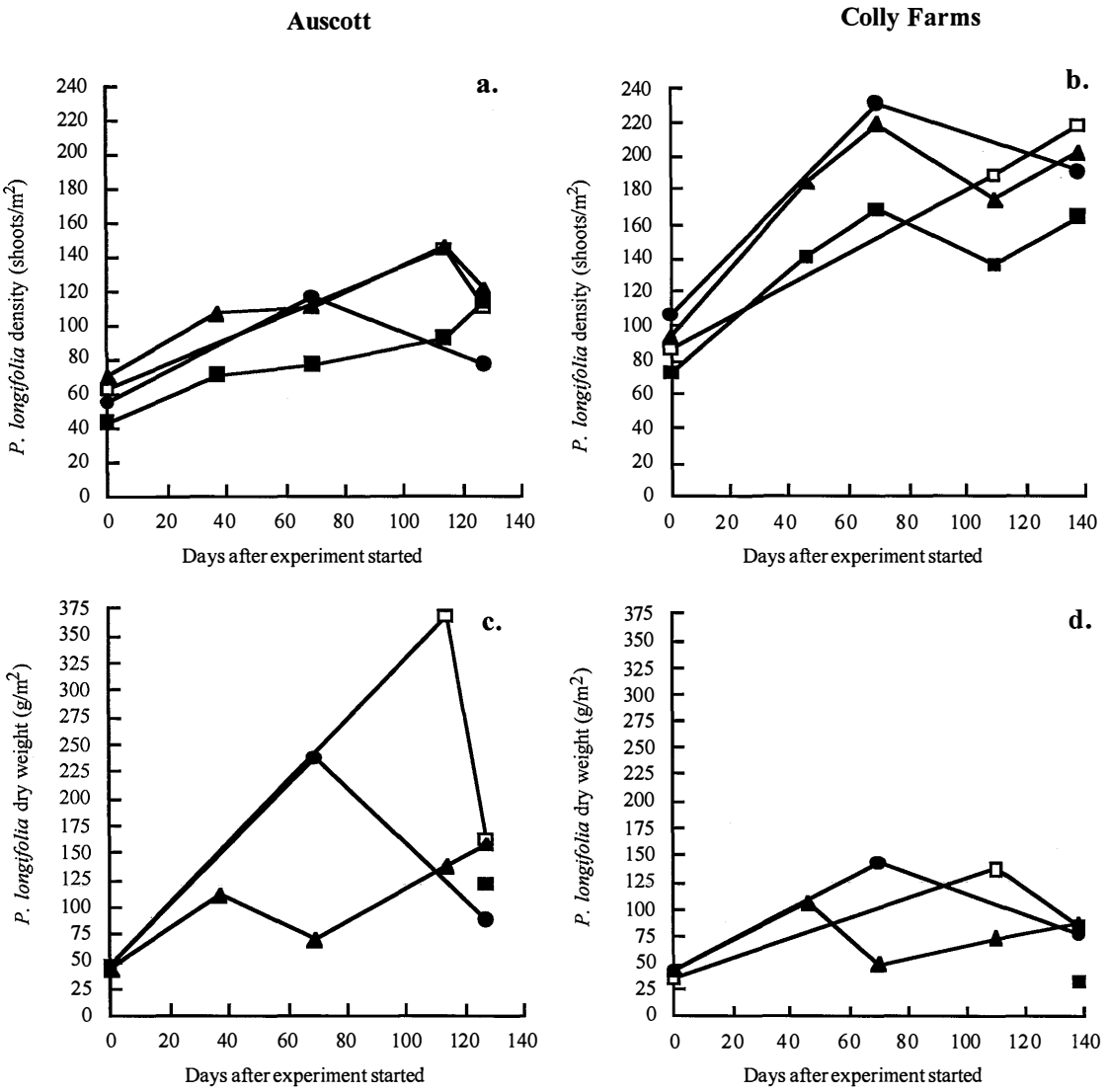


Figure 9.1 The change in *P. longifolia* density (9.1a and b) and regrowth dry weight (9.1c and d) in the control (■), 1 month (▲), 2 month (●and 3 month treatments (□). The three treatments presented were chipped after the initial chipping event and were compared with the control. Data from Auscott has been presented in 9.1a and c and data for Colly Farms in 9.1b and d. The dry weight data are not cumulative.

three month treatments were not always significant. There was no difference in the cumulative dry weight production of *P. longifolia* in unchipped (control) plots compared with those which had been chipped or hand pulled initially and all were much lower than plots that had been chipped regularly.

Table 9.2 A summary of *P. longifolia* harvest parameters measured to determine the effect of chipping and hand pulling. Total *P. longifolia* dry weight is a cumulative figure i.e. a composite of all shoot material harvested from the plots after the initial chipping or pulling at the start of the experiment. The density data for *P. longifolia* were taken at harvest.

Location and *P. longifolia* harvest parameter	Unchipped control	Chipped every 1 month	Chipped every 2 months	Chipped every 3 months	Chipped initially	Hand pulled
Auscott						
P. longifolia density (stems/m^2)	113.3	121.5	76.8	111.5	119.8	105.0
Total *P. longifolia* dry weight (g/m^2)	121.8^a	477.0^{bc}	325.9^b	531.0^c	116.5^a	69.5^a
5% l.s.d.* (DW) **190.3**						
Colly Farms						
P. longifolia density (stems/m^2)	165.3	202.5	190.8	218.0	203.3	231.0
Total *P. longifolia* dry weight (g/m^2)	33.5^a	316.0^c	221.3^b	224.0^b	85.0^a	95.2^a
5% l.s.d.* (DW) **66.5**						

* Means within each row marked with the same letter were not significantly different ($P < 0.05$).

It appeared that chipping stimulated the growth of *P. longifolia* shoots. There was an apparent increase in density in chipped plots throughout the trial and at harvest over the control plot densities, although these were not significant. Regrowth and cumulative dry weights in chipped plots were also increased over control plots. The shallow, lightly disruptive chipping described in this section may have promoted meristematic activity in the rhizome (Section 2.4.6, Plate 2.2a) and an increase in both the number and dry weight of shoots. Furthermore, it is suggested that the intensity of chipping allowed sufficient recovery of the *P. longifolia* stems whereas frequent defoliation in a number of other species has lead to a reduction in both density and dry weight (e.g. *Cyperus esculentus* (Keeley and Thullen 1975) and *Sorghum halepense* (Keeley and Thullen 1981)). A study in Chapter 10 examined the effect of a more frequent and severe defoliation regime on the growth of *P. longifolia*.

An intensive regime of weekly hand chipping was required for the control of both *C. esculentus* and *S. halepense* and the maintenance of cotton yield (Keeley and Thullen 1975; 1981). This level of hand chipping would not be cost effective for *P. longifolia* given that 'heavy' hand chipping in cotton currently costs $42.90 per hectare per year (Anon 1998). A 'heavy' hand chipping operation was defined as the removal of four weeds per metre of row. An infestation of *P. longifolia* may exceed 200 shoots per metre square and very rarely is below 100 per square metre. These levels graphically demonstrate that hand chipping is not a viable alternative for reducing *P. longifolia* infestations in the field.

There was no statistical difference in any cotton harvest parameter between any of the chipping or hand pulling treatments and the control (Table 9.3). The lack of differences indicated that the growth of cotton was no better in treatments where *P. longifolia* had been chipped or hand pulled. There are several reasons why this may have occurred. The most obvious is that the reduction in shoot competition from chipping had little real effect on reducing competition between *P. longifolia* and cotton, at least with the intensity of complete defoliation every month for four months. Early season competition for water and possibly light may have had already occurred (Section 8.4), but it is more likely that vigorous below-ground competition continued despite chipping as the stimulation of regrowth of *P. longifolia* shoots clearly demonstrated.

Monthly chipping may well reduce the shoot density of this weed but sustained damage to the rhizomes is likely to be needed if *P. longifolia* is to be controlled. Herbicides are thought to achieve this more readily and for this reason, herbicide control options have been pursued in the remainder of this chapter and in the industry as a whole.

Table 9.3 A summary of cotton harvest parameters measured to determine the effect of chipping and hand pulling of *P. longifolia* on cotton growth. All data except total dry weight and density have been expressed on an individual cotton plant basis. Mean plant data highlighted any differences more clearly.

Location and Cotton harvest parameter	Unchipped control	Chipped every 1 month	Chipped every 2 months	Chipped every 3 months	Chipped initially	Hand pulled
Auscott						
Total cotton dry weight (g/m^2)	427.8	518.1	513.2	435.6	413.6	357.5
Cotton density ($plants/m^2$)	9.8	11.5	11.8	11.5	12.0	9.3
Mean stem height (cm)	46.6	47.1	45.4	45.6	41.7	44.9
Mean stem diameter (mm)	11.8	10.9	10.9	10.5	10.0	11.8
Boll number/plant	6.2	5.6	5.3	5.1	4.8	5.4
Lint and seeds dry weight (g/plant)	20.2	21.0	19.2	16.2	17.9	17.7
Lint yield (g/plant)	7.6	8.4	7.3	6.3	7.1	6.7
Seeds yield (g/plant)	12.6	12.6	11.9	9.9	10.8	11.0
Colly Farms						
Total cotton dry weight (g/m^2)	644.7	346.2	456.7	483.1	490.5	572.5
Cotton density ($plants/m^2$)	8.5	6.5	7.3	6.5	6.8	10.0
Mean stem height (cm)	79.9	76.7	77.6	80.8	71.2	71.4
Mean stem diameter (mm)	13.1	13.4	14.1	13.7	13.0	12.5
Boll number/plant	9.0	7.9	8.6	10.0	9.2	7.9
Lint and seeds dry weight (g/plant)	31.4	23.2	26.1	31.2	29.6	23.7
Lint yield (g/plant)	12.4	9.6	11.0	13.2	12.5	9.9
Seeds yield (g/plant)	19.0	13.6	15.1	18.0	17.1	13.8

9.3 The effect of glyphosate and fluroxypyr on *P. longifolia*

9.3.1 Aims

This aim of the experiment was to determine the effect of glyphosate and fluroxypyr on *P. longifolia* infestations. These two post-emergence herbicides represented two of the better herbicide options available for the treatment of *P. longifolia.*

9.3.2 Methods

This trial was conducted at Field 11 at the Midkin Farm of Auscott, Moree during the 1998/99 cotton growing season. A basic description of this farm and the management of Field 11 is given in Appendix 4.

The experiment was set around the perimeter of a well established patch of *P. longifolia* (approximately 40 m in diameter) to assist in determining the extent of rhizome death if translocation of fluroxypyr was observed, as had been previously suggested (Foreman 1994). There were four treatments in this trial - 2.5 L/ha of Roundup CT Xtra® (Trademark of Monsanto containing 450 g/L glyphosate active ingredient, a.i.), 2.5 L/ha of Starane® (Trademark of Dow AgroSciences containing 300 g/L fluroxypyr a.i.), 2.5 L/ha of distilled water (a cotton/*P. longifolia* control) and a treatment located outside the patch area (a cotton only control). These herbicide rates had previously achieved reasonable control in other research and were at the upper end of what would be used in the field. The three spray treatments were then allocated randomly to one metre x one metre infested plots within each of four blocks. All plots were marked permanently in the cotton plant line.

The initial density of *P. longifolia* shoots was assessed on 20 November 1998. Cultivation on 25 November slightly reduced the weed density in all plots. Plots were sprayed

between 1 and 2 p.m. on 27 November. The temperature and relative humidity were recorded using a pen-type thermo-hygrometer which was placed 10 cm above the soil surface (i.e. the level of the canopy of *P. longifolia*), with temperatures ranging between 17 - 36°C and relative humidity between 16 - 39% (with plant shading and slightly overcast conditions). The soil moisture level was high i.e. just below the plastic limit, the level of soil water below which cultivation can occur without soil damage (Hulme 1997).

A shielded spray unit in the shape of a square pyramid with a basal area of 0.25 square metres was placed over the area to be sprayed. The square pyramid had plastic covering all sides (except the bottom) to prevent spray drift. The unit had an open top through which herbicide was applied using a 500 mL hand-held plastic spray bottle calibrated to deliver 5 mL per 0.25 square metre area. The shielded spray unit was then moved to the next 0.25 square metre area of the plot until the whole one square metre had been sprayed with a total of 20 mL (200 L/ha) of water or herbicide solution. Cotton plants, which were at the two to six leaf stage, were not included in the quadrat.

The density of live *P. longifolia* stems was counted on 17 December 1998 and 18 January 1999 which were 20 and 52 days after spraying. The density and dry weight of both *P. longifolia* and cotton were measured on 24 March 1999, 117 days after herbicide application, at harvest. In addition, the cotton stem diameter at ground level and height of the stem to the base of the petiole of the youngest opened leaf of each plant were measured to the nearest millimetre. Following dry weight assessment of the cotton plant, all bolls were removed and counted with the cotton lint and seeds being removed by hand. The statistical treatment of the data has been outlined previously (Section 9.2.2).

9.3.3 Results and discussion

The application of fluroxypyr resulted in a decrease in *P. longifolia* shoot density over that found in control plots throughout the experiment while the application of glyphosate resulted in a significant decrease at day 52 and at harvest only (Figure 9.2). There was no difference in the reduction in shoot density between fluroxypyr and glyphosate at day 52 or at harvest.

This experiment was originally conducted to determine the effect that these two herbicides have on shoot and rhizome tissues of *P. longifolia*. This particular aim was abandoned when there was active shoot recruitment of *P. longifolia* after promising early results indicating shoot death. For example, the application of fluroxypyr resulted in the yellowing of approximately half the *P. longifolia* stems with some foliage loss and death for another 15% of stems at day 20. The application of glyphosate resulted in the yellowing of approximately 75% of all stems at day 20. The application of irrigation water on 14 December and again on 11 January resulted in rapid emergence of new shoots so much so that there was very little evidence of previous plant death, yellowing or even stunting at day 52. There was no evidence of shoot death and therefore herbicide translocation outside these plot areas.

The dry weight of *P. longifolia* in the control plots at harvest was almost twice that in the herbicide treatments (Table 9.4), but there was no difference between the two herbicide treatments. There was some damage to cotton plants observed in the fluroxypyr treatments, resulting from the plants either being accidentally brushed with the spray equipment or sprayed weed foliage, which resulted in a reduction in cotton plant density at harvest. In all cases, there was no difference in cotton growth between herbicide treated and control plots within the weed patch (Table 9.4). There was, however, a 48% reduction in

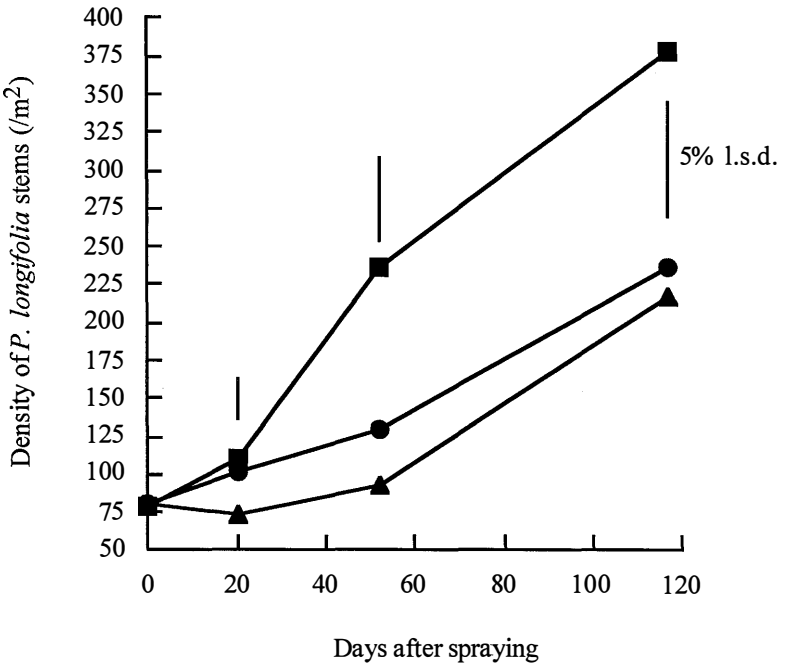


Figure 9.2 The change in *P. longifolia* density after spraying with fluroxypyr (▲), glyphosate (●) and water (■) treatment. Vertical lines are the 5% l.s.d.

Table 9.4 The effects of fluroxypyr and glyphosate on *P. longifolia* and cotton growth at harvest.

Parameter	Water control	Fluroxypyr	Glyphosate	Control outside patch	5% l.s.d.*
P. longifolia density (stems/m^2)	377.5^b	217.5^a	236.5^a	-	69.9
P. longifolia shoot dry weight (g/m^2)	300.6^b	161.5^a	162.4^a	-	97.9
Cotton density (plants/m^2)	10^{ab}	9^a	12^b	12.3^b	2.6
Total cotton dry weight (g/m^2)	492.8^a	447.0^a	599.5^a	947.9^b	280.0
Total boll number/m^2	62.8^a	62.5^a	57.8^a	109.8^b	31.5
Total cotton yield (lint+seeds) (g/m^2)	185.6^a	171.9^a	184.6^a	294.5^b	78.9

* Means within a parameter marked with the same letter are not significantly different (P > 0.05).

total dry weight of cotton in the patch (controls) compared with outside the patch, a 43% reduction in boll number, and a 37% reduction in cotton lint and seeds yield.

These results indicate that while the application of fluroxypyr and glyphosate to *P. longifolia* shoots reduced shoot density and dry weight, a corresponding increase in cotton growth and yield over untreated plots was not achieved. Again, it is highly likely that the herbicide-induced reduction in stem density did not reduce below-ground competition of *P. longifolia* as shoot regrowth showed. Unreplicated excavations of several vertical shoot bearing rhizomes showed that herbicide translocation was limited at most to the top ten centimetres of the soil profile, and reshooting from the next lowest undamaged node occurred (Section 2.4.6, Plate 2.2).

The reasons for spray failure for *P. longifolia* are poorly understood. Anecdotal evidence suggests that if *P. longifolia* is water stressed then translocation of herbicide may not occur. This trial was sprayed when soil moisture levels were high and rainfall throughout the trial was either average or slightly above average. For example, the rainfall for the four month trial period (December - March) at Ashley, approximately ten kilometres away, was 377 mm, little different from the 337 mm average for the same period in the previous four seasons (Bureau of Meteorology 1999). The cotton crop was also irrigated throughout the period of the trial. The effects that high soil water levels have on the regrowth of *P. longifolia* has not been examined although rapid emergence after irrigation is common. There appears to have been little translocation of herbicide in this trial. The reasons why spray failure often occurs in this species still requires research attention.

9.4 The commercial application of a glyphosate and dicamba mixture on light *P. longifolia* infestations

9.4.1 Aims

This experiment was conducted to examine the effect of a glyphosate and dicamba mixture on *P. longifolia* density and cotton growth.

9.4.2 Methods

This trial was evaluated on Field 48 at the Top Box Farm of Auscott, Moree during the 1997/98 cotton growing season. A basic description of this farm and the management of Field 48 is given in Appendix 4.

The trial was conducted by farm staff on small *P. longifolia* patches which ranged upwards in size to three metres in diameter and had an initial stem density of 30 - 76 stems per square metre, (mean 56, n = 6). Six replicate quadrats 0.5 metres x one metre were permanently marked across a cotton hill and furrow with one quadrat in each patch. There were no comparisons made with unsprayed *P. longifolia* patches due to the commercial nature of this trial. Stems were counted and the phenological state of each stem recorded along with the total number of flowers and seeds present in each quadrat at each time of sampling. Stems noted as being 'reproductive' may have had buds and/or flowers present on them but there was no production of seeds observed during the experiment.

A mixture of 2 L/ha of glyphosate with 1 L/ha dicamba and 0.2 L/ha (all trade product rates) of a wetting chemical (the identity of which was not known) was spot sprayed using a shielded spray unit on 14 November 1997, early in the growth cycle of cotton. The herbicide mixture was used as earlier unreplicated trial work by farm staff had indicated

promising control of *P. longifolia*. Within a week of spraying, the site was cultivated which defoliated the spray-damaged stems of *P. longifolia* in the furrow. Very few *P. longifolia* stems were observed in the furrows throughout the experiment after this. The herbicide mix used resulted in a browning and reddening of the stem tissues and eventual death of *P. longifolia* shoots. All reproductive growth on the stems was shed before stem death occurred approximately three weeks later. Some new *P. longifolia* stems did emerge throughout the experiment.

Live *P. longifolia* shoots were counted on 2 and 17 December 1997, 20 January and 5 February 1998 (18, 33, 67 and 83 days after spraying respectively). Plants were harvested on 12 March 1998 (118 days after spraying). The production of cotton inside the six *P. longifolia* patch quadrats was compared with cotton in similar 0.5 square metre paired plots at least three metres outside the patch area.

The density and dry weight of both *P. longifolia* and cotton were assessed, with all cotton bolls then removed and counted. The stem diameter at ground level and mean height of the stem to the base of the petiole of the youngest opened leaf of each cotton plant was measured to the closest millimetre. The cotton lint and seeds were removed by hand and ginned using a 20 saw gin at the ACRI, Narrabri, after which each component was weighed. A sub-sample of 100 ginned seeds was also weighed for each sample collected. The statistical treatment of the data has previously been outlined (Section 9.2.2).

9.4.3 Results and discussion

The application of the glyphosate/dicamba mixture (both post-emergent herbicides) resulted in a large reduction in the stem density of *P. longifolia* (Figure 9.3) which did not recover to initial levels for the remainder of the experiment. It was assumed that the density of

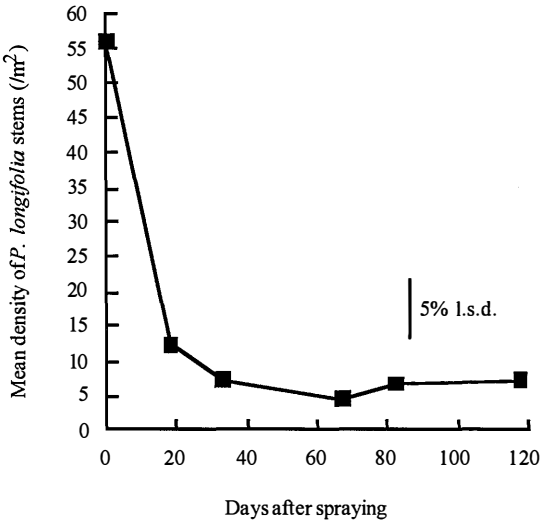


Figure 9.3 The change in *P. longifolia* density after spraying with a mixture of glyphosate and dicamba on 14 November 1997.

P. longifolia stems would have increased throughout the season in the absence of herbicide damage (Figure 5.1) although no such control treatment was included in this trial.

Reproductive stems comprised 48% of the total stem number at the initial observation date with an average of 2.3 open flowers per square metre. Most of these stems only had buds on them. The application of the herbicide mixture stopped all reproductive growth with only one exception, at day 82 (5 February 1998) when 15% of stems were reproductive and 0.7 flowers per square metre were present.

Cotton growth was generally far greater outside *P. longifolia* patch areas than inside the patch area, but the results for inside the patch area were confounded by spraying (Table 9.5). This was true for total cotton dry weight, boll number, lint and seeds yield and lint yield but on the borderline of being significantly different for seeds yield and 100 seed weight. The height of cotton plants was far greater outside the patch than inside but the diameter of stems was similar.

Table 9.5 The effect of the application of a mixture of glyphosate and dicamba on infestations of *P. longifolia* in cotton.

Cotton harvest parameter	Cotton inside patch Sprayed	Cotton outside patch Unsprayed/uninfested	5% l.s.d.*
Cotton density (plants/m^2)	15.0[a]	12.7[a]	6.3
Total cotton dry weight (g/m^2)	616.1[a]	887.1[b]	230.7
Total boll number/m^2	56.3[a]	83.3[b]	23.4
Total cotton yield (lint+seeds) (g/m^2)	226.5[a]	345.1[b]	116.4
Total lint yield (g/m^2)	89.6[a]	139.8[b]	46.6
Total seeds yield (g/m^2)	136.9[a]	205.4[a]	70.0
100 seed weight (g)	10.5[a]	10.1[a]	0.5
Mean stem height (cm)	49.6[a]	68.9[b]	10.4
Mean stem diameter (mm)	9.4[a]	10.6[a]	2.3

* Means within a parameter marked with the same letter are not significantly different (P > 0.05).

These results indicate that the glyphosate/dicamba mixture resulted in a severe and season-long reduction in *P. longifolia* shoot numbers but that this was insufficient to increase the growth of cotton to levels similar to that of uninfested cotton. There are two points which need to be considered when interpreting these results. Firstly, interference between *P. longifolia* and cotton would probably have occurred in the sprayed patch areas despite shoot death as live rhizome material was present, as indicated by some shoot recruitment. The other point to consider was that spray damage may have compounded the cotton growth reduction in the *P. longifolia* patches. Although the herbicide mixture was applied through shielded spot spray units, some spray damage to cotton foliage was observed at the early December observation. This indicated that while relatively successful herbicide mixes do exist for the treatment of *P. longifolia*, they must be applied with great care in-crop if yield reduction, via spray damage, is to be avoided. Unfortunately, due to the commercial nature of this trial, an unsprayed weed patch treatment which would have isolated the effects of *P. longifolia* interference and spray damage on cotton growth was not included in the experimental design.

McMillan (1988a) noted that the application of glyphosate on *P. longifolia* was moderately effective while the application of dicamba was ineffective (Table 2.2). This followed from work which showed a 60% reduction in *P. longifolia* could be expected from the application of glyphosate at 2 L/ha (trade product rate) with 73 - 80% reductions once the application rate was increased to between 4 and 8 L/ha (Scarsbrick *et al.* 1979). However, the variable success of glyphosate applications was illustrated when a 2 L/ha application resulted in only a 46% kill in another trial (Strachan 1983). The application of dicamba at 1.4 L/ha resulted in only an 11% kill of *P. longifolia* shoots in the same trial (Strachan 1983).

Strachan (1983) showed that combinations of two different herbicides were often more effective in killing the shoots of *P. longifolia* than when either herbicide was used by itself. For example, a glyphosate/2,4-D ester mixture resulted in a 99% kill of *P. longifolia* when compared with the 46% resulting from glyphosate alone. A dicamba/2,4-D amine mixture resulted in a 96% kill of *P. longifolia*, an 85% improvement over when dicamba was used alone. However, 2,4-D ester or amine alone gave a 98 - 100% kill of *P. longifolia* shoots. Further work is required to determine if the herbicide mixture used in this section was indeed synergistic in its effects, killing a greater proportion of *P. longifolia* than when either herbicide was applied alone.

This experiment also used a wetting agent to improve herbicide contact with the naturally hairy *P. longifolia* leaves. There is anecdotal evidence that wetting agents may improve spray success with *P. longifolia* (S. Kable, pers. comm.) but no trial work comparing their effects is known to the author. This interesting avenue of research may provide increased penetration for herbicides or herbicide mixtures that are effective against *P. longifolia*.

9.5 What is the impact of the residual herbicide imazapyr on *P. longifolia*?

9.5.1 Aims

This experiment was conducted to observe the effect of imazapyr, a long-term residual herbicide, applied in fallow on *P. longifolia* and the resultant effect on cotton growth in the subsequent cotton growing season.

9.5.2 Methods

The trial was conducted by farm staff on Field 27 at the Central Farm of Colly Farms, Collarenebri during the 1997/98 cotton growing season. A basic description of this farm and the management of Field 27 is provided in Appendix 4.

Harvest of the 1996/97 cotton crop on Field 27 occurred on 11 April 1997. On 30 April, 10.5 hectares of the field covered with dense infestations of *P. longifolia* was spot sprayed with 2 L/ha of Arsenal® (registered trademark of Cyanamid Agriculture, 250 g/L imazapyr active ingredient) using an eight row boom. The *P. longifolia* patches treated were approximately 3 - 100 metres in diameter while the density ranged up to 250 stems per square metre.

There were three treatments in this experiment: an imazapyr sprayed *P. longifolia* patch, a non-treated less dense *P. longifolia* patch and a cotton only area which was approximately 100 metres from either patch site. For each treatment there were six replicate 0.5 metre x one metre quadrats located across a cotton hill and furrow. Stem counts and the phenological state of each stem were assessed with counts made on the total number of open flowers and seeds present in each 0.5 square metre quadrat at each time of sampling. Reproductive stems may have had buds, flowers and seeds present on them.

Cotton was planted on 18 October 1997. The initial density of *P. longifolia* shoots and cotton plants within the plots was assessed 17 days later on 4 November 1997. Further observations were made on 26 November 1997, 12 January and 18 February 1998, (39, 86 and 123 days after planting). The trial was harvested on 17 March (150 days after planting).

At harvest, *P. longifolia* and cotton parameters were assessed as per the previous experiment (Section 9.4.2). The statistical treatment of the data have also been previously outlined (Section 9.2.2).

9.5.3 Results and discussion

At the first sampling time (17 days after cotton planting) the number of *P. longifolia* stems in the imazapyr sprayed area was less than that in the unsprayed patch area (Figure 9.4a). The latter number increased steadily while numbers in sprayed plots remained low up to day 86. Between day 86 and day 123, however, the total stem number in the imazapyr sprayed area increased dramatically, overtopping the stem density in the unsprayed area. It appears that the residual effects of the herbicide may have dissipated by this time and that the weed responded to earlier herbicide damage by both profuse resprouting on spray damaged plants and with rapid stem emergence as had occurred with *P. longifolia* that had been defoliated through chipping (Figure 9.1, Plate 9.1).

A similar trend to that observed for the total stem number was observed in the number of vegetative (Figure 9.4b) and reproductive stems (Figure 9.4c). The exception to this was the peak and subsequent decrease in the number of reproductive stems in the unsprayed area (Figure 9.4c). A similar peak and subsequent decrease in the number of reproductive stems was observed in another experiment conducted in the same season but on a different

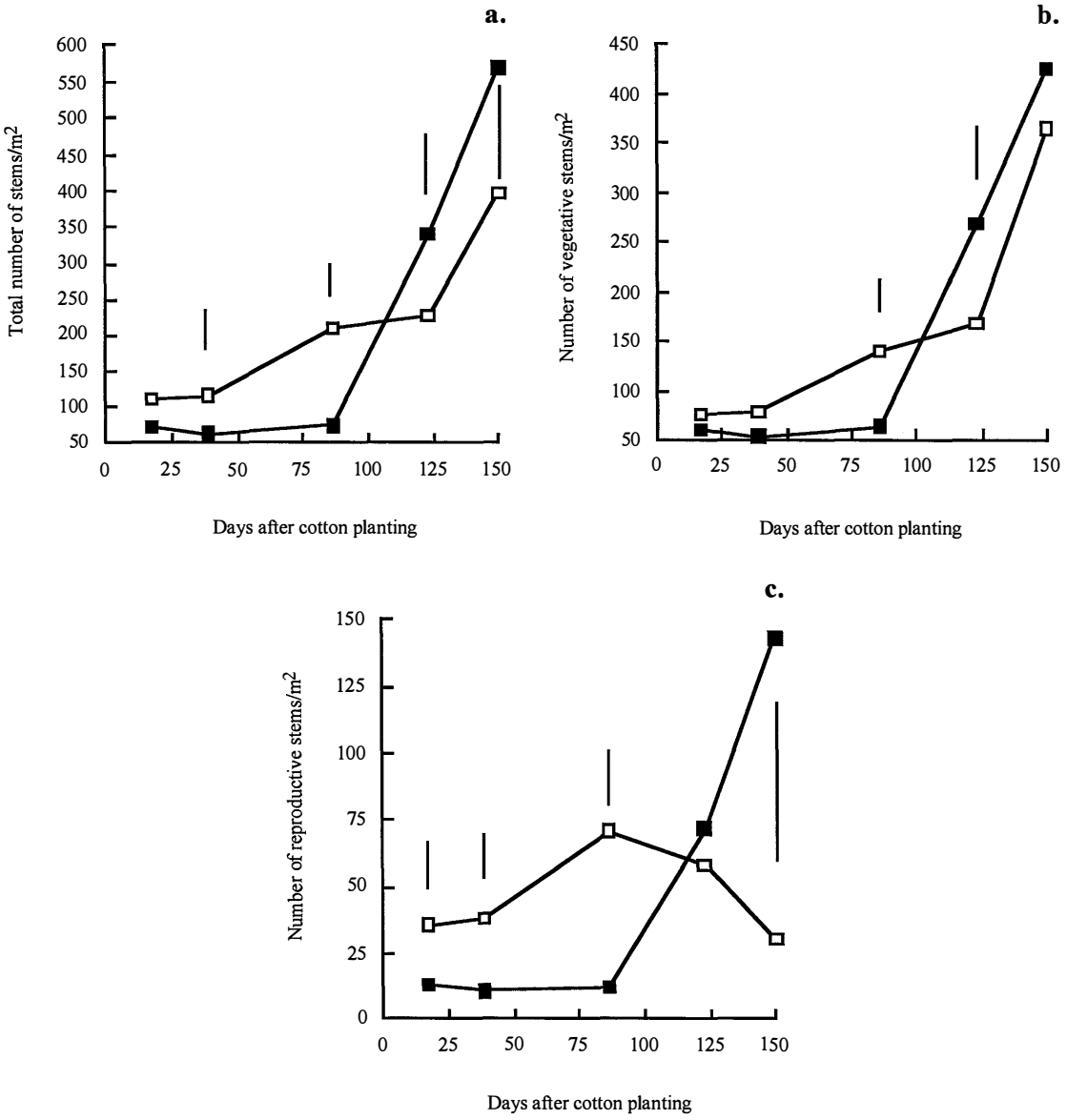


Figure 9.4 *P. longifolia* shoot density after herbicide application with imazapyr (■) or where patches were left unsprayed (□). The vertical bars indicate the 5% l.s.d. Times with no bar were not significantly different.

field (Figures 5.5.1c and d). This peak then decrease may be a result of the weather conditions during this season although data were not obtained to examine this. The total production of flowers and seeds was higher initially in the unsprayed areas than the imazapyr sprayed areas but this trend was also reversed later in the season (Figure 9.5).

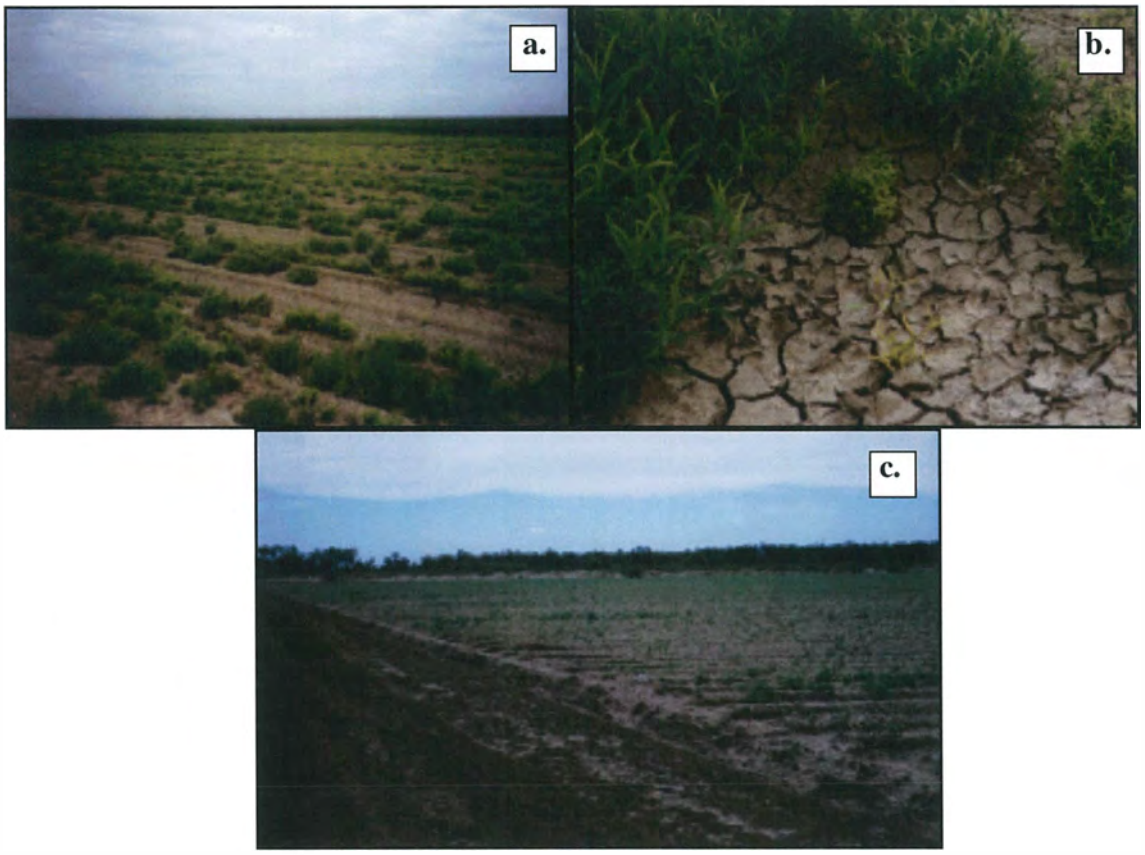


Plate 9.1 The action of imazapyr on a *P. longifolia* patch (9.1a). Plants which were lighter green were severely distorted such as those pictured in the centre of 9.1b while others grew normal foliage (the surrounding plants in 9.1b). Plate 9.1c illustrates the non random distribution of *P. longifolia* patches on Field 48 at Auscott, Moree every 12 - 15 rows along the head ditch end of the field. Patches further away from the head ditch were used in Section 9.4.

The density of *P. longifolia* at harvest was significantly greater in the imazapyr sprayed plots than the unsprayed plots (Figure 9.4a, Table 9.6). In comparison, the total dry weight was not significantly different. While initial seedling density of cotton plants was uniform across the three treatments, cotton plant establishment and subsequent growth were severely reduced by imazapyr application (Table 9.6). Stunting of sprayed cotton plants was evident 17 days after planting and death occurred rapidly until day 86 when nearly all cotton plants within the sprayed areas were dead. The total dry weight, height and stem diameter of cotton plants were all reduced by the imazapyr spray (Table 9.6). No

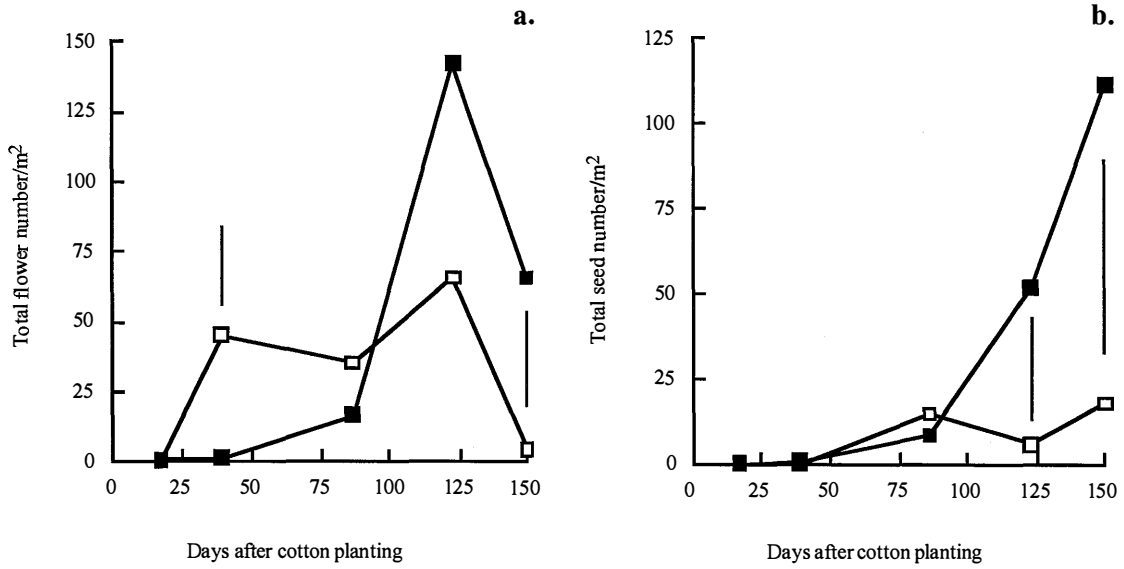


Figure 9.5 Total flower (9.5a) and seeds number (9.5b) in *P. longifolia* patches which had been either sprayed with imazapyr (■) or were unsprayed (□). The vertical bars represent the 5% l.s.d. Times with no bar were not different.

cotton reached reproductive maturity in the sprayed patches and hence no data for these parameters are included.

Interspecific competition again reduced the growth of cotton inside *P. longifolia* patches compared with weed-free areas, although this was again confounded by spraying (Table 9.6). Total dry weight was reduced by 68%, total boll number by 61% and total lint and seeds yield by 59%. The only exception was the similarity in 100 seed weights which suggested that cotton seed weight was strongly preserved here in contrast to Chapter 7.

It was hoped that the application of imazapyr, which has strong residual action, would eliminate the *P. longifolia* problem even though affected areas would have to be sacrificed to cotton production for at least the following season. After early significant damage and

Table 9.6 The effect of application of imazapyr on infestations of *P. longifolia* and on cotton growth at cotton harvest.

Harvest parameter	Sprayed patch	Non sprayed patch	Outside patch	5% l.s.d. *
Cotton density (plants/m^2)	2.3^a	13.7^b	14.0^b	3.2
P. longifolia density (stems/m^2)	568.7^b	395.0^a	-	123.1
Total cotton dry weight (g/m^2)	2.5^a	484.3^b	1504.1^c	264.0
Total *P. longifolia* dry weight (g/m^2)	399.2^a	463.1^a	-	147.1
Total boll number/m^2	0	57.3^a	147.3^b	37.2
Total cotton yield (lint+seeds) (g/m^2)	0	239.3^a	576.3^b	182.4
Total lint yield (g/m^2)	0	98.2^a	225.7^b	70.7
Total seeds yield (g/m^2)	0	141.1^a	350.5^b	111.9
100 seed weight (g)	0	19.8^a	21.0^a	1.3
Mean stem height (cm)	8.2^a	57.4^b	118.1^c	9.2
Mean stem diameter (mm)	1.9^a	8.5^b	12.8^c	2.1

* Means within a parameter marked with the same letter are not significantly different ($P < 0.05$).

severe fasciation to the *P. longifolia* shoots, the damaged plants were able to produce large numbers of stems with normal foliage, flowers and seeds.

Imazapyr is commonly used in off-field areas as a soil sterilant which usually acts over several years. This experiment indicated that even this potent herbicide was unable to reduce *P. longifolia* density permanently, or for as little time as an entire season. Given the experience with this residual herbicide, the use of other strongly residual herbicides to control *P. longifolia* should be treated with caution.

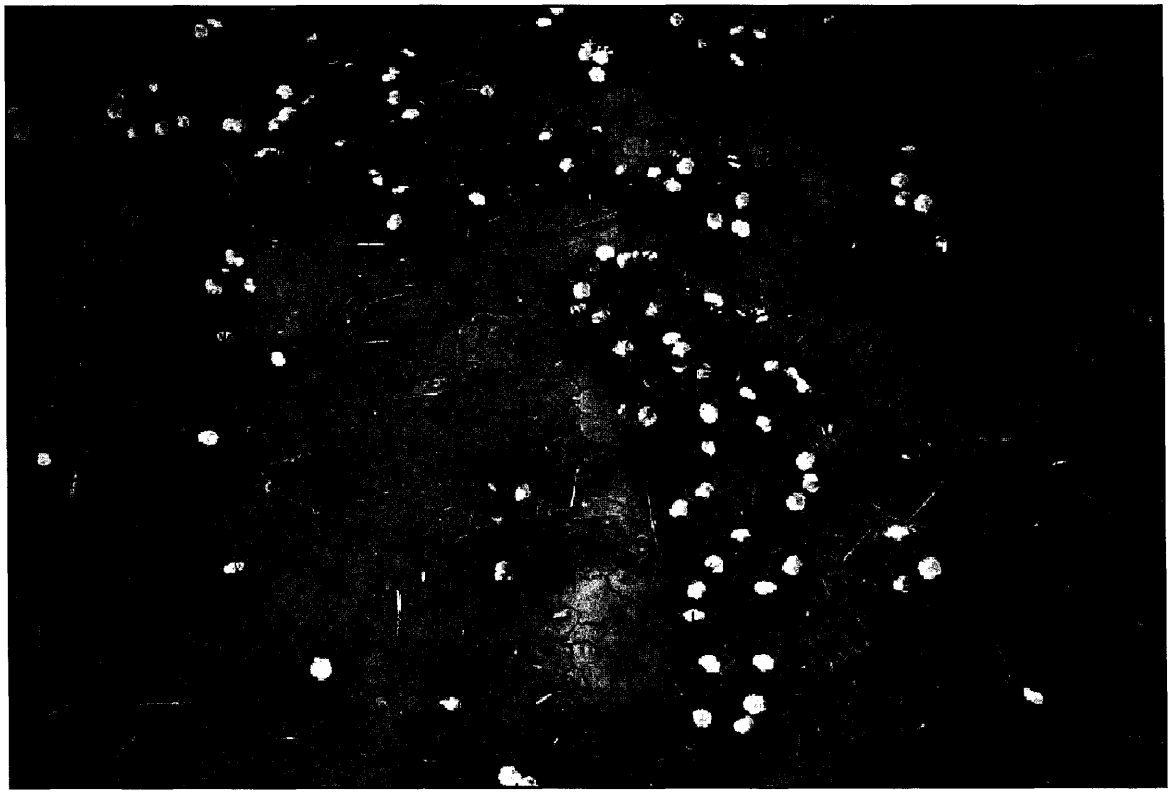
9.6 Conclusions

Any attempt to reduce *P. longifolia* by minimally disruptive defoliation such as by hand chipping, results in stimulation of weed regrowth without an improvement in cotton yield.

While herbicides offered a better solution in that the opportunity for damage to more of the below-ground biomass via translocation may have occurred, season-long control was not achieved, with regrowth occurring in as little time as the next irrigation or rainfall event. One of the major limitations with current research on this and other hard-to-control species is that the mechanisms by which these control measures act on the plant are not well understood.

However, these experiments went a small way in suggesting why control measures against *P. longifolia* do fail. The absence of tissue death either laterally or with depth suggested that herbicide translocation was simply not occurring. Shoot recruitment from the next undamaged node along the rhizome is then possible. The regenerative potential of these rhizomes i.e. the number of times they can be defoliated before they die is not known and such knowledge may be desirable given that intensive defoliation has resulted in the control of other perennial species. Other factors such as cost, herbicide run-off and soil structure concerns would need to be considered if chemical or mechanical control was implemented in this fashion.

Other areas of research which may yield better control of *P. longifolia* could be an investigation into the action of herbicides on shoot initiation and rhizome growth and research into the factors that affect herbicide translocation. Unfortunately, these physiological studies were outside the scope of this thesis. In addition, the long term action of any herbicide or mixture used on *P. longifolia* needs to be investigated over more than one application in one season to obtain reliable results for long term control.



What are the factors that promote the growth of *Polymeria longifolia* ?

Chapter 10

Factors promoting the growth of *Polymeria longifolia* in cotton

Polymeria longifolia is "uncommon except in seasons of abundant summer rainfall" and "has been reported on several occasions as being a weed of cultivation land" (Cunningham *et al.* 1981).

10.1 Introduction

The cultural and environmental factors responsible for the persistence of *Polymeria longifolia* in cotton production systems are not clear. Information derived from the survey (Chapter 3) indicated that three factors intrinsic to most cotton production systems favoured *P. longifolia.* These were irrigated production, conventional cultivation and heavy clay soils. Two of these factors, irrigation and cultivation, with an additional factor, nitrogen application, are examined in this chapter to determine their effect on *P. longifolia* growth. In doing so, an understanding may be gained as to why a native plant like *P. longifolia* has become a weed of cotton farming systems.

10.2 Aims

These experiments evaluated the effect of water, nitrogen application and defoliation on the shoot and rhizome growth of transplanted *P. longifolia* plants in the glasshouse (Section 10.3.1) and in the field (Section 10.3.2).

10.3 Methods

10.3.1 Glasshouse investigation

This trial was conducted in a glasshouse at the University of New England, Armidale, maintained between 15 - 25°C. Twenty-centimetre diameter black plastic pots were filled to within two centimetres of the top with a mixture of sand, loam and peat (3:2:1, by volume).

Fragments were exhumed on 19 November 1998 from actively growing *P. longifolia* plants growing on the edge of a 40 metre diameter patch located in Field 11 at the Midkin Farm, Auscott, Moree. All fragment material was selected for uniformity of stem and rhizome diameter, node number and shoot height. These fragments were stored in damp cloth at room temperature (20 - 25°C) until planting on 21 November. Loose soil was shaken off the fragments before they were trimmed to size so that the shoot and rhizome length were each 15 cm (the total fragment length was 30 cm). This fragment size was chosen because it gave the best regeneration in the trial conducted in Chapter 6 (Tables 6.2 and 6.6). Rhizomes were buried horizontally to a depth of 7.5 cm with the shoots placed vertically in the media.

The average dry weight of the 15-cm shoot and rhizome fragments was 0.61 ± 0.06 grams (mean ± s.e.m., n = 30, range 0.09 - 1.22 grams). Although uniformity in fragment size was selected on collection, any further variation in fragment size was accounted for by planting each replicate with similarly sized fragments and each pot with three fragments. There were five pot replicates per treatment.

The pots were watered daily to maintain the soil close to field capacity during the initial establishment period of 17 days. All eight treatments were imposed on day 17. These treatments included the application of water, nitrogen and defoliation each applied at one of two levels. Water was applied every three or seven days while for nitrogen there was a once only application of either 10 kilograms per hectare or 100 kilograms per hectare (pot surface area equivalent) of urea (46% nitrogen) sprinkled over this area. Defoliation was applied once using a pair of secateurs at two centimetres below the soil surface or not at all. The treatments were imposed in a 2 x 2 x 2 factorial design, illustrated in Table 10.1. The treatment combination without defoliation and having the lower levels of water and nitrogen was used as a control.

Plants were harvested 102 days after planting on 3 March 1999. At harvest, the total numbers of shoots present were counted prior to washing of media away from the plants and the counting of unemerged shoots. Since there were very few unemerged shoots, only the total shoot number was recorded. Total length and number of nodes of all rhizome fragments were determined. Separate shoot and rhizome/root dry weights were calculated after drying at 75°C for 48 hours. All excised shoots from the defoliation treatment were dried and weighed. There was no statistical difference between treatments in shoot dry weights.

Table 10.1 The treatment combinations imposed in the 2 x 2 x 2 factorial glasshouse experiment to determine the effect of water, nitrogen and defoliation on the growth of transplanted *P. longifolia*.

	Treatment levels							
Water	W+[a]				W-			
Nitrogen	N+		N-		N+		N-	
Defoliation	D+	D-	D+	D-	D+	D-	D+	D-
Treatment	W+N+D+	W+N+D-	W+N-D+	W+N-D-	W-N+D+	W-N+D-	W-N-D+	W-N-D-

[a] High levels of water, nitrogen and defoliation are represented by a + sign and low levels, or no defoliation, represented by a - sign.

10.3.2 Field investigation

This trial was conducted on a large population of *P. longifolia* approximately 150 square metres in total area adjacent to Field 48 at the Top Box Farm of Auscott, Moree during 1998 and 1999. A description of Top Box Farm is given in Appendix 4. The experimental area had never been cultivated. It supported a number of native and introduced grasses, e.g. *Panicum* and *Chloris* species with *Acacia farnesiana* (mimosa bush) interspersed throughout the patch area (Plate 10.1). The experimental area was near, but distinct from, that outlined in Section 5.7.

In total, 32 quadrats each two metres x two metres were chosen on the basis of uniform *P. longifolia* stem number and marked with wooden pegs. These four metre square quadrats were assigned to four blocks based on the locality of individual areas to one another and changes in relief down a very slight slope of approximately 1°. This blocking accounted for some variation in the density of *P. longifolia* stems across the patch area. In the centre of

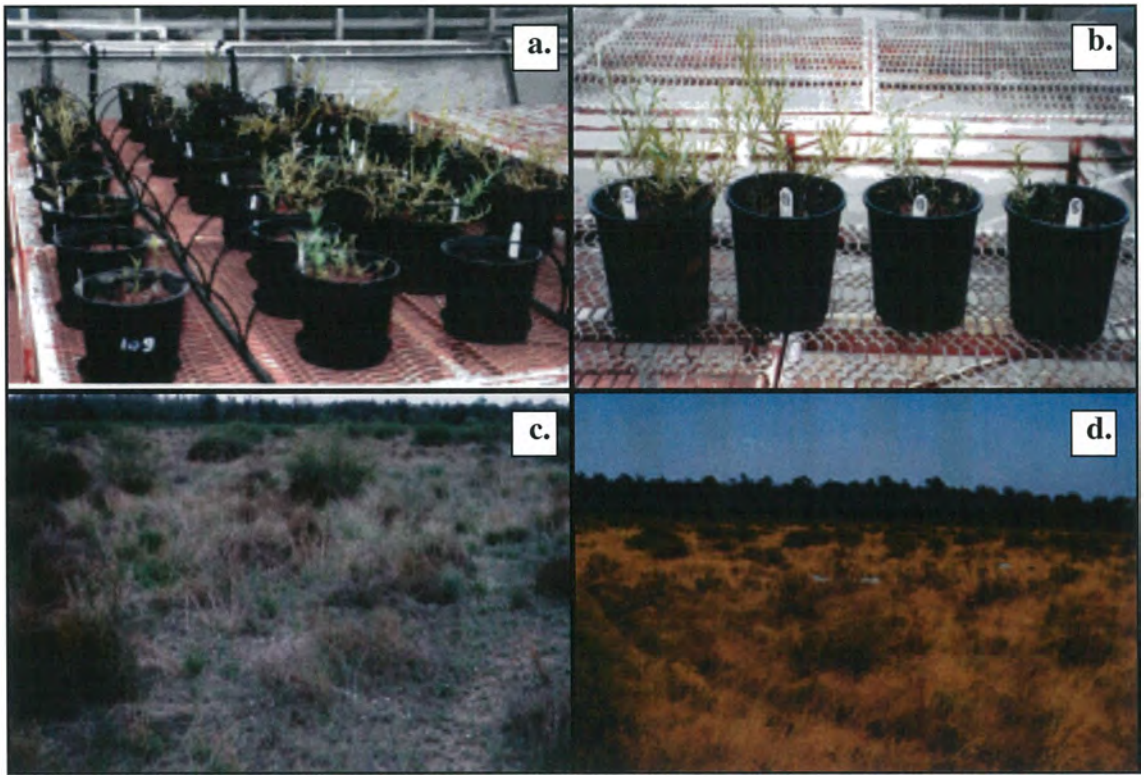


Plate 10.1 An investigation into the factors which promote the growth of *P. longifolia.* The glasshouse trial outlined in Section 10.3.1 has been illustrated in 10.1a (with the watering system) and undefoliated pots in block 1 in 10.1b. The treatments illustrated are (L to R) W+N+, W+N-, W-N+, W-N- with a distinct difference in shoot growth between W+ and W- treatments observed. The field site is illustrated in 10.3c (late 1997 before commencement of the trial) and 10.3d at harvest in April 1999.

each four metre square quadrat another plot of one metre x one metre was marked with wooden pegs. While treatments were applied to the whole four metre square area, all measurements were made on this one metre square plot throughout the experiment and at harvest. The four metre square quadrat areas were selected to be as monospecific for *P. longifolia* as possible. The treatment area outside the one metre square plot but inside the four metre square quadrat area served as a buffer zone from the untreated outside population. Each four metre square area was separated from all others by at least one metre, but often more. A small amount of grass (*Chloris* and *Panicum* species) was removed at the start of the experiment in some plots.

Eight treatments were imposed across each block. These treatments were plus or minus the application of water, nitrogen and cultivation in a 2 x 2 x 2 factorial randomised complete block design. The application time for treatments was as close as possible to the time the corresponding event would have occurred on the cotton field (Table 10.2). The effect the treatments had on the density of *P. longifolia* was assessed at each sampling date. Because each treatment was applied at a different date, cultivation was the only factor affecting *P. longifolia* density until 238 DAIO (days after initial observation), and after this cultivation and fertiliser until 304 DAIO. After 304 DAIO, the interaction of all treatments on *P. longifolia* density could be determined (Table 10.2).

Cultivation was to a depth of between 10 and 15 cm using a mattock at 74 and 238 DAIO. A faster means of cultivation was deemed necessary after this and so a rotary hoe was used to cultivate the plots at 276 and 304 DAIO. The soil was levelled using a spade after each cultivation event. These shallow cultivation events aimed to simulate the shallow, reduced tillage operations commonly employed in-crop. No cultivation was performed after December as this was when inter-row cultivation was usually stopped in the field.

The nitrogen treatment involved two applications of urea (46% nitrogen), broadcast on the soil surface without incorporation, after cultivation and watering - 100 kg N/ha in October and 50 kg N/ha in December 1998, 238 and 304 DAIO, respectively. Urea is either incorporated into the soil or applied in the irrigation water in cotton fields but because neither method was suitable for all treatments where nitrogen had to be applied the decision to broadcast the nitrogen was made. Irrigation water was applied at a rate of 100 litres per four metre square area poured gradually over the entire area so that there was no surface run-off. Rainfall delayed the need to water the plots until December instead of a common September/October pre-irrigation before cotton planting. Rainfall removed the need for a final irrigation in March.

Table 10.2 The dates at which observations were made and treatments applied to the uncultivated *P. longifolia* field population.

Date of treatment	Days after initial observation (DAIO)	Treatment performed
14 February 1998	0	Initial observation
29 April 1998	74	Cultivation
1 June 1998	107	Observation only
10 October 1998	238	Cultivation, Fertiliser
17 November 1998	276	Cultivation
15 December 1998	304	Cultivation, Water, Fertiliser
11 January 1999	331	Water
8 February 1999	359	Water
8 March 1999	387	Observation only
19 April 1999	429	Harvest

The initial density of *P. longifolia* stems was determined on 14 February 1998 (Plate 10.2). The density of all one square metre plots was assessed at each date after this (Table 10.2). Due to an extremely wet winter, the cultivation and fertiliser applications that would have normally occurred in either July or August were not possible. The first time that access could be gained to the area was in October, when the soil was cultivated and fertiliser applied, and which corresponded to the time that cotton was commonly planted. Shoots were harvested at ground level on 19 April 1999. Dry weights were determined as per Section 10.3.1.

In an effort to ascertain the effect of the treatments on rhizome growth an area 19 cm x 38 cm (7.2% of the surface area of each plot) was excavated by spade to a depth of ten centimetres. Deeper excavations were not possible due to the dryness of the soil. The percentage of surface area excavated was related to the dimensions on the spade. These soil

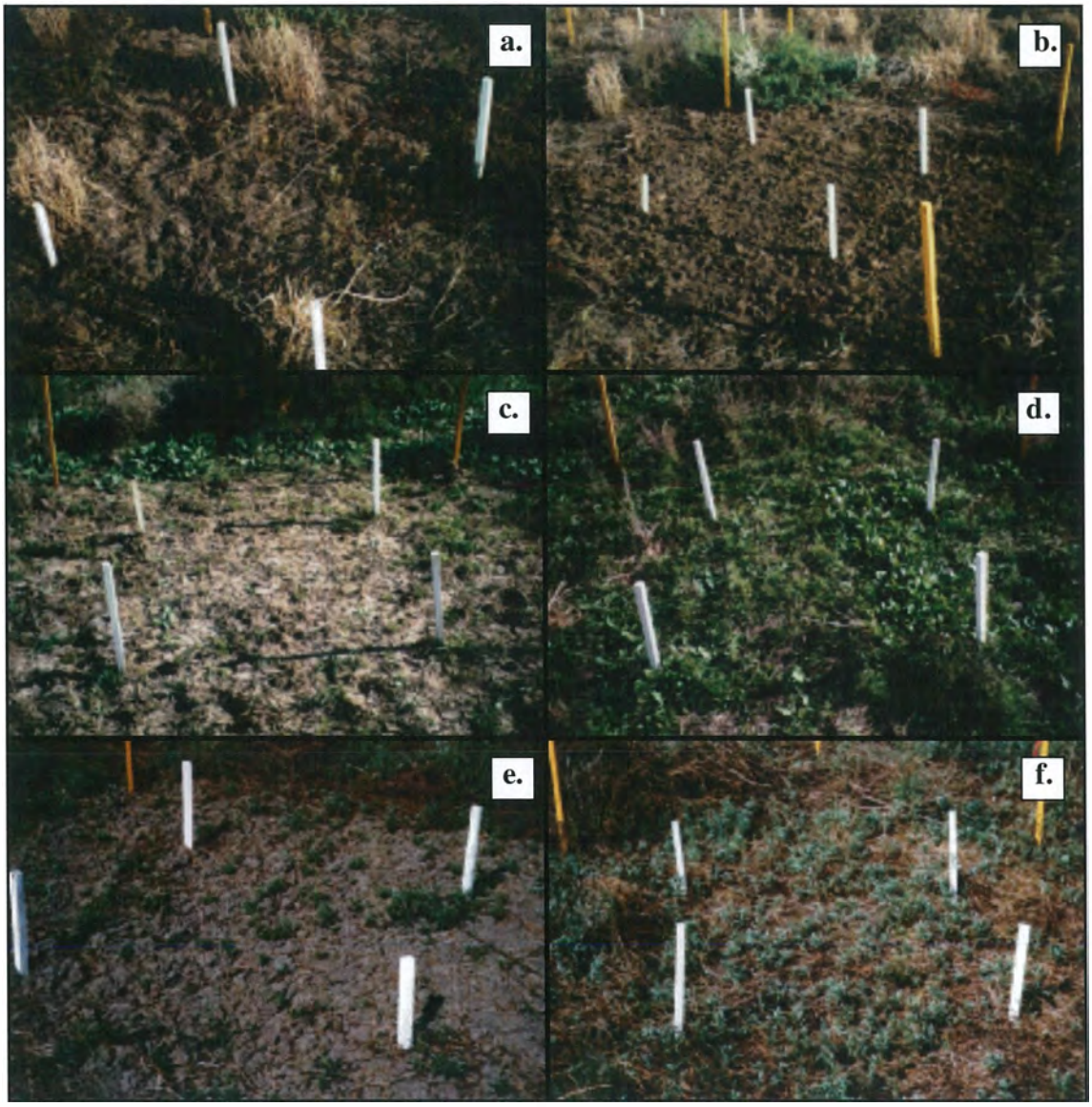


Plate 10.2 The field trial conducted to determine factors which promote *P. longifolia* growth. Plate 10.2a illustrates *P. longifolia* at the start of the experiment under drought conditions in February 1998 (0 DAIO) and after cultivation (10.2b). A comparison of the effects of cultivation on *P. longifolia* growth can be observed in the remainder of the plates, in June (107 DAIO) and November (276 DAIO) 1998 in cultivated (10.2c and e) and uncultivated plots (10.2d and f).

samples were brought back to UNE where they were soaked in water before all rhizome and root material was carefully washed from the soil. The total length, node number and dry weight of rhizomes were determined with the lengths determined by hand.

10.3.3 Statistical analyses

The data were analysed statistically using an analysis of variance with S-Plus 4.5 (S-Plus 1997). Both experiments were originally designed as completely randomised block designs. In the glasshouse, however, the automatic watering treatments had to be separated from each other on either side of a glasshouse bench (Plate 10.1a). In effect, this produced a split block design, except that the watering treatment was not replicated. In terms of analysing these results, the water main effect may have been confounded with the block effect. Each block contained 20 pots that were watered at one of the two levels. Although there appeared to be no difference between the blocks, the water main effect was treated with caution.

There was a significant effect when the initial density of the plots in the field experiment was used as a co-variant for the total shoot density, individual shoot dry weight, rhizome dry weight and length, and rhizome length per gram of dry weight analyses at harvest.

Upon inspection of the residual plots it was discovered that some untransformed data were not normally distributed and variance depended on the mean. For this reason, an appropriate transformation was performed and where this has occurred the means presented have been back transformed. The P value presented in the tables is the level of significance, e.g. $P < 0.05$ represents significance below the 5% level. The P values for the water effect in the glasshouse are bracketed for the reason outlined above. In general, only the main effects and interactions which were significantly different will be discussed.

10.4 Results

10.4.1 Glasshouse investigation

There were no main effects or interactions involving the application of nitrogen. The defoliation treatment almost completely eliminated the production of any new shoots at harvest. Only one pot out of the 20 defoliated had a single shoot. The effect of defoliation on shoot dry weight was obvious and has not been presented with the water main effect for shoot dry weight (Table 10.3).

The application of water every three days (W+) versus every seven days (W-) increased shoot dry weight production considerably (Table 10.3). This was the only significant water main effect. On the other hand, defoliation decreased both rhizome dry weight and the total dry weight of *P. longifolia.* Defoliation decreased the length of rhizome per node and per gram of dry weight (DW) (Table 10.3).

The application of water every three days resulted in a higher dry weight in the undefoliated treatment but a slightly lower dry weight in the defoliated treatment (Table 10.4). The application of water every three days resulted in a lower rhizome length per gram of dry weight in the undefoliated treatment but a higher rhizome length per gram of dry weight in the defoliated treatment. This interaction was probably the result of the single shoot that emerged in the W-D+ treatment (a defoliated pot that was watered every seven days) which increased the total dry weight and decreased the rhizome length per gram of dry weight of the W-D+ treatment over the W+D+ treatment.

Table 10.3 A summary of the main effects which influenced harvest parameters of transplanted *P. longifolia*.

Parameter	Main effect	Parameter mean		P value
		+	-	
Shoot DW (g/pot)	Water	2.67	1.62	0.003
Rhizome DW (g/pot)[a]	Defoliation	0.13	1.74	0.000
Total plant DW (g/pot)[a]	Defoliation	0.14	5.87	0.000
Total node number/pot	Defoliation	9.5	14.5	0.000
Rhizome length/node (cm)	Defoliation	3.62	2.32	0.000
Rhizome length/g DW (cm)[a]	Defoliation	239.53	5.47	0.000

[a] Back transformed means have been presented for these parameters.

Table 10.4 A summary of the interactions between water and defoliation for total plant dry weight and rhizome length per gram of dry weight.

Parameter		Water		P value
	Defoliation	W+	W-	
Total plant DW (g/pot)[a]	**D+**	0.13	0.15	
	D-	7.03	4.86	0.021
Rhizome length/g DW (cm/g)[a]	**D+**	267.53	214.45	
	D-	4.22	7.09	0.009

[a] Back transformed means have been presented for these parameters.

10.4.2 Field investigation

10.4.2.1 Treatment effects on P. longifolia density throughout the trial

There was no cultivation main effect on *P. longifolia* density until 238 DAIO, however, there was a significant cultivation x time interaction between 107 and 238 DAIO (Figure 10.1a). Between these two dates density decreased dramatically in the uncultivated treatment and increased in the cultivated treatment.

Although fertiliser was applied at 238 and 304 DAIO, there was no fertiliser main effect throughout the experiment. Cultivation severely reduced *P. longifolia* density between 276 and 304 DAIO from 209 to 68.9 stems per square metre. There was also a significant cultivation x time interaction between these dates with the density of *P. longifolia* falling rapidly in cultivated treatments and remaining constant in uncultivated treatments (Figure 10.1b).

Water was applied at 304 DAIO and from this point all factors were allowed to interact. There was no water main effect on *P. longifolia* density and no interaction between the three treatments from this date. Cultivation severely reduced the density of *P. longifolia* compared with the uncultivated treatment during the period from 304 and 429 DAIO (Figure 10.2), however, density gradually increased with time in treatments over this period. Cultivation x time interactions were not examined between the periods 238 - 276 and 304 - 331 DAIO because of the imposition of new factors during these periods.

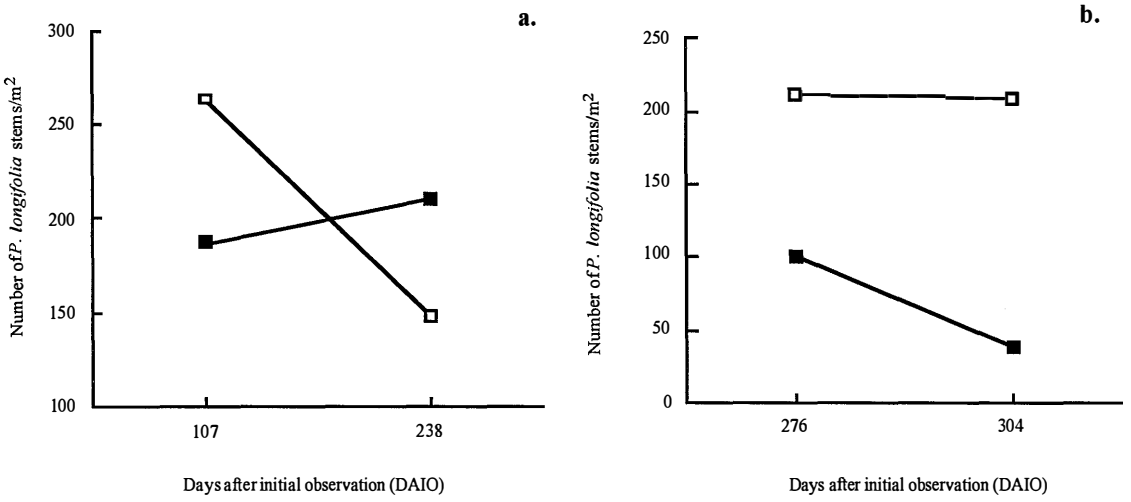


Figure 10.1 Effects of cultivation over time on *P. longifolia* density. Figure 10.1a shows the interaction between 107 and 238 DAIO while 10.1b shows the interaction between 276 and 304 DAIO. The treatments are represented on both graphs as uncultivated (□) and cultivated (■). The quadrat areas were cultivated 74, 238 and 276 DAIO after stem counts were taken for that date. The P values for both interactions were less than 0.001.

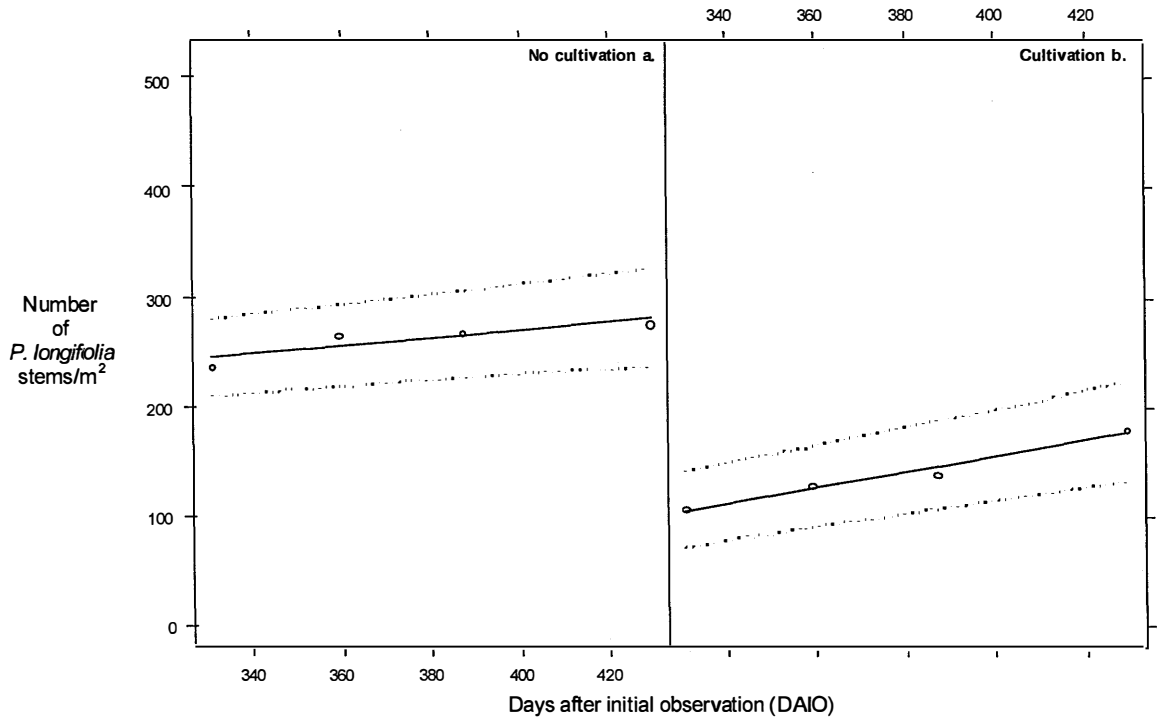


Figure 10.2 A summary of the cultivation x time interaction for *P. longifolia* density between 304 - 429 DAIO. The mean plots with 95% confidence intervals have been presented for the uncultivated (10.2a) and cultivated treatments (10.2b).

10.4.2.2 Treatment effects at harvest

The only statistically significant main effect observed on any harvest parameter was for cultivation, which greatly reduced total shoot density and total and individual shoot dry weight (Table 10.5). Cultivation also greatly reduced the length and number of nodes on rhizomes recovered from the top ten centimetres of the soil profile. Cultivation decreased the number of nodes per gram of dry weight of rhizomes, which was probably a result of death of individual rhizomes.

The rhizome dry weight in the top ten centimetres of the soil profile in the uncultivated plots was 193.9 grams per square metre or 1,939 kilograms per hectare (Table 10.5). The total length of these rhizomes was 117.6 metres per square metre with a massive 2,905 nodes per square metre. These nodes represented active sites where shoot or rhizome initiation could occur. By way of contrast, in cultivated plots the dry weight of rhizomes was 119.4 grams per square metre or 1,194 kilograms per hectare, a reduction of 38% on the uncultivated plots. The total rhizome length was 80.8 metres per square metre, a 31% reduction, while the node number was 1,764, a reduction of 39%.

There was a significant water x cultivation interaction for total shoot density, rhizome dry weight, rhizome length and node number (Table 10.6). The application of water resulted in an increase in each parameter in the cultivated treatment but a decrease in the uncultivated treatment.

There was also a significant water x cultivation x fertiliser interaction for total and individual shoot dry weight (Figure 10.3). In fertilised plots, cultivation resulted in a decrease in both total and individual shoot dry weight, whether water was applied or not (Figures 10.3a and c). In unfertilised plots, cultivation resulted in a decrease in total and individual shoot dry weight in unwatered plots but an increase in watered plots (Figures 10.3b and d).

Table 10.5 The effect of cultivation on harvest parameters of *P. longifolia*.

Parameter	Parameter mean		P value
	C+	C-	
Total shoot density (shoots/m^2)	180.19	276.88	0.001
Total shoot DW (g/m^2)	71.81	109.14	0.003
Individual shoot DW (g)	0.42	0.59	0.013
Rhizome DW (g/m^2)	119.36	193.92	0.001
Rhizome length (m/m^2)	80.83	117.58	0.006
Total node number/m^2 [a]	1763.96	2904.57	0.004
Rhizome length/g DW (cm)[a]	73.41	61.96	0.001

[a] Back transformed means have been presented for these parameters.

Table 10.6 A summary of the interactions between water and cultivation for total shoot density, rhizome dry weight and length and total node number.

Parameter		Water		P value
	Cultivation	W+	W-	
Total shoot density (shoots/m^2)	C+	224.50	135.88	
	C-	264.63	289.13	0.050
Rhizome DW (g/m^2)	C+	141.67	97.05	
	C-	158.33	229.51	0.011
Rhizome length (m/m^2)	C+	9392.36	6772.92	
	C-	9875.00	13461.67	0.020
Total node number/m^2 [a]	C+	2261.72	1327.99	
	C-	2292.18	3589.38	0.006

[a] Back transformed means have been presented for this parameter.

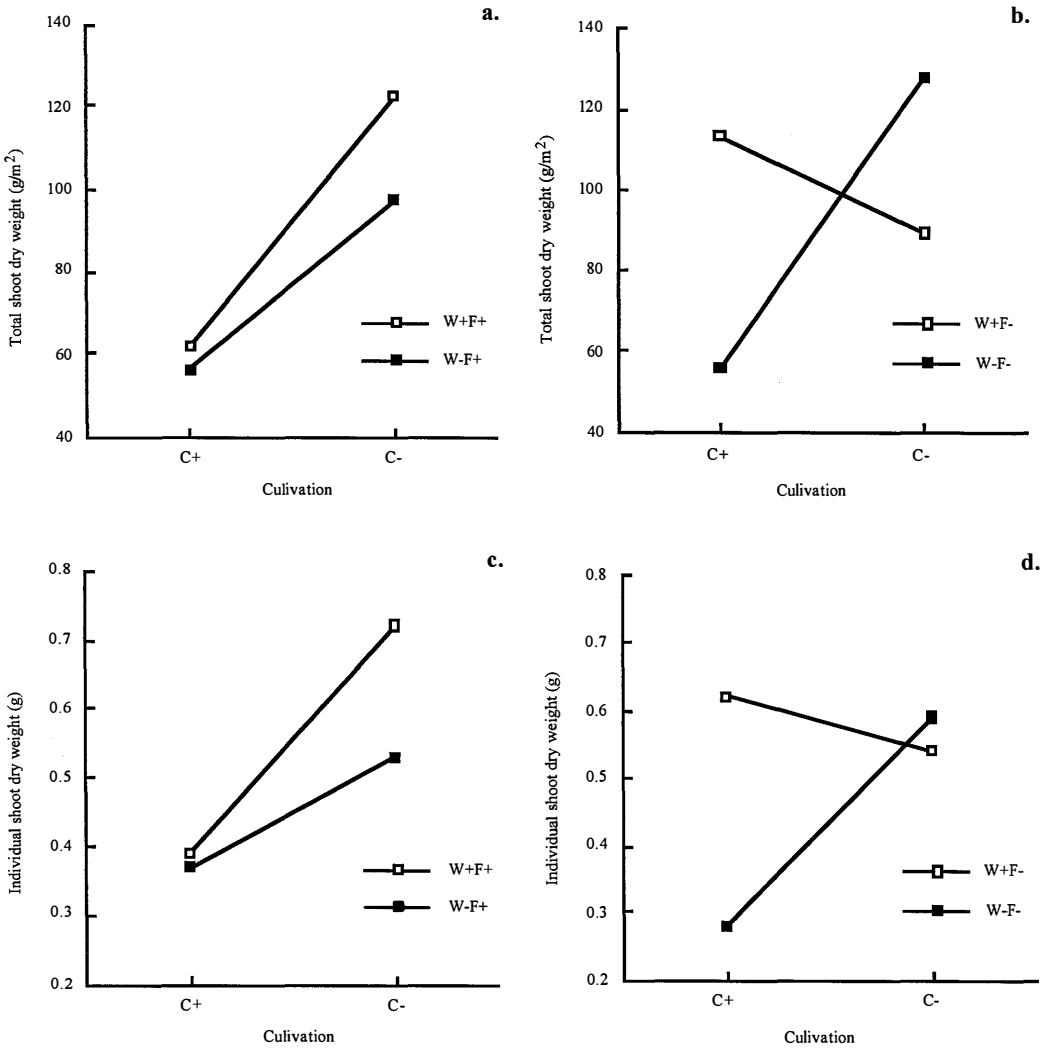


Figure 10.3 A summary of the water (W) x fertiliser (F) x cultivation (C) interaction for total shoot dry weight (10.3a and b) and individual shoot dry weight (10.3c and d) in the field trial. The P value for the total shoot dry weight interaction was 0.011 and 0.046 for individual dry weight interaction.

10.5 Discussion

10.5.1 Defoliation/Cultivation

Shoot and rhizome growth was reduced by defoliation in both the glasshouse and the field. This was probably as a result of the rhizome death, as observed at harvest in the glasshouse

(Table 10.3). Rhizome decomposition and death in *P. longifolia* would also have resulted in a reduced production of new nodes and a concomitant increase in the length of rhizome per node or per gram of dry weight. There was a similar decrease in rhizome growth from transplanted fragments of *Agropyron repens* after defoliation (Turner 1968).

In the field trial, cultivation was the only treatment that had any effect on *P. longifolia,* reducing the density at and between each observation date (Figures 10.1 and 10.2) and the weeds' growth at harvest (Table 10.5). There was one exception to the density reductions which was between 107 and 238 DAIO when over 337 mm of rainfall fell, preventing sampling for 131 days (Figure 10.1a). During this time the density of *P. longifolia* in the uncultivated treatments decreased while the density in the cultivated treatments increased. A possible explanation for this is that high rainfall prompted the germination and growth of dense stands of *Medicago truncatula* (barrel medic) in the uncultivated treatments which then competed for resources that *P. longifolia* needed for growth. The cultivated treatments were largely free of *M. truncatula*. Cultivation may have resulted in pod burial to a depth that prevented emergence.

The intensity of cultivation damage on the cultivated plots in the field experiment may have been more severe than that experienced in the nearby cultivated fields, where inter-row cultivation achieves little more than a severing of the shoots from the rhizomes and possibly the severing of some rhizome connections. Rapid shoot recruitment is usually observed after these events (Section 2.4.6).

Most of the dry weight of *P. longifolia* is below-ground. For example, the dry weight of roots and rhizomes in the top ten centimetre profile was between 1,194 and 1,939 kilograms per hectare in the cultivated and uncultivated treatments respectively (Table 10.5). The dry weight of *P. longifolia* shoots in these treatments was 718 and 1,090 kilograms per hectare (60% and 56% of the rhizome and root dry weight respectively). Furthermore, it has been

shown that only 18% of all rhizome and roots of *P. longifolia* in the top metre of soil in a cultivated field are in the ten centimetres of the profile and many more lie underneath this layer (Table 4.2). Cultivation can reduce rhizome growth however, particularly in this upper soil layer where a 39% reduction in node number occurred. However, those nodes remaining (1,800 per square metre) still represented a huge potential for the production of new shoots, rhizome or root material.

10.5.2 Water

Increased water application resulted in an increase in shoot dry weight production in the glasshouse but had no effect on either rhizome or total dry weight (Table 10.3). The application of irrigation water in the field trial neither favoured nor reduced the density of *P. longifolia* throughout the trial period or the parameters measured at harvest. It is important to note that in the field trial a total of 906.8 mm of rainfall was recorded at the closest weather observation site (6 km away at Garah) during the 12 months preceding the harvest of the trial i.e. from March 1998 until March 1999. This rainfall was far in excess of the total rainfall in any of the three previous years during the same 12 month period. For example, in the 1997/98 period rainfall was 352.6 mm, in the 1996/97 period 747.4 mm fell and in the 1995/96 period 568.0 mm fell (Bureau of Meteorology 1999). A long-term yearly average was not available. The experimental period was therefore very wet and this would have reduced any effect that applied water had on *P. longifolia* growth.

10.5.3 Nitrogen

The application of nitrogenous fertiliser had no influence on the growth of *P. longifolia* fragments in the glasshouse or plants in the field. The reason for the lack of growth response from nitrogenous fertiliser was not ascertained in the glasshouse and it is suggested that leaching of the nitrogen may have occurred. In the field the high soil nitrogen levels at

the previously uncultivated site may have masked the nitrogen effect. These levels, however, were not measured.

10.5.4 Interactions

The field trial indicated that in the presence of cultivation the growth of *P. longifolia* was enhanced by the application of water but in the absence of cultivation the growth of *P. longifolia* was reduced by the application of water (Table 10.6). The cultivated plots were almost exclusively monocultures of *P. longifolia* so that most of the water applied was probably captured for *P. longifolia* growth. It is postulated that severe competition for water from other weedy species, e.g. *Panicum* spp., in the uncultivated treatments may have promoted the growth of these species over *P. longifolia*. On the other hand, it appears that cultivation in the absence of irrigation in a dry year, or simply a dry season, may reduce the growth of *P. longifolia*.

The significant fertiliser x water x cultivation interaction was not believed to be a real treatment effect. Instead, one of the plots for the C-W+F- treatment suffered grazing damage by kangaroos very near to harvest with the effect being a reduction in the C-W+F- treatment mean and the interaction observed. Below-ground parameters showed no such interaction which again indicates some form of above-ground damage.

10.5.5 Management

Defoliation was required to inhibit the growth of *P. longifolia*. In the glasshouse, defoliation resulted in the complete death of almost all transplanted *P. longifolia* fragments possibly because the fragments had insufficient reserves to produce new shoots after defoliation. From a management perspective, if fragment transplants are encountered in the field then

some form of defoliation, perhaps by shallow cultivation or herbicide application soon after the transplant event, should result in the death of most fragments.

In the field, intensive cultivation reduced the growth of *P. longifolia* particularly when cultivation was performed in the absence of irrigation. This is understandable given that any plant needs water for active growth and the less water available after plant damage has occurred the less growth is likely to eventuate. The results from this experiment strongly suggest that a large scale field trial should be conducted to confirm the effect that defoliation has on the growth of *P. longifolia* under both irrigated and non irrigated conditions. This field trial should include treatments which give a gradation in defoliation damage (Timmons and Bruns 1951) perhaps with herbicide application included in some capacity (Russ and Anderson 1960) as personal observations made by several industry consultants indicate that herbicide application followed by cultivation may be an effective means of management.

Although this research recommends that intensive cultivation be carried out to reduce the incidence of *P. longifolia*, the use of cultivation for weed control is not regarded as a long-term sustainable solution by others (Roberts 1998b). This is partly due to the move towards permanent bed, reduced tillage and stubble retention systems to enhance soil organic matter, soil structure, water infiltration and to reduce soil loss due to erosion, particularly in dryland cropping systems (Yule and Rhode 1996; Charles 1999). This management method must therefore be carefully weighed against the complete objectives of the cotton farming system and a compromise achieved if this means of management is employed.

10.6 Conclusions

Several factors have probably contributed to the weediness of this native species in cotton. Certainly, the difficulties encountered in trying to control this weed with herbicides have a part to play (McMillan 1988a) but so do some of the factors intrinsic in cotton production. For example, the presence of shallow inter-row cultivation may not only spread vegetative fragments of the weed outside the patch area (Section 6.7.3), but also appears to stimulate shoot recruitment from undamaged nodes in the upper soil profile (Sections 2.4.6 and 9.2.3).

The evidence from this chapter, however, was that deeper, more destructive cultivation may play a role in reducing both shoot recruitment and rhizome growth of *P. longifolia*. Likewise, there was evidence that irrigation promoted *P. longifolia* growth, particularly shoot growth. The contribution of irrigation to the plant's success was not supported by significant main effects in this chapter (with one exception in the glasshouse trial), however, the competition that *P. longifolia* displayed for water in parts of the soil profile in Section 8.3.1 and the growth reductions in uncultivated populations examined in Section 5.7.4 (in contrast with irrigated fields) strongly suggests that it is important. Finally, the application of nitrogen did not enhance the growth of *P. longifolia* in this study but the reasons for this result were not pursued.

Chapter 11

General conclusions

This research set out to determine the distribution, spread and potential control of *Polymeria longifolia* by mail questionnaire, the biology and ecology of the species, its competitive impact on cotton production, and to elucidate principles for managing *P. longifolia* based on an understanding of the weed's biology and ecology. This chapter draws together the main findings from this work and illustrates where future research should be focussed.

11.1 Distribution, spread and potential control (mail questionnaire)

Polymeria longifolia is a small but significant problem in many cotton growing areas, particularly in the Gwydir, Namoi and Macintyre Valleys in northern New South Wales and around St. George in southern Queensland (Figure 2.1). Vegetative reproduction appeared to aid in the dispersal of this species with around 1% of the production area infested in the season surveyed. The cost of existing control of *P. longifolia* infestations was substantial but unfortunately mostly ineffective or inconsistent.

11.2 Biology and ecology

Masses of *Polymeria longifolia* shoots begin to emerge in late September/October, (coinciding with cotton planting) and continue to be recruited throughout the cotton growing

season. The cessation of active shoot growth coincides with defoliation of the cotton crop in cultivated fields but continues in uncultivated areas and is possibly linked to soil water status. It is suggested that irrigation combined with shallow cultivation in cotton fields promotes *P. longifolia* growth. Rapid shoot recruitment can occur after shallow defoliation, particularly from undamaged rhizome nodes in the upper soil profile. Anatomical studies suggested that the rhizomes of *P. longifolia* may be inhibited by auxin based herbicides and that some sort of allelochemical interaction between *P. longifolia* and cotton may occur. The large below-ground biomass is probably one of the main reasons for the success of this native weed and also why it is so difficult to kill.

11.3 Competitive impact

Patches of *P. longifolia* with a density of 100 stems per square metre or more may reduce the yield of cotton lint and seeds by 50%. This or higher densities are common in many patches. However, cotton may not be harvested in patches with lower densities than this because of the possibility of lint contamination.

Polymeria longifolia appears to compete strongly for soil water and is most readily detected at levels approaching the refill point of cotton (the point at which fields should be irrigated to allow for optimal cotton growth). The weed may compete for nutrients at depth even though the shallow soil cores sampled here did not detect differences in the major soil nutrients in the upper soil profile. Evidence indicated that allelochemical interference may have also caused yield reductions of cotton and it would have been useful to examine this possibility if time had allowed.

11.4 Management

11.4.1 Prevention

Polymeria longifolia is a native species in many of the plant communities that have been, and continue to be, developed for cotton production. For this reason, it may be wise to carry out botanical surveys of potential production areas before land development to determine whether infestations of *P. longifolia* are present. Identifying *P. longifolia* infestations may mean three things. Firstly, vegetative fragments are less likely to be moved to new areas during the development process because care can be taken to isolate large existing patches and implement some form of control on them. Secondly, control may be more successful because a small infestation can be controlled with greater ease than a larger infestation that becomes firmly established in a cotton field. Thirdly, and if all else fails, these areas may be left out of production until a successful control measure can be found.

While this advice has limited value in areas where extensive land development has already occurred, it should be heeded in areas of expanding production particularly around St. George/Dirranbandi, Walgett (lower Namoi Valley), Richmond (Queensland) and in parts of northern Australia where *P. longifolia* is known to occur (Figure 2.1). This research calls for more pre-emptive action rather than simply waiting until *P. longifolia* becomes a problem and both losses to cotton production and expenditure on an increasingly entrenched weed in cotton fields have occurred.

11.4.2 Herbicides

In many respects the best management practices for herbicide control of *P. longifolia* have changed little since Max McMillan's recommendations 12 years ago (McMillan 1988a).

For example, all herbicides that are commonly applied as either pre- or post-emergent applications in cotton are ineffective on *P. longifolia*. This means that there is no herbicide that can safely be sprayed on cotton to control *P. longifolia*. Herbicides such as those in the phenoxy group, e.g. 2,4-D amine, 2,4-D ester and fluroxypyr, are likely to be more effective against *P. longifolia* than other herbicides, but care is needed in the application of these herbicides under fallow conditions because of the potential for spray drift and the residual nature of fluroxypyr. Single applications of strongly residual herbicides such as imazapyr will probably not reduce the size of *P. longifolia* infestations permanently but will further compromise cotton production in sprayed areas.

Since herbicides are more likely to be effective when applied to actively growing plants of *P. longifolia*, applications should be restricted to times after irrigation or rainfall. Repeated applications of herbicides have been shown to control other hard-to-control species and may hold some promise in the treatment of *P. longifolia*. In addition, the introduction of herbicide resistant cotton cultivars which will allow in-crop herbicide application, and spot spraying technology allowing specific areas of weeds to be treated, may help in treating *P. longifolia* infestations.

11.4.3 Cultivation and hand chipping

Severely disruptive cultivation of the upper soil profile, where the rhizomes of *P. longifolia* are located, for example by a rotary hoe, can reduce the growth of the weed. Likewise, cutting *P. longifolia* rhizomes and shoots into small pieces on cultivation will prevent fragment regrowth. Persistent soil disturbance by cultivation is likely to be the key to controlling *P. longifolia*. However, to prevent equipment from spreading *P. longifolia* fragments, cultivation for *P. longifolia* control should only be carried out within *P. longifolia* patches and, where possible, not before rainfall or irrigation. Otherwise fragments may be successfully transplanted.

Shallow, minimally destructive inter-row cultivation and hand chipping will more than likely stimulate the growth of *P. longifolia*. While an intensive weekly regime of hand chipping may result in a reduction in *P. longifolia*, the cost of this control measure is likely to be prohibitive.

11.4.4 Field hygiene

Good field hygiene should be practised particularly to prevent the movement of vegetative fragments or seeds from infested to uninfested areas. For example, vegetative fragments should be removed from machinery with any mud that may contain seeds, after cultivation through patches has occurred. Also, the spread of vegetative fragments in soil moved in laser levelling operations should be avoided.

11.5 Future research

The most pressing needs for further research have been indicated below. It should be understood, however, that this is not an exhaustive list of all the ideas posed throughout the thesis.

There is a need to conduct a larger scale investigation into the effect of intensive and repeated defoliation on *P. longifolia*. Defoliation may be achieved by a range of mechanical or chemical means, or even flaming, but each means should be tested at varying time intervals and certainly more than once. A combination of cultivation and herbicide applications may be effective in reducing the size of *P. longifolia* infestations. Altering irrigation practice may have some part to play in aiding this.

Carbohydrate movement around *P. longifolia* plants also needs to be examined. By depleting carbohydrate reserves by intensive defoliation events early in a growing season (the time of rapid shoot production in *P. longifolia*), and by achieving better herbicide translocation (when maximum carbohydrate storage is occurring), a more successful management strategy for *P. longifolia* may be suggested. Cultivation and/or herbicide applications could then be timed for maximum impact.

Other areas of research that may aid in the control of *P. longifolia* include:

- determining under what environmental conditions physiological stress occurs in *P. longifolia*. This should aid in more timely herbicide applications and prevent spray failure;
- determining the physiological action of any herbicide on *P. longifolia*;
- determining whether fragment survival is related to phenological development of the parent plant;
- determining if cultivation perpendicular to the normal row direction in rotational fields helps to break up *P. longifolia* infestations;
- whether there is any synergistic action using combinations of herbicides on *P. longifolia*;
- whether a wetting agent will improve herbicide penetration into the naturally hairy *P. longifolia* leaves and hence increase translocation.
- an examination of the possible allelopathic effects of *P. longifolia*.

The studies conducted in this thesis have revealed promising areas for further research and management of this difficult to control perennial weed, *Polymeria longifolia*.

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Appendix 1

Personal communications

This appendix contains a list of people who provided personal communication throughout the thesis and their contact details.

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Appendix 2

Published papers and posters

This appendix contains photocopies of papers and posters presented throughout the period of this PhD candidature. The poster presented at the Eighth Australian Cotton Conference was not included in the proceedings and therefore only the text has been presented here.

Papers

Johnson, S., Sindel, B. and Jones, C. (1998). Pesky polymeria - the perennial problem. *Proceedings of the 9th Australian Cotton Conference*, August 12th - 14th. Broadbeach, Queensland. pp. 187-192.

Johnson, S., Sindel, B. and Jones, C. (1998). Polymeria take-all : A perennial problem. *The Australian Cottongrower*, **19**, no. 5, pp. 37-43.

Johnson, S. (1999). Polymeria take-all case study. Australian Cotton Co-operative Research Centre, Cotton Protection Course notes (1999). University of New England, Armidale. pp. 4.21 - 4.23.

Posters

Johnson, S. B., Sindel, B. M. and Jones, C. E. (1996). Polymeria take-all weed. Poster presented at *The Eighth Australian Cotton Conference*, August 1996. Broadbeach, Queensland.

Johnson, S. B., Sindel, B. M. and Jessop, R. S. (1999). The ecology of *Polymeria longifolia* in cotton. Poster presented at the *Proceedings of the 12th Australian Weeds Conference*, September 1999. Devonport, Tasmania. pp. 196-197.

Appendix 3

Mail questionnaire

This appendix contains the three pages sent to cotton consultants and farm agronomists to ascertain basic biological and distribution information about *P. longifolia.* These pages included a copy of the covering letter, a coloured information sheet about *P. longifolia* and a pink double-sided questionnaire sheet.

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3/10/1996

Dear Cotton Consultant/Agronomist

As you may be aware, polymeria take-all, otherwise known as Peak Downs curse or clumped bindweed is among the 'take-all' group of weeds which can severely reduce cotton yields. The plant is a native of Australia but despite this, very little is known about its biology or ecology.

Stephen Johnson from this Department has been funded by the Cotton Research and Development Corporation (CRDC) to determine how widespread polymeria take-all is, how it reproduces, how it spreads and its impact on yield. This information will be fundamental in designing efficient and practical methods of control. The attached questionnaire is part of this study and will be sent to all consultants or agronomists in the Australian cotton industry. The results of this research will be made available to you through the Australian cottongrower and at the Australian Cotton Conference.

The success of this survey in accurately describing the polymeria problem depends on your willingness to answer the questions and to return the questionnaire. I invite you to complete the pink survey form included with this letter, mailing it as soon as possible in the reply-paid envelope, even if polymeria take-all does not occur or is not a problem on the properties for which you consult.

In piloting the survey we found that most respondents completed the questionnaire in about 10 minutes. The information you provide will remain confidential and all respondents will remain anonymous. The number on the survey form is to ensure that a re-mail does not occur once your form has been returned. All consultants, agronomists and growers confronted by this weed will benefit from your experience. Thank you for your co-operation.

Yours faithfully

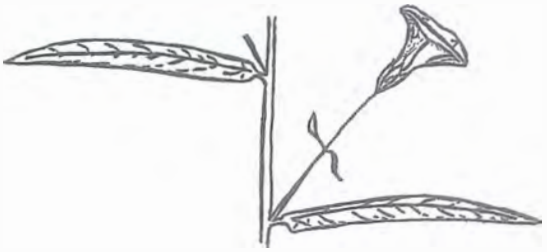
[redacted]

Associate Professor Robin Jessop

Polymeria 'take-all'
is one of the Take-all weeds

There are ***two types of polymeria*** that are weeds in cotton

Polymeria 'take-all'
(Polymeria longifolia)
Long narrow leaves, 2-7 cm long
and 0.2-1 cm wide.
It grows upright.



Annual polymeria
(*Polymeria pusilla*)
Rounded leaves, 1-3 cm long
and 0.7-2 cm wide.
It creeps along the ground and roots
where the stems touch the ground.

This survey is ***only*** interested in *Polymeria longifolia* (polymeria 'take-all') which is also called polymeria, Peak Downs curse or clumped or erect bindweed

The pink/mauve, yellow centred flower of polymeria take-all
Line drawings redrawn from the Flora of NSW, Vol 2 pp. 383-384

Stephen Johnson, Dept of Agronomy & Soil Science
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Polymeria 'take-all' survey

Instructions

This survey relates only to *Polymeria longifolia* (see leaflet-upright plant with long, narrow leaves) on properties for which you consult. In answering the questions please circle the number next to the most appropriate response(s), unless specified otherwise. If differences exist between properties please circle only the response that applies to the average farm.

1. What is the number and general location of properties where you consult?
(circle as many as apply)

Number of properties..... ☐

Namoi valley..... 1
Gwydir valley..... 1
Macintyre river..... 1
Macquarie valley..... 1
Lachlan valley..... 1
Tandou..... 1
Bourke/Brewarrina area..... 1
Darling Downs/South Burnett..... 1
St George..... 1
Theodore/Biloela/Moura..... 1
Emerald area..... 1
Other location, please specify_____ 1

2. In total, approximately how many hectares do you consult on?

_____

3a. In order of importance, list up to 5 of the worst weeds you encountered in cotton crops last season? (No. 1, being the worst).

1.

2.

3.

4.

5.

3b. If polymeria 'take-all' was present but has not been listed above, please rank its importance
e.g. 6th, 7th or etc. worst weed_____

4. How would you currently rate polymeria 'take-all' as a weed problem on the properties for which you consult?

Does not occur..... 1
Present, but not considered a problem 2
Present, but has been controlled..... 3
Minor problem..... 4
Moderate problem..... 5
Major problem..... 6

Continue only if polymeria take-all is present

5a. Could you estimate the total area of fields that polymeria 'take-all' is found growing on?

_____(ha)

5b. What percentage of this area is actually covered with the weed?_____(%)

6. How do polymeria 'take-all' infestations appear in fields? Plants are: (circle all relevant)

Scattered..... 1
In dense clumps..... 2
(Give average diameter_____(metres)
Other, please specify_____ 3

_____

7. From your experience, is the presence of polymeria 'take-all'

Decreasing..... 1
Not changing..... 2
Increasing..... 3

8. For how long do you think polymeria 'take-all' has been present on these properties?

Less than 5 years..... 1
Between 5 and 10 years..... 2
More than 10 years..... 3
Unsure how long ago..... 4

9. Within polymeria 'take-all' infestations, is the yield of cotton decreased?

No..... 1
Yes, by 0-25%..... 2
Yes, by 25-50%..... 3
Yes, by 50-75%..... 4
Yes, by 75-100%..... 5

10. On which soil types is polymeria 'take-all' more prevalent? (circle all relevant)

Light..... 1
Heavy..... 1
Other, please specify_____ 1

(Please turn over)

Appendix 4

Field descriptions

This appendix describes the fields at Auscott, Moree (Section A4.1) and Colly Farms, Collarenebri (Section A4.2) on which much of this research was conducted. All farms had originally been open grassy woodland, dominated by *Eucalyptus microtheca* (coolibah) at Moree and *E. microtheca* (dominant) with co-dominant *Casuarina cristata* ssp. *cristata* (belah) and *Acacia harpophylla* (brigalow) in areas, at Collarenebri. *Polymeria longifolia* existed in these plant communities prior to land development.

A4.1 Auscott, Moree

A4.1.1 Midkin Farm, Field 11

The Midkin Farm is located 21 km north west of Moree along the Mungindi road in north western New South Wales (NSW) (latitude 29° 18' south, longitude 149 ° 25' east). The soil was a heavy red-brown clay (Ug 5.3, Northcote 1979). Further details of the chemical properties of this soil can be found in Section 6.5.2. Field 11 had one of the heaviest infestations of *P. longifolia* at the Midkin Farm (ca. 1% of the 244 ha was infested).

Cotton field management for the period 1996-1999

This field was planted to cotton on 2 October 1996 (Table A4.1). The field was managed similarly to all other cotton fields at Auscott with respect to pre- and post-cotton emergence weed control. Patches of *P. longifolia* were neither cultivated or hand chipped. Instead, herbicide was applied to *P. longifolia* patches in December 1996 and February 1997 (Table A4.1). On 28 April, the hills were removed and the field was levelled before barley was planted on 6 June. This rotational crop was grown for several reasons; firstly it was believed that the barley crop would remove water from the soil which would then be unavailable for the growth of the weed in the following season; secondly, that ground preparation for the barley crop would disrupt the rhizome growth of *P. longifolia* and hence the emergence of stems in the following spring; and thirdly, that herbicides could be applied to the barley crop pre- or post-planting, or post-harvest, which would be able to reduce the size of the weed infestation.

The barley crop was ploughed in on 10 August 1997. At least one herbicide was applied to the patches of *P. longifolia* during January 1998, although information regarding herbicide applications in the fallow have not been recorded. The end result of these measures was a 50% reduction in the area of infestation on the field, largely in one very large patch. A basic summary of planting, in-crop cultivations and harvest in the 1998/99 cotton crop is given in Table A4.2.

Table A4.1 Farm management of Field 11, Midkin Farm, Auscott pre- and post-planting of the 1996/97 cotton crop. Management of the field until the planting of barley in June 1997 has been included. The herbicides mentioned here and in other tables are trade product rates.

Operation	Date	Specification	Rate
Seedbed preparation	14/6	Slash/Flail	
	1/7	Slash/Flail	
	4/7	Root cutter	
	22/7	Forming up rows	
	14/8	Gas sled	
	11/9	Sled - bed shaping	
Nutrient application	14/8	Anhydrous ammonia	99 kg/ha
	26/8	Urea	52 kg/ha
Herbicide application	15/9	Cotogard[a]	2.0 L/ha
		Stomp[b]	3.0 L/ha
Planting	2/10	Sicala V-2 with Discplanter	12.7 kg/ha
Seedbed preparation	2/10	Chain harrows	
	2/10	Compaction (roller)	
Cultivation	1/11	Orthman cultivators	
	20/12	Orthman cultivators	
Herbicide application	2/10	Cotogard®[a]	1.0 L/ha
		Dual®[c]	1.0 L/ha
	13/12	Diurex®[d]	1.5 L/ha
		Cotoran®[e]	1.5 L/ha
	28/2	Starane®[f] spot spray (*P. longifolia* patches only)	2.0 L/ha
Irrigation	20/12		
	8/1		
	21/1		
	10/2		
Defoliant application	27/2	Defoliant	
	23/3	Salt and Accelerate®[g]	1.0 L/ha
Harvesting	26/3		
Seedbed preparation	28/4	Discing in cotton stubble (Towner discs)	
	4/5	Laser levelling field (Grader board)	
Planting	6/6	Barley with Flexicoil	60 kg/ha

[a] Fluometuron 250g/L, Prometryn 250g/L
[b] Pendimethalin 330g/L
[c] Metolachlor 720g/L
[d] Diuron 900g/kg
[e] Fluometuron 500g/L
[f] Fluroxypyr 300g/L
[g] Endothal 64g/L

Table A4.2 Farm management of Field 11, Midkin Farm, Auscott after June 1997, through the 1997/98 summer fallow until the harvest of the 1998/99 cotton crop.

Operation	Date	Specification
Seedbed preparation	10/8	Light discing
	4/9	Laser levelling
	15/9	Heavy discing
	29/10	Lister
	20/1	Sled
	18/3	Alfarm scarifier
	24/3	Lister
	12/10	Harrows
Herbicide application	-/1	Not recorded
Planting	12/10	Unnamed variety with Max Emerge planter
Cultivation	27/11	Sled
	28/12	Excel
Irrigation		Not recorded
Harvesting	23/4	

A4.1.2 Wilson's Farm, Field 4

The Wilson's Farm is a leasehold property of Auscott and located nine kilometres west of Garah along the Talmoi road in north western NSW (latitude 29° 07' south, longitude 149° 33' east). Garah is located 48 km north west of Moree along the Mungindi road. The soil varied from a heavy red-brown clay at the north eastern corner of the field (Ug 5.3) to a heavy grey clay throughout the rest of the field (Ug 5.1) (Northcote 1979).

Field 4 had one of the heaviest infestations of *P. longifolia* at the Wilson's Farm (ca. 1% of the 63 ha was infested). Weed control practices had not been as stringent in the previous management on this property and many weeds including *P. longifolia* were to be found in and around the cultivated field areas and channels.

Cotton field management for the period 1997-1998

This field was planted on 14 October 1997 and managed similarly to all other cotton fields with respect to pre- and post-emergence weed control (Table A4.3). *Polymeria longifolia* in the cotton crop was cultivated on this field instead of the usual herbicide applications, e.g. Field 11 (Table A4.1).

A4.1.3 Top Box Farm, Field 48

The Top Box Farm of Auscott is located 43 km north west of Moree along the Mungindi road) (latitude 29° 06' south, longitude 149 ° 37' east). The soil was a heavy grey clay (Ug 5.1) (Northcote 1979).

Field 48 had one of the heavier infestations of *P. longifolia* at the Top Box Farm, estimated to cover between 1 - 2% of this 144 ha field. It was not known how long this field had been cropped to cotton. A large amount of *P. longifolia* was also observed immediately adjacent to the field in an uncultivated area. Observations for Sections 5.7 and 10.3.2 were made using different parts of this area.

Cotton field management for the period 1997-1999

This field was managed in a similar fashion to Field 11 at the Midkin Farm in the previous season. A mixture of 2 L/ha of glyphosate with 1 L/ha dicamba (trade product rates) was spot sprayed on the *P. longifolia* patches on 14 November 1997. Wheat was planted in April 1998 after cotton harvest in March. After wheat harvest in late November, the field was left fallow to allow for cultivation and herbicide applications to reduce the size of *P. longifolia* infestations.

Table A4.3 Farm management of Field 4, Wilson's Farm, Auscott pre- and post-planting of the 1997/98 cotton crop.

Operation	Date	Specification	Rate
Seedbed preparation	29/4	Slash/Flail	
	8/5	Root cutter	
	4/6	Forming up rows	
	10/6	Gas sled	
	3/7	Gas sled	
	6/8	Herbicide application - lillistons	
	14/9	Roller	
Nutrient application	10/6	Anhydrous ammonia	95 kg/ha
	3/7	Anhydrous ammonia	56 kg/ha
	26/8	Nitram	30 kg/ha
Herbicide application	6/8	Trifluralin[a]	2.8 L/ha
	14/10	Cotogard®[b]	0.6 L/ha
		Stomp®[c]	1.2 L/ha
Planting	14/10	Sicala V-2i	14.2 kg/ha
Cultivation	25/11	Orthman cultivators	
	20/12	Orthman cultivators	
Irrigation	22/9	Pre-irrigation	
	22/12		
	5/1		
	15/1		
	25/1		
	8/2		
	21/2		
Defoliant application		Not recorded	
Harvesting	2/4		

[a] Trifluralin 400g/L
[b] Fluometuron 250g/L, Prometryn 250g/L
[c] Pendimethalin 330g/L

A4.2 Colly Farms, Collarenebri

The Central Farm of Colly Farms is located approximately 29 km east of Collarenebri along the Moree road in north western NSW (latitude 29° 27' south, longitude 148° 38' east). The soil was a heavy grey cracking clay (Ug 5.1, Northcote 1979).

A4.2.1 Central Farm, Field 27

Field 27 had one of the heaviest infestations of *P. longifolia* at the Central Farm (an estimate of 22% of the 150 ha field area in 1995/96 season, up from 8% in the 1987/88 season). This field had been cropped to cotton since the 1988/89 season, except for a fallow in 1994/95.

Cotton field management for the period 1996-1998

This field was planted on 26 September 1996 (Table A4.4). The field was managed similarly to all other fields at the Central Farm with respect to pre- and post-cotton emergence weed control. *Polymeria longifolia* patches were cultivated but not hand chipped. Patches of *P. longifolia* were spot sprayed with 2 L/ha of imazapyr (trade product rate) after harvest in April 1997 (Table A4.5). This strongly residual herbicide was applied in the hope that it would eliminate the *P. longifolia* problem even though these areas would have to be sacrificed to cotton production for at least the following season. The effect that this herbicide had on *P. longifolia* and subsequent cotton growth has been outlined in Section 9.5.

In the 1997/98 season, this field was planted on 18 October (Table A4.5). Again, the field was managed similarly to other fields with respect to pre- and post-cotton emergence weed control.

Table A4.4 Farm management of Field 27, Central Farm, Colly Farms pre- and post-planting of the 1996/97 cotton crop.

Operation	Date	Specification	Rate
Seedbed preparation	-/4	Stubble was pulled, raked and burnt	
	-/6		
	-/8		
Planting	26/9	Sicot 189 with Discplanter	15 kg/ha
Cultivation	25/10		
	-/12		
Nutrient application	15/8	Anhydrous ammonia	120 kg/ha
	25/10	Anhydrous ammonia	60 kg/ha
Herbicide application	20/6	2,4-D amine	4.0 L/ha
		Glyphosate	0.5 L/ha
	26/9	Convoy[a]	2.0 L/ha
		Dual[b]	2.0 L/ha
	24/12	Karmex[c]	1.63 kg/ha
Irrigation	28/11		
	30/12		
	14/1		
	10/2		
Defoliant application	24/3	Dropp[d]	0.2 L/ha
		Prep[e]	1.0 L/ha
	30/3	Prep[e]	1.0 L/ha
Harvesting	11/4		

[a] Fluometuron 250g/L, Prometryn 250g/L
[b] Metolachlor 720g/L
[c] Diuron 900g/kg
[d] Thidiazuran 490g/kg
[e] Ethephon 720g/L

A4.2.2 Central Farm, Field 12

Field 12 had a moderate level of *P. longifolia* infestation with less than 5% of the area covered in the 1997/98 season. This field was planted on 23 September 1997 (Table A4.6). The field was managed similarly to all other fields at the Central Farm with respect to pre- and post-cotton emergence weed control.

Table A4.5 Farm management of Field 27, Central Farm, Colly Farms pre- and post-planting of the 1997/98 cotton crop.

Operation	Date	Specification	Rate
Seedbed preparation	-/4	Stubble was pulled, raked and burnt	
	-/4	Rows listed	
	?	3 cultivations throughout winter	
Nutrient application	-/4	Nitrogen application	150 kg/ha
	-/12	Anhydrous ammonia	30 kg/ha
Planting	18/10	Sicala V-2	
Cultivation	-/12		
Herbicide application	30/4	Spot-sprayed Arsenal®[a] (10.5 ha)	2.0 L/ha
	18/10	Stomp®[b]	4.0 L/ha
	18/10	Diuron	3.5 L/ha
Irrigation	26/9	Pre-irrigation	
	20/12		
	3/1		
	17/1		
	31/1		
	23/2		
Defoliant application	10/3	Dropp Ultra[c]	0.2 L/ha
		Prep[d]	0.8 L/ha
	17/3	Prep[d]	2.0 L/ha
Harvesting	31/3		

[a] Imazapyr 250g/L
[b] Pendimethalin 330g/L
[c] Thidiazuran 490g/kg
[d] Ethephon 720g/L

Table A4.6 Farm management of Field 12, Central Farm, Colly Farms pre- and post-planting of the 1997/98 cotton crop.

Operation	Date	Specification	Rate
Seedbed preparation	-/4	Stubble was pulled, raked and burnt	
	-/4	Rows listed	
	?	3 cultivations throughout winter	
	17/8	Rolled	
Planting	23/9	Sicot 189	?
Cultivation	-/12		
	-/1		
Nutrient application	-/4		150 kg/ha
	-12		30 kg/ha
Herbicide application	17/8	Diuron	3.5 L/ha
	23/9	Cotogard®[a]	3.5 L/ha
		Dual®[b]	2.0 L/ha
	-/1	Diuron	3.5 L/ha
Irrigation	28/9		
	5/12		
	25/12		
	7/1		
	23/1		
	3/2		
	21/2		
Defoliant application	23/3	Dropp Ultra[c]	0.2 L/ha
	30/3	Prep[d]	2.0 L/ha
Harvesting	14/4		

[a] Fluometuron 250g/L, Prometryn 250g/L
[b] Metolachlor 720g/L
[c] Thidiazuran 490g/kg
[d] Ethephon 720g/L