A STUDY OF
SEED PRODUCTION IN DESMANTHUS
(*Desmanthus virgatus* L.)

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ABSTRACT

Desmanthus (*Desmanthus virgatus* (L.)) is a tropical forage legume of potential use in cattle rangeland. Currently this potential is not realised because of unreliable seed supply. The effect of plant density, chemical weed control, pre-harvest and harvest techniques on plant vigour, seed yield and seed yield components (SYC) were studied in field trials (1994/1995 and 1995/1996) in South-East Queensland on an early ('Marc') and a late ('Bayamo') flowering cultivar.

Potential seed yield per plant of both cultivars was most influenced by inflorescence number. High levels of floret abortion (>50% regardless of pollinator presence) occurred prior to pod expansion. Cultivar differences in flowering pattern and pod dehiscence resulted in differences in presentation seed yield.

Plant density effects on vegetative growth, flowering pattern, SYC and seed yield of 'Marc' were investigated using a Nelder 4.5° radial spacing trial (3 to 160 plants/m^2). Increasing plant population decreased branching, inflorescences per plant and flowering duration. However increasing plant density over the tested range caused a linear increase in potential seed yield (to 200 g/m^2) at peak flowering although actual seed yields (120 g/m^2) did not respond similarly to plant density changes probably because of masking effects caused by insect (psyllid) damage after peak flowering and problems with sampling fallen seed.

Three different pre-harvest treatments were examined to try to improve subsequent seed harvesting efficiency. These included application of pre-harvest (polyvinylacetate (glue), diquat (desiccant) and paclobutrazol (plant growth regulator)) treatments. None of these increased combine harvested seed yields in either cultivar. However desiccation did increase both seed germination percentage and the proportion hard seeds but decreased seed weight. The effects of paclobutrazol on SYC in this trial were inconclusive. However, a further study on the effects of paclobutrazol revealed that it increased branching and inflorescences per plant when applied at the onset of flowering but had no obvious effect when application was delayed until peak flowering.

Combine and keyhole stripper harvesting systems both resulted in poor (12%) recovery of presentation yield in cv. 'Marc'. Combine harvesting decreased seed germination and the proportion of hard seeds, while unthreshed pods recovered by keyhole harvesting required additional threshing to remove seed. 'Marc' plants recovered poorly after harvest while frost caused premature abscission of 'Bayamo' pods and reduced harvest yields. This suggests 'Marc' may be economically viable as a commercial seed crop only in the first year and that satisfactory yields of 'Bayamo' will only be obtained in crops sown early or grown in delayed frost onset areas.

One pot trial and four field trials assessed the suitability of 28 pre-emergence and 44 post-emergence herbicides for use in desmanthus seed crops. Several new weed control options were identified though legume weeds remain difficult to kill selectively.

Results are discussed with reference to commercial desmanthus seed production practices.

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CHAPTER ONE
GENERAL INTRODUCTION

Desmanthus (*Desmanthus virgatus* (L.) Willd.) is a useful forage shrub legume in its native habitats in Central and South America where it is grazed in its wild state (Burt, 1993a). Wide edaphic adaptation and the existence of similar geomorphological niches to desmanthus habitats in Queensland has resulted in the introduction and evaluation of desmanthus as a forage species for extensive pastoralism in Queensland.

The establishment of leguminous species in grazing and browsing pastoral systems has a long history particularly in temperate regions where *Trifolium* spp. and *Lolium* spp. systems have been dominant. Benefits to stock production stem from the provision of dietary nutrients which are limiting stock performance (notably protein), extending the seasonal productivity of pastures and (often) the provision of a persistent and productive sward over seasons. Most legumes also have the ability to fix atmospheric nitrogen via symbiotic association with *Rhizobium* bacteria which becomes available for both the legume and companion species (Allen and Allen, 1981). The introduction of legumes into tropical and sub-tropical pastures is less developed than in temperate countries and involves a wider range of species.

Agricultural production in Queensland is based largely on extensive beef pastoral systems which were traditionally mostly native grasses of poor nutritive value. Improvement of pasture through the introduction of grass and legume species has resulted in 10 to 15-fold increases in production on average throughout Queensland (Mannetje, 1984) over an area of approximately 5 million ha. An additional 17 million ha of native pasture is regarded as having strong potential for improvement (Walker and Weston, 1990).

To date introduced legumes in Queensland have been dominated by *Stylosanthes* spp. particularly on acid soils along the wetter Queensland east coast. A well adapted, persistent, productive forage legume for some 1.7 million ha of clay soils, particularly in low rainfall areas, has been unavailable (Clem and Hall, 1994). Many of these clay soils are potentially very productive and have been improved by the introduction of grass

species. Rapid declines in the productivity of these improved pastures is thought to be due to reduced nitrogen availability. The introduction of legumes, particularly on cracking clay soils, is seen to be the most economical way to improve this (Cameron, 1977). Desmanthus has proved to be high yielding and persistent on these clay soils (Cook *et al.*, 1993). Desmanthus grows aggressively in even low rainfall environments and has good dry matter digestibility (Brewbaker, 1985) and protein levels (Adjei and Pitman, 1993; Johri *et al.*, 1987; Rao *et al.*, 1987). Generally, minerals are present at levels required for good stock performance. Desmanthus is grazing tolerant (Burt, 1993a) and persistence in the sward is attributed to perenniality and recruitment of seedlings (Graham *et al.*, 1991b). Three cultivars ('Bayamo', 'Marc' and 'Uman') were released for commercial production in 1991 and plant variety rights obtained by Wrightson Seeds Ltd. The three cultivars originate from different habitats in South America and significantly differ in development.

Adoption of desmanthus by graziers has been steady and the demand for seed is expected to increase markedly in the future (Wrightsons Seeds Ltd., 1994b). Although seed yields of over 2000 kg/ha have been achieved occasionally in controlled conditions these have not been achieved in commercial practice where yields of 300 to 400 kg/ha are typical (Anon, 1993b). Like many sub-tropical and tropical herbage legume species desmanthus retains many of its 'wild type' characteristics which present problems to the seed grower. These include extended flowering periods and ready pod dehiscence which vary between the cultivars released. Other problems reported from commercial practice include weed infestation and uncertainty as to which agronomic practices maximise seed production (Loch pers. comm., 1994).

To date no detailed research has been conducted on seed production in desmanthus. The development of potential seed yield (PSY) and its conversion to presentation yield has not been documented as are most fundamental principles of seed production. Even simple morphological development of the plant has not been documented. Where losses of PSY are occurring, there is no supporting research to indicate where in the developmental sequence these are and therefore no guide as to which steps should be

taken to enhance seed production. Similarly there is no supporting information useful for increasing PSY in the first instance.

The current research programme was conducted in order to increase understanding of this plant and in doing so attempt to increase the magnitude and reliability of desmanthus seed yields through improved agronomic practices. Because information is so limited it was decided to initially document development of the seed crop as a function of seed yield components. This enabled identification of seed yield potential and stages in the seed development sequence which may be limiting to seed production. Once identified further trials were conducted to confirm these findings and evaluate a range of agronomic practices at stages identified as problems both in commercial practice and within this study.

The present study was divided into four sections:

(a) Section one (Chapter 3) involves a study of plant development with emphasis on the quantifying and mapping of seed yield components and the interaction of population density on this. Particular attention has been paid to seasonal flowering patterns and the contributions of branching tiers to subsequent seed yield.

(b) Section two (Chapter 4) includes five (one pot based and four field) trials evaluating and refining the use of various herbicides on desmanthus at various growth stages.

(c) Section three (Chapter 5) continues on from findings in Chapter 3 and investigates methods of synchronising seed presentation (plant growth regulator (PGR) and desiccant application), reducing losses due to pod dehiscence (glue application) and evaluates a number of harvesting techniques. Effects are monitored in terms of seed yield components and potential and realised seed yields.

(d) Section four (Chapter 6) involves a further detailed evaluation of PGR application in controlled conditions. Rates of self-pollination are documented and compared with results from field trials.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General Description of Desmanthus

2.1.1 ORIGIN AND TAXONOMY

Desmanthus (*Desmanthus virgatus* (L.) Willd) (2n = 28, Luckow, 1993) is an erect, perennial, leguminous shrub to 1.3 m tall (Hacker, 1990) and native to the Americas (Burt, 1993a). The word 'desmanthus' originates from the Greek terms 'desme' meaning bundle and 'anthos' meaning flower (Allen and Allen, 1981).

The *Desmanthus* genus is a member of the Mimosaceae family of legumes which includes some 56 genera and 2800 species typically distributed within the tropics and sub-tropics (Hutchinson, 1973). The Mimosaceae are typically trees or shrubs with uses including human foodstuffs (*Entada gigas*), many valuable timbers (*Acacia* spp.) and forage trees and shrubs (*Leucaena leucocephala*) (Hutchinson, 1973).

In a recent review of *Desmanthus* taxonomy Burt (1993a) describes considerable confusion surrounding previous classification. The genus has been reported to include between 15 and 40 species based on regional revisions in North and Central America. It is likely that some *Desmanthus* species have been reported as more than one species and that Madagascan *Dichrostachys* spp. have been falsely reported as *Desmanthus* species (Lewis and Elias, 1981). Confusion between *Desmanthus* (Burkhardt, 1952 as cited by Burt, 1993a) and the morphologically similar *Neptunia* has also resulted in false identifications. A list of the 18 currently most accepted *Desmanthus* species has been published (Burt, 1993a) along with an artificial key and species descriptions (Burt, 1993b). If Madagascan species are excluded, all *Desmanthus* species are native to the Americas and range from near Minnesota (*D. illinoensis*) in the north to Santa Fe and Buenos Aires (*D. brevipes*) in the south. The *Desmanthus* genus occupies a wide variety of environments and soil types although is generally not well adapted to high rainfall / poor drainage locations and prefers alkaline or calcareous soils (Table 2.1).

Table 2.1 Geographical and edaphic distribution of *D. virgatus* subspecies.

D. virgatus type	Location	Environment
D. virgatus var. ***virgatus***	S. Arizona, Florida, Texas, Mexico, Brazil, Uruguay, West Indies	Pastures of good soil fertility. Lithosols with compacted clay horizons in Uruguay.
D. virgatus var. ***glandulosus***	W. Texas, Arizona, New Mexico	Rocky hillsides, plains and roadsides. Usually associated with limestone soils.
D. virgatus var. ***depressus***	Texas, Florida, Arizona, Mexico, Caribbean Islands, Brazil, Argentina, Galapagos	Widespread weed of lawns and dry pastures, disturbed ground and roadsides. Great soil tolerance.

(adapted from Burt, 1993a)

Being a forage plant with wide edaphic adaptation in its native habitats and a 'weedy' growth habit provide the *Desmanthus* genus with considerable potential for development in Australia as a herbage species. A comprehensive botanical monograph on the *Desmanthus* genus lists 24 species (Luckow, 1993).

Virtually all records of *Desmanthus* species as an introduced plant refer to what is currently recognised as the *D. virgatus* complex. Burt (1993a) suggests that a reason for this is that introductions may have been included in the *D. virgatus* complex as a 'default option' because of limited knowledge of the taxonomy of *Desmanthus* species. Burt (1993a) reported that *D. virgatus* has been introduced to Africa, Australia, Fiji, Hawaii and India.

Many synonyms of desmanthus exist reflecting the current, broadly based geographical distribution and (often) forage value of *D. virgatus*. Examples include: South America, 'frijillo de burro' (donkey bean) and 'anil de bode' (food of the goat) (Burt, 1993b); Caribbean Islands, 'hedge lucerne' (Carvalho and Mattus, 1974); Indonesia 'leucaena mini' (Suyadi *et al.*, 1989 as cited by Gardiner, 1992) and 'bundleflower' in the United States (Muncrief and Heizer, 1985).

Within its genus *D. virgatus* is recognised by the small, few-flowered heads, leaves with relatively few pairs of pinnae, well-developed stipules and broad pods (4 mm) compared to other sympatric species (Burt, 1993a). If treated as a single species, *D. virgatus* Willd is extremely variable in habit and the number of petiolar glands. The species has been further divided into three types (Isely, 1970):

D. virgatus var. *virgatus*: Erect or ascending, herbaceous or suffrutescent, to 1 m high. Pinnae 3 to 6 pairs, leaflets 4 to 9 mm glabrous, a single gland present.

D. virgatus var. *glandulosus*: The habit of var. *virgatus*, but glands also present between uppermost, and sometimes other, pairs of pinnae.

D. virgatus var. *depressus*: Plants prostrate or low, rarely exceeding 20 cm high; pinnae 2 to 4 pairs, petiole glands small, leaflets 3 to 4 mm (Burt, 1993b).

Geographical distributions of these three types are listed in Table 2.1.

2.1.2 LEGUME BASED PASTORALISM

2.1.2.1 Benefits to Tropical Pastoralism

The introduction of persistent and palatable legume pasture species is a commonly used strategy to increase tropical pasture productivity through:

(a) an increase in the supply of plant available nitrogen to the (usually grass) companion species

(b) provision of a more digestible and nutritive forage for animals.

In the past, this approach has been very successful especially in temperate regions where *Trifolium* spp. are generally recognised as being the most productive forage legumes. These species are generally not persistent in sub-tropical and tropical regions meaning that alternative species have to be found. Lower socio-economic situations of most sub-tropical and tropical countries has meant that pasture development in these regions has been slower than in temperate regions. Unlike temperate forage species, tropical forage plants have only recently been commercialised and among the most recent are the

tropical pasture legumes (Burt, 1993a). This is despite a history as a valuable fodder to domesticated animals dating back some 2000 years (Robinson, 1985).

Legume trees and shrubs provide a very useful forage source particularly in sub-tropical and tropical areas where they are grazed *in situ* or lopped casually (Brewbaker, 1985). Benefits of tree and shrub legumes include complementation of grass feed (high protein and often high energy feed), often persistence and N-fixation. Complementation of feed is especially important in tropical areas because of the relatively lower levels of digestibility of tropical grasses. Crude protein contents of N-fixing trees are generally high (Brewbaker, 1985). Average protein contents approximate 16% for tropical and temperate legumes compared with 9% for grasses (Minson, 1981) and legumes are often used to supplement protein supply to the grazing animal (Brewbaker, 1985).

2.1.2.2 Pasture Development in Queensland

Prior to the introduction of new herbage species, pastoralism in Queensland was based on existing native pastures. These were dominated by grasses of low digestibility and contained legumes which often did not persist under heavy grazing (Pollock, 1925 as cited by Burt, 1993a). As a result 'safe' stocking rates of 3 to 40 ha per beef animal are typical depending on the pasture type. The introduction of more palatable and persistent plant species has the potential to markedly increase production through increased reproductive performance, increased liveweight gain and provision of a year round feed supply (through conservation) (Gramshaw and Walker, 1988).

Improvement of pastures by the introduction of more productive grass and legume species began in Queensland and the Northern Territory (NT) with the introduction of *Panicum maximum* in 1867 (Bailey, 1919 as cited by Burt, 1993a) and paspalum (*Paspalum dilatatum*), para (*Brachiaria mutica*), rhodes (*Chloris gayana*) and kikuyu (*Pennisetum clandestinum*) grasses near the turn of the century. Many new species were introduced in the 1950s, mostly legumes introduced from South and Central America, Africa, India and South-East Asia (Gramshaw and Walker, 1988).

Before 1945, 17 grass and 6 legume species were in use (Cameron, 1977) and only the coastal lowlands and tropical speargrass country contained adapted legumes. Formation of the Queensland Pasture Liaison Committee in 1961, (which later became the Queensland Herbage Plant Liaison Committee (QPLC) in 1964 - a joint Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Queensland Department of Primary Industries (QDPI) body), signalled the beginning of the 'legume revolution'. Key genera introduced included *Stylosanthes, Neonotonia, Macroptilium, Desmodium, Leucaena, Macrotyloma, Trifolium* and *Lotononis*. Few new grass species were released by the QPLC as most useful grasses were in use prior to this period. Before the mid-1970s some 8000 grasses and 22000 legumes had been collected but only 24 grasses and 21 legumes released as cultivars (Mannetje, 1984).

Improved Queensland pastures are estimated to be 10 to 15 times more productive than native pastures (Mannetje, 1984) and up to 50-fold increases in production have been reported in the NT as a result of improving native pastures (McIvor, 1983).

Walker and Weston (1990) estimate that in Queensland, an easily attainable area of 22.1 million ha of a total area of 172.8 million ha can be converted to sown pastures. In 1988 over 1.5 million ha of improved legume / grass pasture (mostly in high and medium rainfall regions) and 3.5 million ha in grass-only pasture (mostly fertile brigalow lands of central and inland Queensland) had been established with a further 5 million ha naturalised (Mannetje, 1984). About 70% of this area was planted to grasses only. Legumes are required to prolong sward productivity in these areas (Walker and Weston, 1990).

Considerable potential to improve pastures within the Australian tropics \ sub-tropics exists and further introduction and development of new and existing species is an on-going process (Gramshaw and Walker, 1988). A five-fold increase in pasture production due to pasture improvement is expected in coastal and subcoastal Queensland (Mannetje, 1984).

2.1.2.3 The Need for Forage Legumes Adapted to Low Rainfall / Clay Soil Areas of Queensland

Despite considerable development of tropical pastures in Australia the choice of legume cultivars for the dry tropics is very limited. Genetic material used is dominated by *Stylosanthes* spp., *Leucaena leucocephala* and *Macroptilium atropurpureum*. However all have limitations including susceptibility to insect and fungal pests. Other genera have been investigated (e.g. *Centrosema, Arachis*) and *Desmanthus* is one of these (Burt, 1993a).

In Queensland, an estimated 1.7 million ha of clay soils have been sown to grass pasture with potential for a further 4 million ha of improved pasture on these soils (Weston *et al.*, 1981 as cited Keating and Mott, 1987). Rapid declines in pasture productivity on clay soils is thought to be due to reduced nitrogen availability and the introduction of legumes into native and sown pastures on cracking soils (vertisols) is seen as the most economical way of improving this (Cameron, 1977).

Popular legumes such as lucerne (*Medicago sativa*) and the stylos (*Stylosanthes* spp.) are not well adapted to low rainfall (600 to 1000 mm per annum) clay areas (Clem and Hall, 1994). Early trials evaluating alternative species involved *Macroptilium atropurpureum, M. lathyroides, Neonotonia wightii,* and *Centrosema pubescens* but even when these successfully established persistence was poor, the legumes often dying out in the first few years (Silvey *et al.*, 1978; Jones and Rees, 1972; Russel and Coaldrake, 1970; Scateni, 1964). Suggested reasons for poor persistence on clay soils include: water stress due to high 'wilting point' on clay soils, physical problems with seed germination and establishment, waterlogging / poor aeration, subsoil salinity, poor nodulation and disease (e.g. root rots in lucerne). Poor persistence due to grazing pressure is not a major factor (Keating and Mott, 1987).

Finding persistent, palatable, drought tolerant pasture legumes for clay soils is a priority for introduction and agronomic research in Queensland (Clem, 1992). In 1992, the Legumes for Clay Soils (LCS) programme, a collaborative project between CSIRO,

QDPI and the Meat Research Corporation began with emphasis on the introduction of forage legumes suitable for beef pastures particularly in the central and northern brigalow regions (low rainfall, clay soils) of Queensland (Clem, 1992).

2.1.3 DESMANTHUS AS A FORAGE PLANT

Members of the *Desmanthus* genus have been recognised as productive forage plants in their native habitats and have been introduced to a number of countries for that purpose. The available literature generally presents *D. virgatus* and other members of the genus as a palatable, moderately nutritious, persistent feed which responds well to grazing and has no harmful effects on the grazing or browsing animal.

2.1.3.1 Feed Quality and Animal Performance

In a review of important forage trees and legumes Brewbaker (1985) rated *D. virgatus* as a productive forage feed because of its aggressive growth and good dry matter digestibility. He stated that desmanthus occupied the same ecological niche as leucaena (*Leucaena leucocephala*), a plant which has traditionally been grown on low rainfall sites in Queensland (Brewbaker, 1985). Despite being a nutritious and palatable feed, leucaena has a number of characteristics which limit its use as a forage plant and which have contributed to poor productivity in leucaena stands. These include: the presence of a chemical (mimosine) which impairs stock performance; slow establishment and difficulty in managing the plant once it becomes a mature tree; and decimation of many leucaena stands by an introduced psyllid (*Heteropsylla cubana*) (Shelton *et al.*, 1991). A search of literature shows desmanthus to be free from these problems although a native psyllid may be a problem in seed crops (National Research Council, 1979).

Legumes are often used to supplement minerals, energy and, most importantly, protein in the diet of the grazing animal as well as to promote the growth of companion species through biological N-fixation. When compared to other common tropical forage legumes desmanthus has a moderate protein content (Johri *et al.*, 1987) being slightly lower than leucaena, its predecessor (Brewbaker, 1985; National Research Council, 1979). Reports

of desmanthus crude protein content range from 15 to 23% (Adjei and Pitman, 1993; Battad, 1993; Johri *et al.*, 1987; Rao *et al.*, 1987) and appear to be higher when plants are in the vegetative state. This variation is thought to reflect differing stages of plant development and the content of differing plant parts in analysis (often not specified). Protein content is lower in stem than leaf tissue (Battad, 1993; National Research Council, 1979). Therefore as the plant gets older and produces a higher component of stem material it would be expected that average crude protein content of forage declines.

Seeds and pods of legumes are typically of high protein content and *D. illinoensis* is no exception (Latting, 1961). Latting (1961) argues that because pods of *D. illinoensis* do not readily dehisce they are a good source of feed. Within extensive grazing systems this is particularly important as the pods and seeds of pasture legumes provide a significant contribution (protein and energy) to the nutritive value of pastures especially during the dry season, a time when high quality forage levels are often low.

Comparative evaluation of chemical composition (DM%, crude fibre, protein, Ca and P) of desmanthus with other tropical and sub-tropical forage legumes reveals desmanthus to be a nutritious feed (Johri *et al.*, 1987). Similar results have been published for desmanthus when prepared as a component of a concentrate feed for rabbits (Rao *et al.*, 1987).

The use of chemical composition as an indicator of the feed value of a forage assumes that uptake of different components of differing feeds are metabolised by the grazing animal similarly. Consideration must be made of the uptake and 'output' value of a feed on animal performance. Analysing digestibility and weight gain and comparing it with other feeds is one way of achieving this. Forage legumes with similarities to desmanthus include *Medicago sativa* (growth habit) and *Leucaena leucocephala* (edaphic niche). Both of these have higher digestibilities than desmanthus (Adjei, 1995; Kharat *et al.*, 1980) although differences are small. The high cell wall fraction of desmanthus compared to the other two species probably contributes to this (Kharat *et al.*, 1980).

Palatability and stock acceptance of the feed is important. Early reports of desmanthus being grazed in its native state describe it as being 'fresh' when other plants are dry or mature and to sprout vigorously from the crown (Carvalho and Mattus, 1974). Preferential grazing of other *Desmanthus* species (*D. illinoensis*) has also been reported (Latting, 1961).

2.1.3.2 Forage Yield and Persistence

Forage yield, persistence in pasture and seasonal period in which the plant can be grazed are important features of a productive forage plant. Within Australia desmanthus has been reported as being a palatable browse shrub, aggressive, persistent and tolerant of heavy grazing. Dry matter yields generally compare favourably with other tropical forage legumes but are lower than leucaena (National Research Council, 1979). Desmanthus has the ability to produce up to 13 t leaf DM/ha/yr (Adjei and Pitman, 1993) but yields of 7.6 t DM/ha/yr are typical (Payne *et al.*, 1955).

Desmanthus is generally reported as being very tolerant to, and persistent under, intensive grazing (Burt, 1993a). Grazing tolerance has been exhibited at many locations and in combination with vigorously growing grasses such as *Bothriochloa pertusa* (Caribbean islands)(Stehle, 1956 as cited Burt 1993a) and *Cynodon aethiopicus* (Pitman *et al.*, 1992). Repeated grazing leads to the development of a crown with as many as 50 stems being produced (Takahasi and Ripperton, 1949 as cited Burt 1993a). Desmanthus is an aggressive competitor and was noted to improve in productivity and density when grown with buffel grass (*Cenchrus ciliaris*) when other legumes have declined (Anon, 1994). Drought tolerance of desmanthus has also been shown at Piaui (Carvalho and Mattus, 1974).

Sward persistence of forage legumes is dependent on adequate seedling recruitment (Burrows and Porter, 1993). Desmanthus is a prolific seeder with 2000+ seeds per m^2 being recorded (Jones pers. comm. as cited by Burrows and Porter, 1993). Because of this, it has the ability to spread within the sward (Graham *et al.*, 1991a). Desmanthus seed is extremely hard (usually above 80% hardseed at pod dehiscence, Muir and Pitman,

1991) requiring rupturing or breakdown of the seed coat or strophiole before imbibition for germination can occur (Hopkinson, 1993). Breakdown of the hard seedcoat in soil can take many years. This, combined with an often extended presentation period, means that there is usually an abundance of seed ready for germination when appropriate conditions occur.

2.1.4 SCREENING AND COMMERCIAL RELEASE OF DESMANTHUS IN QUEENSLAND

2.1.4.1 Screening of Desmanthus in Queensland

Reports of *Desmanthus* spp. in Australia date back to the early 1900s (Bailey, 1909 as cited by Burt, 1993a) but few introductions occurred until the 1960s. Since then interest in desmanthus has increased and by 1984 272 accessions had been introduced for agronomic evaluation (Burt, 1993a).

Early screening of *Desmanthus* spp. accessions throughout Queensland was conducted by CSIRO and QDPI between 1978 and 1981 at a number of sites (Cook *et al.*, 1993). Evaluation on a variety of soil types and contrasting climates showed desmanthus to be both persistent and aggressive. Desmanthus performs well on a variety of soil types including heavy, medium and light clay soils, red podzols and solodic, strongly bleached sandy loams (Gardiner and Burt, 1995; Graham *et al.*, 1991a). Forty-one desmanthus accessions have been tested throughout Queensland as part of Co-ordinated Plant Evaluation (COPE) trials and desmanthus, notably CPI78373, has been shown to persist well even under drought and winter frost conditions (~600 mm) early in its development (Graham *et al.*, 1991b). High sodium contents (>20% CEC) have been noted in some soils where desmanthus has performed well (Cook, 1996). Higher rainfall and acid soil sites are associated with poor desmanthus growth (Cook, 1996; Cook *et al.*, 1993; Graham *et al.*, 1991a).

Desmanthus has consistently been persistent, aggressive in the sward and produced useful amounts of dry matter when grown in clay soils of low rainfall. This is despite

often strong competition by companion grasses (*Cenchrus ciliaris*, *Bothriochloa* spp.) which contribute to the decline of other legume species in pasture (Strickland *et al.*, 1986 as cited by Clem and Hall, 1994).

Current evaluation of desmanthus forage performance is being conducted in the LCS project with emphasis on grazing management and establishment (Jones, 1992). Evaluation is being conducted on clay soils in the 600 to 800 mm rainfall zone from Wandoan (south) to Collinsville (north) and includes open downs and brigalow areas. To date desmanthus has compared favourably with other species being evaluated (e.g. *Indigofera schimperi*, *Stylosanthes* aff. *scabra*) (Anon, 1993b).

2.1.4.2 Cultivar Release of Desmanthus

Three accessions (CPI78373, CPI82285 and CPI92803) were released for commercial production based on performance during evaluation in Queensland. Plant variety rights (PVR) of the three cultivars were obtained by Wrightson Seeds Ltd. in August 1991 from the New South Wales Department of Agriculture (NSWDOA) and the QDPI. The three released desmanthus accessions were selected to provide a range of flowering period (to encourage seedling regeneration) and forage production over the season. Features of the three cultivars (which are included in this study) are as follows:

cv. 'Marc' early flowering (2 to 3 months after sowing), decumbant to ascending, to 50 cm high and 100 cm diameter; stems 2 to 3 mm thick and 55 to 75 cm long, green coloured; derived from CPI78373 which originated from 23°15'S on a clay loam in Argentina, altitude 300 m, rainfall 650 mm, pH = 7.8

cv. 'Bayamo' mid-season flowering (late autumn), ascending, to 150 cm high and 150 cm diameter; stems 6 to 8 mm thick and 65 to 90 cm long, green coloured; derived from CPI82285 which originated from 20°21'N in Cuba, altitude 75 m, rainfall 1200 mm

cv. 'Uman' late flowering, decumbant, to 80 cm high and 250 cm diameter; stems 4 to 6 mm thick and 60 to 85 cm long, red coloured; derived from CPI92803

which originated from 18°09'N on an alkali clay soil in Mexico, altitude 50 m, rainfall 1250 mm (Graham *et al.*, 1991b).

Projected tonnages of seed required to meet expected domestic demand in Australia are listed by Wrightsons Seeds Ltd. (1994b) as being 15 t in 1997 and increasing to 165 t by 2002. Similar desmanthus seed production forecasts (>100 t annually) have been made by the QDPI and NSWDOA (Loch pers. comm., 1994) based on the large area of adaptation suitability of desmanthus and the absence of any other suitable tropical legume.

2.1.4.3 Commercial Production of Desmanthus Seed

Current commercial production of desmanthus seed occurs on two farms on the Atherton Tableland, North Queensland. Previous production in South-East Queensland was stopped due to low yields resulting from poor crop management practices. An annual production of 7 t has been estimated (Smith, 1996).

2.2 Plant Morphology

The legume family is large and contains considerable variation in habit and development from small, postrate, twining plants (*Macroptilium* and *Vigna* spp.) to woody trees greater than 4m high (some *Acacia* spp.). Detailed morphological reports are available for most species but in-depth studies of vegetative and floral development tend to be associated with species being exploited economically. Although desmanthus has long been recognised as a useful species, it has been used mostly in a 'casual' grazing capacity. Details of *Desmanthus* plant morphology are available mainly as a result of taxonomic revisions (Burt, 1993a, 1993b; Luckow, 1993) and preliminary investigations after its potential was identified (Latting, 1961). Because desmanthus is a newcomer to cropping systems, few 'crop related' features of plant development have been investigated previously. Virtually no information is available on plant physiology. Where knowledge has been collected it is often available only through informal sources.

2.2.1 VEGETATIVE

Considerable variation in morphology and agronomy exists within the *D. virgatus* complex (Burt, 1993a; Luckow, 1993). Despite site variation in morphology, underlying genetic unity between 69 *D. virgatus* accessions from the Americas (62) and areas of uncertain origin such as India and Malaysia (7) has been demonstrated by chemotaxic studies (Burt, 1993a). However, there was little geographical pattern between morphological and agronomic characteristics of the accessions.

2.2.1.1 Stems and Leaves

The *Desmanthus* genus includes herbs or shrubs all of which are unarmed (Allen and Allen, 1981). Leaves are bipinnate with many small, narrow leaflets with a sessile gland between the lowest pair. Stipules are bristly and persistent (Allen and Allen, 1981).

As a species *D. virgatus* is recognised by the few-flowered heads, leaves with relatively few (often 2 to 4) pairs of pinnae, well-developed stipules and pods somewhat broader (4 mm) than in other sympatric species (Burt, 1993b) (Figure 2.1). Stems are covered

with minute coarse hairs. Stipules (6 to 8 mm long) are narrow, hairlike and persistent. The petiole and primary rachis (together 20 to 50 mm long) bear 2 to 7 pairs of pinnae which has an axis of 20 to 60 mm. Leaflets (10 to 20 pairs per pinna, 2 to 6 mm long, 1 mm wide) are bluntly pointed (Hacker, 1990).

Within the *D. virgatus* complex considerable variation exists in above ground structural components. Plants vary in habit from prostrate, sprawling forms (CPI85178) to erect, 'woody' forms (Allen and Allen, 1981) up to 2 m tall and foliage colour from blue green (CPI85178) to bright green ('Marc').

2.2.1.2 Roots

Root structure has been shown to vary within the *D. virgatus* complex with a tap root recorded on some accessions (Gardiner, 1992). Roots of the three cultivars released in Queensland have not been described. The roots of desmanthus have been reported to be xylopodic (store water) (Carvalho and Mattus, 1974) although there is little complementary evidence in literature.

2.2.1.3 Nodulation

One of the most important features of legumes is the ability to fix atmospheric N via symbiotic association with *Rhizobium* bacteria (Beijerinck, 1888 as cited by Allen and Allen, 1981). The formation of nitrogen fixing nodules on the roots is most common to the Fabaceae although there are a few exceptions. Not all members of the family form this association, however and not all strains of *Rhizobium* nodulate (Allen and Allen, 1981). The three legume sub-families vary in the ability to nodulate, nodulation being the rule in the Papilionoideae and Mimosaceae but less common in the Caesalpiniodeae (Faria *et al.*, 1989).

Figure 2.1 Flowering branch and seed pod of *Desmanthus virgatus* L.

Source: Wrightson Seeds Ltd., 1994a

Nodules of temperate zone legumes tend to be annual (shed at end of season) whereas those of tropical species tend to be perennial (Allen and Allen, 1981). *Rhizobium* strains are often only able to nodulate one or a few legume species. Cultures of specific inoculum for given legume species are therefore created and used to inoculate seed or soil (Allen and Allen, 1981). Inoculation is usually economic because the cost of inoculant is generally less than one tenth the annual returns from increased production (Frederick, 1978).

Investigation into the identification of an effective *Rhizobium* strain for desmanthus has paralleled its evaluation and release in Queensland. In a pot screening of 48 accessions of *Desmanthus* (one each of *D. brevipes*, *D. fruticosus*, *D. illinoensis*, *D. subulatus,* two

of *D. covillei* and 42 of *D. virgatus*) against 17 strains of *Rhizobium* for effectiveness of N-fixation 23 accessions formed effective associations with 10 or more *Rhizobium* strains showing that *Desmanthus* does not generally have a high affinity for specific *Rhizobium* strains (Date, 1991). Similar promiscuity of rhizobia was previously observed in *D. virgatus* (Davis, 1982; Carvalho and Mattus, 1974; Norris, 1965) and *D. Illinoensis* and *D. Leptobolus* (Wilson, 1939a as cited by Allen and Allen, 1981). Five *Rhizobium* strains (CB1397, CB3126, CB3128, CB3130 and CB3132) have formed effective associations with most accessions. CB1397 (from neutral or alkaline soils) was recommended as the best overall strain for a wide range of accessions although CB3126 (from acid soils) was recommended for *D. virgatus* CPI38351 and TQ90 indicating a possible strain / soil type interaction (Date, 1991). Since this trial CB3126 has been released as the inoculum accompanying commercial supplies of desmanthus seed.

2.2.2 REPRODUCTIVE

2.2.2.1 Flower Structure

The inflorescence of *Desmanthus* spp. contains 4 to 10 (advanced) or 20 to 50 (primitive) florets variously including sterile (basally arranged), male and perfect florets. These are found singly or paired in the axils of leaves. Andromonoecy is common and varies from an increase in the number of male florets to functionally male plants. Generally, florets are receptive for 1 to 2 days with sterile florets falling off in the first morning. The clavate receptacle contains ovate, 1-veined sessile, peltate bracts at the base of each flower (Luckow, 1993).

The most comprehensive taxonomical description of *D. virgatus* inflorescence structure is provided by Luckow (1993):

> "One inflorescence per leaf axil, born on peduncles 0.6 to 4 cm long with a bract subtending each floret 1 to 2.2 mm long, 0.4 to 0.8 mm wide, deltate, pale green with red tips, membranous with an opaque midvein, peltate and pedicellate at the center of the head, sessile and often fused into a whorl at the base of the head, strongly 1-nerved, glabrous or minutely ciliolate. Floral buds obovate, apically

rounded. Heads 0.3 to 1.0 cm long containing 3 to 22 sterile, male and perfect flowers (sterile or male flowers sometimes absent)."

The sterile florets of the *Desmanthus* genus are smaller than the perfect and male flowers and have (5-) 10 (-12) white or pink staminodia. Differentiation of sterile florets is variable amongst *Desmanthus* species. In both male and perfect flowers the calyx is campanulate, 5-toothed and more or less regular. The corolla consists of 5 separate basally attenuate petals, typically 1-nerved, white or pale green with white margins. Some have red anthocyanic blotches. The androecium contains 5 to 10 (sometimes variable) separate stamens located in 2 ranks of differing maturation times. The white filaments are constricted at the point of insertion with the anthers so the anther is caducous. Anthers are dorsifixed to nearly basifixed, oblong, the connective broad and darker than the thecae (Luckow, 1993). Similar information is provided by Hacker (1990) and Allen and Allen (1981).

Floret structure of *D. virgatus* as described by Luckow (1993):

> "Sterile flowers 1 to 8: calyx 0.6 to 1.2 mm long, 0.4 to 1.0 mm wide, 5-lobed, widely obconic, pale green with white margins; staminodia 10, 1.7 to 7.5 mm long and white. Male flowers usually absent, rarely 1, born above the sterile florets, no ovary but with a similar androecium and perianth to perfect florets. Perfect florets 3 to 14; calyx 1.5 to 3.0 mm long, obconic, the tube 1.5 to 2.6 mm long, 0.6 to 1.4 mm wide, rimmed with free acute lobes 0.2 to 1.0 mm long, pale green with white margins, glabrous; petals 2.4 to 4.0 mm long, 0.4 to 0.8 mm wide, oblanceolate, green with red or purple tips, glabrous; stamens 10, rarely 5, 3.5 to 7.0 mm long, anthers eglandular; ovary 1.5 to 2.4 mm long, linear, glabrous, style 1.9 to 4.4 mm long, not exserted beyond the stamens."

Differences in flower structure occur among Queensland cultivars of *D. virgatus*. All cultivars are described (Cook *et al.*, 1995) as having a solitary, axillary, pale green-cream head but numbers of perfect flowers vary: 'Marc' 7 to 13, 'Bayamo' 8 to 15, 'Uman' 9 to 20. Whereas the petals and sepals of 'Marc' have pale tips, those of 'Bayamo' and 'Uman' have increasing proportions of red colouration at the tip.

2.2.2.2 Pollen

Incorporation of pollen into polyads is a common pollen economy feature of the Mimosaceae (Kalin Arroyo, 1981). The only literature referring to pollen structure was published by Luckow (1993) as part of a monograph. All species of desmanthus have tricolporate eumonads except *D. balsensis*. The *D. virgatus* complex is characterised by oblate or spheroida grains of 4 to 9 µm diameter and polar and equatorial axes of 31 to 46 and 37 to 50 µm respectively (Luckow, 1993).

2.2.2.3 Fruit

The fruit, or 'legume' of leguminous species are sessile, linear or falcate, subterate to dorsi-ventrally flattened and have a woody, coriaceous or rarely chartaceous pericarp. Fruits are generally dehiscent along both sutures, rarely along one suture or indehiscent (Luckow, 1993).

Luckow (1993) provided the following description of *D. virgatus* pod structure:
"Fruiting peduncles 1.0 to 5.2 cm long bearing 1 to 11 pods; legumes dehiscent along both sutures; pod 2.2 to 8.8 cm long, 2.5 to 4.0 mm wide, linear, straight or slightly falcate, tips acute, rarely attenuate and form a short beak to 1 mm, valves chartaceous, convex, glabrous, reddish brown to nearly black at maturity, somewhat wrinkled with raised reticulate veins; 9 to 27 seeds per pod." Allen and Allen (1981) add that the pods are membranous to leathery in texture.

Cultivar variations in legume structure relate to both pod and peduncle lengths, colour and seed number. All pods are described (Cook *et al.*, 1995) as smooth, two valved, flat linear and straight to slightly falcate. The number of pods per peduncle is stated to be less variable in 'Marc' (7 to 9) than 'Bayamo' (5 to 10) or 'Uman' (6 to 15). Lengths of fruiting peduncles ('Marc' 16 to 43 mm, 'Bayamo' 22 to 44 mm, 'Uman' 20 to 43 mm) and pods ('Marc' 36 to 64 mm, 'Bayamo' 43 to 63 mm, 'Uman' 32 to 63mm) vary although pod width is generally about 4 mm. Pod colour varies from green ('Marc') to red ('Uman' and 'Bayamo') when immature and generally becomes mid-brown when

mature although shade can vary from light to dark brown. Hacker (1990) states that pods often become nearly black when mature. Variation in seed number per pod is significant: 'Marc' (18 to 28), 'Bayamo' (14 to 23) and 'Uman' (12 to 17) (Cook *et al.*, 1995).

2.2.2.4 Seed

Leguminous seeds consist of two cotyledons separated by an embryonic axis from which the radicle and plumule emerge. Surrounding this is a seedcoat or testa which is water-tight over most of its surface. The only exception is the strophiole, a small protuberance in which the columnar cells are under apparent tension and which tend to split allowing water access into the seed. The strophiole acts as an important means of water access in many sub-tropical legumes, particularly of the Mimosaceae. The hilum is another structure located on the seed surface which acts as a one way hygroscopic valve letting water escape from the seed reducing the moisture content necessary for full development of hardseededness (Hopkinson, 1993).

Desmanthus seed dimensions reported by Luckow (1993) are 2.1 to 2.9 mm long by 1.4 to 2.7 mm wide and agree with Hacker (1990). Seeds are ovate and flattened and obliquely arranged within the pod. Colouration is red, golden brown (Luckow, 1993) or dark purple brown (Hacker, 1990). A 'U' shaped to lunate symmetrical pleurogram is present with dimensions 0.6 to 1.1 mm wide, 0.3 to 1.0 mm deep (Luckow, 1993).

Cultivar differences have been recorded. Seed descriptions as recorded for PVR description are:

'Marc' mid to dark brown, flattened, ovate, 2.1 to 3.6 mm long, 1.4 to 2.3 mm wide, mean mass 4.0 mg

'Bayamo' mid to dark brown, flattened, ovate, 2.4 to 3.3 mm long, 1.6 to 2.4 mm wide, mean mass 4.0 mg

'Uman' light to mid brown, flattened, ovate, 2.7 to 3.1 mm long, 2.1 to 2.8 mm wide, mean mass 4.4 mg (Cook *et al.*, 1995).

2.3 Plant Development

Little information has been published on crop development of desmanthus. The best sources of information tend to be informal through evaluation work, particularly that conducted in Queensland.

2.3.1 VEGETATIVE GROWTH AND DEVELOPMENT

Establishment can be divided into two phases: germination and emergence (imbibition to beginning active root growth), and seedling growth and survival (root growth onwards) (Cook, 1980).

2.3.1.1 Germination and Emergence

In order to germinate seeds require oxygen, water and an appropriate temperature. For vigorous establishment and eventual homogeneity of the crop the seeds used should be of suitable quality. This has been described (Hopkinson, 1993) as 'vital quality' and is simply the sum of all those attributes which will provide a successful seedling when the opportunity arrives.

All tropical pasture legumes produce seeds with prolonged impermeability to water (hardseededness). Water enters desmanthus seed either through the seed coat or via the strophiole. The former method requires scarification of the seed coat, the latter 'eruption' of the strophiole plug usually by physical shocks or temperature changes (Hopkinson, 1993).

Once water is imbibed at levels sufficient for germination, appropriate soil temperatures are required for rapid establishment. There are no references in the literature of stratification requirements for germination of desmanthus or of minimum temperatures required for establishment although the optimum temperature range for germination of scarified desmanthus seed is 26 to 33°C (Njarui *et al.*, 1992). Emergence of the radicle (embryonic root) is followed by emergence of the plumule both of which are sustained by

reserves within the seed. The cotyledons of legumes either remain below (hypogeal) the soil surface or, as in the case of desmanthus, emerge above the soil surface (epigeal) and photosynthetically sustain the seedling.

Cook (1980) reports that different species require exposure of the germinable seed to a given soil moisture content for different lengths of time to germinate and that perennials generally require longer than annuals. Desmanthus germination is sensitive to soil moisture, declining rapidly at osmotic potential below -300 kPa (Njarui *et al.*, 1992).

In Queensland, rainfall is generally sporadic and during summer there are very strong evaporative forces. The soil surrounding the seed can pass from field capacity to wilting point in less than one day. Most germinable legume seeds can survive dehydration after germination, as long as it is before radicle emergence, and return to a pre-germinative state (Hopkinson, 1993). This process of 'drying back' is clearly a mechanism to enhance survival in areas of sporadic rainfall. Desmanthus seed has shown poor establishment in these conditions possibly because the mechanism of drying back is apparently less effective than in other legumes (Loch pers. comm., 1995).

2.3.1.2 Seedling Growth and Survival

Early seedling growth is strongly related to daily minimum temperatures in legumes (Cooksley, 1986). Vegetative growth after seedling emergence is largely a product of soil moisture and temperature with growth rate being positively correlated with temperature until a temperature is reached whereby plant function is inhibited. Although not documented in *D. virgatus* other members of the *Desmanthus* genus (*D. illinoensis*) have shown poor seedling growth when exposed to low temperatures (Latting, 1961).

In most legumes the first true leaf is formed 10 to 12 days after sowing and lateral branching may begin after another 2 weeks (Crowder and Chheda, 1982). Desmanthus appears to be no exception. The establishment of desmanthus, although more rapid than other useful sub-tropical legume species (e.g. *Leucaena leucocephala*, Shelton *et al.*,

1991) is slower than in many weed species which can result in competition effects in seed crops (Section 2.6.8).

Further documentation of desmanthus development prior to transition into the reproductive phase (induction) was not found. This was documented as part of this study.

2.3.2 REPRODUCTIVE GROWTH AND DEVELOPMENT

In a comprehensive review of legume breeding systems and pollination biology, Kalin Arroyo (1981) reports voluminous but scattered literature on reproductive biology within the Fabaceae. More emphasis has been placed on the Papilionoids than Mimosoids and Caesalpinioids especially at more detailed physiological levels.

The conversion to a reproductive state will reduce vegetative growth in most determinate and some indeterminate species (Lorenzetti, 1993). In desmanthus, the response seems to be variable because of what are apparently differing controls of induction and subsequent initiation. In its original habitat (the district of Sao Joao do Piaui, Mexico) plants of *D. virgatus* were observed to begin flowering 90 to 120 days after sowing (Carvalho and Mattus, 1974). There is considerable variation in flowering time within the *D. virgatus* complex however. In Queensland, different cultivars of *D. virgatus* have varying flowering times i.e. 'Marc' early, 'Bayamo' mid season and 'Uman' late (Graham *et al.*, 1991b). Flowering duration in 'Marc' is also extended compared to the other cultivars. The impact of flowering on vegetative growth is not documented although 'Marc' has been described (Graham *et al.*, 1991b) as being more 'indeterminant' than 'Uman' or 'Bayamo'.

An indeterminate habit refers to reproductive development where the terminal apex of a stem or shoot continues to grow vegetatively after flowers are produced from axillary buds. Axillary buds can be vegetative or floral and at their base is found a pair of dormant secondary vegetative initials which act as a reservoir of new shoots. These can replace the primary axillary bud if it dies. Indeterminance therefore has the potential to

allow plants to produce more than one seed crop per year. Compensation for the loss (abortion) of a triad comes in the form of the successive triad which will subsequently develop. On the other hand a 'determinate habit' refers to the situation in which the main apex of the shoot becomes floral and vegetative development in that shoot ceases. Once in full flower there may be no vegetative buds left meaning that annuals die or perennials regrow but from dormant vegetative buds e.g. crowns. Flowering is influenced by photoperiod and moisture stress. Each floret is produced independently of other florets in the inflorescence and therefore there is no compensation for abortion (Hopkinson, 1988). Desmanthus, especially cultivars 'Bayamo' and 'Uman', appear to fit into this category. 'Marc' certainly has an extended flowering period but whether this is due to indeterminance or simply to flowering continuing as further flowering sites become available through normal plant growth is uncertain. It is possible to have determinate and indeterminate types of a single species (e.g. *Glycine max*, Wilcox and Frankenberger, 1987) and it is possible that *D. virgatus* is another species which exhibits this dual characteristic.

The principle controls of initiation and induction in legumes are photoperiod and stress. Photoperiodic responses become more marked (and predictable) with increasing distance away from the equator (Hill and Loch, 1993). The latitudes where the accessions which later became desmanthus cultivars were collected are sub-tropical (18° +) and it is likely that photoperiod is involved in the onset of flowering. It is thought that flowering in cultivars 'Bayamo' and 'Uman' are influenced by short day conditions (Loch, 1994) although critical daylengths / nightlengths have not been defined for any species of *Desmanthus* in literature. Induction in 'Marc' on the other hand appears to be insensitive to photoperiod with flowering beginning as early as a few months after emergence. Stage of plant development and possibly stress (e.g. moisture) appear to be key factors influencing flowering. Again conclusive documentation is missing from the literature.

Within a detailed taxonomic monograph (Luckow, 1993) of *Desmanthus*, each species was tested for autogamy. All species were self-compatible except for *D. covillei*. In some species cross pollination by hand resulted in greater fruit set than controls

(uncovered and tagged) (Luckow, 1993). *D. virgatus* may therefore require fertilising by pollinating vectors for enhancement of seed set. The degree of selfing also has a large effect on selection rates and approaches to selection. Strongly selfing species (e.g. *Leucaena glauca*, Hutton and Gray, 1959) show less genotypic and therefore less phenotypic variation on which to base selections (assuming phenotype is being used for selection). Therefore rates of sampling for selection of a trait differ between selfing and crossing species (Heering, 1994).

Reproductive development of desmanthus after pollination has not been documented other than the appearance of reproductive structures published in taxonomic studies (Section 2.2.2).

2.4 Expression of Seed Yield

2.4.1 SEED YIELD COMPONENTS

2.4.1.1 Introduction

Seed yield and quality of tropical herbage species vary widely both between and within districts and seasons. This has been attributed largely to a limited understanding of the growing seed crop and a failure therefore to manage it in such a way as to maximise seed yields (Hill and Loch, 1993). Generally the potential seed yields (PSY) of forage species are much higher than recovered seed yields (conversion percentages are often as low as 15% in forage species compared with 40% experienced in many grain crops). High potential numbers of seed sites, small seeds, dormancy, often indeterminate growth, pod dehiscence and uneven ripening in many forage species mean that specialised management is often required to maximise conversion of potential to realised seed yields (Lorenzetti, 1993).

Increases in temperate herbage seed yields have occurred during the past 50 years despite the absence of breeding for reproductive performance (Nordestgaard and Andersen, 1991). This has been attributed to site selection and improved agricultural

practices (Lorenzetti, 1993). Comparatively, tropical species have been almost totally neglected. Certainly no information is available on seed yield components and their expression in desmanthus. Information is limited to realised seed yields and duration of flowering.

Seed yields of over 2000 kg/ha have been achieved by the QDPI and CSIRO from desmanthus plants grown on weed mat. However these yields have not been achieved under field conditions. A total seasonal 'Marc' seed yield of over 1000 kg/ha (750 kg by header and a further 350 kg by vacuum harvesting) has been achieved (Hopkinson pers comm., 1995) although this is atypical. Yields of up to 800 kg/ha have been recorded in commercial seed production stands on the Atherton Tableland (cultivars unspecified) (Anon, 1993a) although later 'excellent' yields of 'Bayamo' and 'Uman' of 300 to 400 kg seed/ha are quoted (Anon, 1993b). At the other extreme some commercial crops have been 'abandoned' because of poor performance (Kenny pers. comm., 1995).

Seed yield

Seed yield can be expressed as a product of inflorescence density (unit area), potential seed site per inflorescence (e.g. fertile female and perfect flowers), percentage seed set, and mean individual seed weight (Hill and Loch, 1993).

In legumes, for example, seed yield can be expressed as:

SY/ua = Pl/ua X mean Inf/Pl X mean Pd/Inf X mean Sd/Pd X mean Sdwt

where: SY = seed yield
ua = unit area
Pl = plant
Inf = inflorescence
Pd = pod
Sd = seed
wt = weight

and Pd/Inf and Sd/Pd can be replaced by percentage seed set.

It must be noted that expression of seed yield is static and does not reflect the degree of crop synchronisation which can greatly influence presentation yields (Section 2.3.2).

Potential seed yield

Potential seed yield is commonly defined as the total weight of seeds per unit area produced by the crop over several weeks or, in the case of crops in which seed is allowed to fall on the ground prior to harvest, over the entire season. On this basis, it is substantially different from the more agronomically applicable concept of presentation seed yield i.e. that proportion of the potential seed yield present on the standing crop for harvest at a given time. Harvested seed yield is that proportion of the presentation seed yield recovered by the harvest process (Hill and Loch, 1993).

In order to measure the effectiveness of cropping practices some measure must be made of PSY so that comparisons can be made with presentation and harvested yields. This is an area which has had relatively little attention in herbage species particularly physiological expression of seed yield potential through ovule production and the subsequent physiological conversion efficiencies of this into presentation yield (Lorenzetti, 1993).

Although the definition of PSY allows losses at harvest to be calculated it does not allow losses prior to mature seed formation to be taken into account. Ultimately the size of the reproductive system depends on the number of reproductive stems per unit area, inflorescences per stem, flowers per inflorescence and ovules per flower. Therefore a useful alternative involves measuring total ovules present at anthesis per unit area (Lorenzetti, 1993).

i.e. PSY/ua = Pl/ua X Stm/Pl X Inf/Stm X Flt/Inf X Ov/Flt

where: Stm = stem(s)
Flt = floret(s)
Ov = ovule(s)

Expression of seed yield potential in this manner is sometimes inconsistent, being quoted assuming 100% seed set or, alternatively, using an arbitrary figure representing 'realistic' values for seed set (Hill and Loch, 1993). Care must be made to define percentage seed set.

The expression of PSY is complicated by the degree of crop synchronisation and the rate of seed shedding. Environmental (site, temperature, rainfall, humidity, soil type) and managerial (fertiliser, weed and pest control, irrigation timing and frequency) factors affect both PSY as a function of the seed yield components and the rate at which the potential is expressed (Hill and Loch, 1993). These factors are reviewed separately in Sections 2.5 and 2.6.

2.4.1.2 Contribution of Seed Yield Components (SYC) to Seed Yield

Analysis of various SYC is commonly used to identify areas which contribute to low PSY and their expression as presentation yields. Once problem areas have been identified techniques can often be used to improve seed yield performance. Literature involving the expression of seed yield as a product of its yield components in *Desmanthus* is virtually non-existent and is limited to one study on *D. illinoensis*. For this reason, discussion on development of SYC is extended to other forage species with emphasis on sub-tropical legumes.

Plant breeding

Genotype effects on plant vegetative performance generally correlate positively with reproductive performance and therefore seed production potential. Thus selection for a productive vegetative framework in forage legumes is often associated with increased seed yields. Correlations can be inconsistent, however, suggesting that there is no dependency between vegetative and reproductive performance (Somaroo, 1988). This means that plants from some species can be selected for either forage or reproductive performance or a combination of both.

Pre-anthesis

Management of legume seed crops is initially concerned with developing a vegetative framework upon which reproductive sites can be maximised (Hill and Loch, 1993). Maximising the number of inflorescences per unit area (at a given time) is the most important component of PSY in both grasses and legumes (Bullitta *et al.*, 1989; Evans *et al.*, 1986; Marshall, 1985). The establishment of a fully closed canopy is also important

to reduce weed competition (Hill and Loch, 1993). A balance between vegetative and reproductive matter which maximises inflorescences per unit area, flower induction and ovule development per plant must be achieved. Interception of light (as determined by population and defoliation), plant structure and the satisfaction of any development requirements are all influential in maximising flower number (Lorenzetti, 1993).

Population density is extremely important as branching responses (of mostly perennial) can alter PSY by changing the number of reproductive sites per plant (Humphreys and Riveros, 1986). The effects of plant density on SYC is discussed in detail in Section 3.1 as a precursor to the plant density trial (Chapter 3) conducted in this study.

Anthesis

Flowering plants commonly produce many more flowers than fruits (Bookman, 1984; Stephenson, 1981; Lloyd, 1980). In the wild state this provides certain advantages such as selection of superior fruits by the mother plant and maximising the chance of reproduction where resources are limiting (Lloyd, 1987; Stephenson, 1981). Seed production, however, usually involves maximising eventual seed presentation. This requires the production of maximum numbers of quality seed while reducing the period in which the seed ripens for (destructive) harvest[1]. In order to fulfil these requirements a rapid change from a strong vegetative to a vigorous reproductive phase is required after an adequate framework has been established.

In determinate, stress insensitive plants in which photoperiod strongly controls initiation and induction, this is generally out of the grower's control (Hopkinson, 1983 as cited by Shultze-Kraft and Keller-Grein, 1996).

[1] Other harvesting techniques (e.g. brush harvesting in many grasses and recovery of seed from the ground (e.g. by vacuum)) do not require as much emphasis on reducing the presentation period.

Pollination and seed set

Pollination refers to the transfer of pollen from the anther (angiosperms) or male cone (gymnosperms) to the stigma or female cone respectively (Weier *et al.*, 1982). Ultimately, the seed produced by a flowering plant is dependent on the number of ovules produced and the expression of this potential yield at harvest. Successful fertilisation of ovules (except by apomicts) is the first requirement in the expression of seed yield potential. Pollination can occur with (crossing or tripping by insects in some selfing species) or without (selfing species) the influence of a pollination vector (usually bees but can include birds, bats, some beetles) (Kalin Arroyo, 1981).

Non-viability or incompatibility of pollen grains or egg cells can considerably reduce seed set before anthesis (Marshall and Ludlam, 1989). Generally self-compatible plants have higher levels of seed set than incompatible plants with fruit:flower ratios around 3.5 times higher in the former (Wiens *et al.*, 1987). It has been suggested (Burd, 1994) that self-compatible plants can make use of a pollen source that self-incompatible plants cannot - from themselves. This implies that pollination deficits may also be responsible for low seed set in self-incompatible species. It is also possible that self-pollen may interfere with crossing in self-incompatible species by clogging stigmas. Self-incompatible species also seem to receive greater benefit from hand out-crossing than self-compatible species, reinforcing this idea. Burd (1994) also found that species with >15% fruit set showed little benefit from hand out-crossing. A linear relationship should exist if pollination alone is limiting. It was suggested therefore that a combination of pollination limitation and genetic load contribute to differences in levels of seed set.

Latting (1961) found that although flowers of well watered *D. illinoensis* occur in the axils of most leaves many abort. Anthers fall within a few hours after the flower opens providing only a limited time for pollination. This may be compensated by a high (average 51 (29 to 82)) number of florets per head. It is not certain whether this result can be applied to *D. virgatus* as *D. illinoensis* has a higher proportion of florets per inflorescence and may therefore reach a 'threshold' of seed set at a lower level of pollination. In the same evaluation Latting (1961) found discrepancies in the average number of flowers and the average number of pods in inflorescences on plants collected

at different sites. Losses of over 25% were attributed to poor seed set or ovule abortion after pollination. Latting (1961) also found that about 50% of *D. illinoensis* capsules examined held at least 1 undeveloped seed and less than one-fifth contained 2 or 3 undeveloped seeds. Again, however, whether this was a result of poor seed set or competition for assimilate between ovules is uncertain.

Enhancement of seed set is achieved in legumes through various means. These 'pollen economy' measures mean that less pollen needs to be produced, relative to say wind pollinated species such as grasses, in order for sufficient levels of pollination to occur. A common pollen economy measure in the Mimosaceae is female sterility of florets. Female sterility is present in a number of leguminous species and acts to reduce the amount of reproductive energy needed to produce maximum numbers of viable seed while maintaining the structure of the inflorescence for pollinator attraction (Kalin Arroyo, 1981). Differentiation of sterile florets is variable within the *Desmanthus* genus with *D. virgatus* containing a total of 3 to 22 sterile, male and perfect flowers. The number of sterile flowers varies from 1 to 8 whereas there is only one male flower or none at all (Luckow, 1993). It is possible that cultivar differences exist in the ratios of sterile and male florets to perfect florets. This may have implications for improvement in seed set by the introduction of pollinators if numbers of sterile florets and levels of self-incompatibility are limiting seed set.

In addition to pollen access to the stigma, pollen quality can also affect seed set or subsequent ovule abortion. Pollen quality or viability has been shown to affect quality of *Asclepias speciosa* pods probably through selective abortion (Bookman, 1984). Pollen viability is also affected by stresses during anther and pollen development. These include nutrient deficiencies (Dell, 1981; Agarwala *et al.*, 1979; Graham, 1975; Lohnis, 1940), drought (Austin, 1972), high temperatures (Herrero and Johnson, 1990) and cold stress (Brooking, 1976).

Post-anthesis

Post-gametic losses of PSY in forage legumes may reach as high as 50% as a result of abortion shortly after pollination. The reasons for this remain unclear promoting a

recommendation for research into this area (Lorenzetti, 1993). Although nutrition and stress effects are related to abortion, the genetic load as it relates to the breeding system of the species in question also appears to be important. For example outbreeders have much higher (often circa 50%) rates of post-gamic abortion than inbreeders (~ 15%) (Wiens *et al.*, 1987) and this is thought to be due to the more frequent expression of deleterious genes as a result of recombination (greater genetic load). These 'lethal' genes impair or prevent further development of the ovule (Lorenzetti, 1993).

High levels of abortion within 5 days of pollination have been demonstrated in *Trifolium repens* (Pasumarty *et al.*, 1993) and *Lotus* spp. (Hill and Supanjani, 1993; Tabora and Hill, 1991) although beyond 5 days some abortion may still occur. Pasumarty *et al.*, (1993) suggested that ovule degeneration before pollination was responsible for much of the post-pollination abortion.

Lorenzetti (1993) generalises that assimilation rate and partitioning have little effect on ovule site utilisation in perennials and that at least in some species this may be due to the often small size of reproductive sinks relative to vegetative sinks in perennials compared to annuals. Other authors however suggest that competition between reproductive and vegetative sinks may be responsible for ovule abortion of grasses and legumes (Griffith, 1992; Tabora and Hill, 1991).

Supply of nutrients to the developing ovule is thought to be often responsible for ovule losses (Evenari, 1984). The pod and its subtending leaf probably act as the major nutrition source for the developing desmanthus seed as is the case in annual legumes and in many perennial legumes. The roots may also act as another nutrition source as is probably the case in lucerne (Cohen *et al.*, 1972; Dovrat *et al.*, 1969; Dobrenz and Massengale, 1966).

Stresses on the mother plant can result in reduced assimilate supply to the ovule (Evenari, 1984). The ability of an ovule to compete with other parts of the plant for nutrients also determines its survival. In many dicotyledonous plants reproductive structures (e.g. existing seeds) are associated with a high 'sink strength' i.e. a high

potential capacity to accumulate assimilates and therefore a 'competitive' ability to attract assimilates relative to other (including ovules) parts of the plant. The reasons for this high sink strength are unclear and are explored by Wolswinkel (1992). Wolswinkel (1992) suggests that the ability of a sink (an ovule) to draw resources is related to its previous exposure to the resources. Initial sink demand is therefore random (as initial exposure to the resource will be random) with more sink demand being exhibited by sinks closer to the resource supply. Once the ovule becomes a sink it commands a higher sink demand for assimilate resulting in further supply of assimilate to that sink.

Competition between reproductive sites for assimilate can relate to:

(a) position on the mother plant e.g. abortion rates are often higher at proximal rather than distal sites (Nakamura, 1988)

(b) the stage at which a reproductive site is initiated and subsequently fertilised, early developing sites commanding a greater sink demand than late developing sites (Heitholt *et al.*, 1986).

Mean seed weight is the final component of seed yield. Generally larger seed is desirable because it produces seedlings which are more vigorous, particularly in small seeded species. However, high seed weight does not necessarily contribute to higher seed yields. In the large seeded *Pisum sativum*, for example, seed yield has been found to be positively correlated to pods per plant and seeds per pod but negatively correlated with seed weight (Malik and Hafez, 1977 as cited by Somaroo, 1988). A similar effect has been noted in *Trifolium repens* (Hampton *et al.*, 1987), a small seeded species. Thus management to maximise PSY and seed set and to minimise ovule abortion is generally more important than increasing seed weight. Similarly selection for higher seed weight is only beneficial if it has a positive effect on seed quality (Lorenzetti, 1993).

2.4.2 FLOWERING SPREAD

The low proportion of seed presented at a particular time is the key factor leading to lower harvested seed yields in forage grasses and legumes (Lorenzetti, 1993). Patterns of flowering, namely the timing and spread of maximal anthesis, has a large influence on

harvestable seed yield. This is particularly important for crops with a reduced standing time (e.g. due to pod dehiscence) as it reduces presentation yield (Hill and Loch, 1993).

Extended seed presentation time is common in sub-tropical forage legumes. For example, Wynn cassia (*Chamaecrista rotundifolia*) is capable of producing over 2 t of seed over the season but may often only present less than 50% of this for harvest at any one time. A similar trend is reported for siratro (*Macroptilium atropurpureum*) but only one third may be presented for harvest (Loch, 1993). Both of these species have indeterminate growth habits which are known to contribute to low seed yields in other forage species e.g. *Lotus pedunculatus* (Hare and Lucas, 1984). Crop synchronisation is also a function of seed set and the period required for seeds to reach maturity although this is less important than inflorescence number (Hopkinson and English, 1982).

The extended flowering period of desmanthus appears to be the main contributor to an extended seed presentation period. Commercial harvesting of desmanthus in Queensland involves a single destructive harvest between February and July depending on cultivar (Murat pers. comm., 1995). Because of the extended flowering period there are likely to be significant losses of desmanthus seed if harvest timing is not coincided with optimum presentation yield.

2.5 Environmental Effects on Seed Production

2.5.1 INTRODUCTION

The main environmental controls which influence reproductive growth, and therefore choice of seed production site, are discussed below. In many cases there is no literature on environmental effects on desmanthus development, particularly on 'Bayamo', 'Marc' and 'Uman'. It has been necessary, therefore, to extend the discussion to other herbage legume species.

2.5.2 TEMPERATURE AND PHOTOPERIOD

2.5.2.1 Latitude

Of particular interest to the seed grower is the potential to manipulate the time and period of flowering. Timing of flowering is determined almost exclusively by photoperiod and temperature responses. Crops originating from a Mediterranean environment tend to have long day (flower later in shorter days) and often vernalisation responses whereas tropical species tend to have a short day response (flowering is delayed in longer days). Generally shortday flowering tropical / sub-tropical legumes require:

(a) sufficient daylength change for photoperiodic responses

(b) a reliable wet season over the long day period for vegetative and early reproductive growth (~600 to 700 mm is often ideal especially if supplemented with irrigation)

(c) warm reliable dry season - usually 6 to 8 months beginning 0 to 3 months after the autumnal equinox and with rainfall of less than 300 to 400 mm

(d) freedom from frost (Hopkinson 1988).

If 'Uman' and 'Bayamo' are accepted as being short-day flowering responsive it is possible that the above guidelines are applicable. Site selection of 'Marc' however, is less certain and would appear to be more flexible as a photoperiodic cue for initiation

and induction is apparently not obligatory. These differences in requirements for flowering within one species agree with findings in other sub-tropical legumes (e.g. *Stylosanthes guianensis*, Trongkongsin and Humphries, 1988; Ison and Humphries, 1984).

Temperature tends to modify photoperiodic responses so that removal of photosensitivity genes can result in temperature responses taking over (Roberts *et al.*, 1993). Temperature / photoperiod interactions can be very influential on site selection. Although 'critical' photoperiods (Roberts *et al.*, 1993), or more precisely dark periods, which coincide with vigorous flowering of given species or cultivars are the key indicator of site (by latitude), interaction with temperature must also be considered. For example, birdsfoot trefoil (*Lotus corniculatus*) is an indeterminate long day species requiring a 16 hour photoperiod for full reproductive activity with a critical photoperiod of 14 to 14.5 hours (McKee, 1963). It has been observed in southern areas of the United States that birdsfoot trefoil begins to flower earlier, probably in response to warmer soil and air temperatures, and the result is a less synchronised crop than if grown in cooler climates i.e. in cooler climates birdsfoot trefoil breaks dormancy shortly after spring and by the time it reaches initiation is well over the daylength required for induction. This results in a more synchronised crop of early season umbels. These tend to produce more pods per umbel, more seeds per pod, more rapid development and greater seed masses than later developing umbels. Therefore sowing in cooler areas increases presentation yield by synchronising flowering (photoperiod and temperature effects) and increasing various seed yield components (temperature effects) (Beuselinck and McGraw, 1988).

2.5.2.2 Temperature

Species differences in temperature tolerance are common and influence site selection at a given latitude. In Queensland, for example, 'Greenleaf' (*Desmodium intortum*) and 'Silverleaf' (*D. uncinatum*) desmodiums and glycine (*Neonotonia wightii*) grow best in cooler (by latitude or elevation) conditions whereas centro (*Centrosema pubescens*) and puero (*Pueraria phaseoloides*) require lowland tropical environments (Hopkinson 1988).

Although cool temperatures are required to induce flowering in many temperate species this is not common in sub-tropical species and induction is largely a result of photoperiod. In some temperate forage legume species minimum temperature at anthesis accounts for up to 70% of the variance in seeds per head (Hampton and Hebblethwaite, 1983). There is no literature referring to temperature effects during anthesis on desmanthus seed yield development and expression.

Temperature can affect both rate of development, and partitioning of assimilate to the developing seed thereby influencing rates of flower and ovule abortion. Exposure of *Lupinus angustifolius* plants to short periods of high temperature before flowering prevents early flowers from forming pods. Later formed flowers on the same inflorescence, however, are able to set seed successfully (Downes and Gladstones, 1984a). Also, stress at flowering can reduce the number of pods per inflorescence (Downes and Gladstones, 1984a) and seeds per pod (Hampton and Hebblethwaite, 1983). Stress during pod development has increased seed abortion in young *L. angustifolius* pods but had little effect on older pods. This temperature sensitivity at flowering in *L. angustifolius* is supported by earlier work (Pate and Farrington, 1981) which showed that flowers attract assimilate strongly at the bud stage, lost sink strength after opening and regained it after corollas had senesced and fruits had begun to develop (Downes and Gladstones, 1984a, 1984b).

Plants raised under conditions which promote vegetative growth also tend to perform better reproductively than those with poor vegetative growth. Some plants (*Lupinus angustifolius* cv. Unicorp) however, have the ability to recover from temperature stress in the vegetative phase if post anthesis conditions are optimal for reproductive development and it has been suggested that conditions in the period after flowering have more impact on final seed yield than those prior to flowering (Downes and Gladstones, 1984b). Similarly, cold stress (21/16°C) of *Stylosanthes hamata* cv. 'Verano' during seedfill are associated with poor reproductive performance due to reduced seed set and fewer pods per inflorescence compared to warmer treatments (Argel and Humphries, 1983a).

Seed quality is also affected by temperature during seed fill. Seed size tends to be increased by exposure of the mother plant to cooler temperatures during seedfill. High temperatures after abscission increase hardseededness in some species (e.g. *Stylosanthes hamata* cv. Verano, Argel and Humphries, 1983a) by increasing lignin and hemicellulose content relative to cellulose in the testa. High temperatures also affect cutin deposition resulting in a less even surface than on seeds exposed to cooler conditions during seed maturation. Thus more soft seed can be expected from seed lots harvested from cool districts, from late crops or from crops with cool seed maturation conditions (Argel and Humphries, 1983b). High temperatures after abscission can reduce hardseed levels in some legume species (*Medicago* and *Trifolium*) but the extent of such reduction is cultivar dependent (Lodge *et al.*, 1990).

2.5.3 SOIL MOISTURE

Soil moisture has been shown to be a major determinant of seed yield in temperate legume species (Somaroo, 1988). However, research on the effect of rainfall on the growth of sub-tropical legume seed crops is limited and restricted to pasture situations e.g. rainfall has increased seed yields of South-East Queensland sown round-leafed cassia (*Chamaecrista rotundifolia* cv. Wynn) (pasture) by increasing vegetative growth (Jones and Bunch, 1995).

Suppression of flowering period is a common response to water stress in legumes (Muchow, 1985; Lawn, 1982) and can be beneficial in single pass harvest cropping systems. The strategic use of irrigation can be a useful management tool for promoting higher and better synchronised forage seed yields. In *Macroptilium atropurpureum* (indeterminate, daylength neutral for flowering) for example, wetting / drying cycles can be used to induce vigorous flowering (Hopkinson, 1977). Manipulation of the desmanthus seed crop in this way is probably limited to 'Marc' (because of its apparent 'indeterminance'). Strategic use of irrigation can also be used to reduce the incidence of disease (Hill and Loch, 1993) or lengthen the growing season by reducing the incidence of frost (by light sprinkling) in early sown cultivars in some districts (Hopkinson, 1988).

During reproductive development dry conditions with water supplementation by irrigation is usually desired. Dry conditions during anthesis enhance insect pollination and supplementation with irrigation during reproductive development allows greater control of partitioning of assimilate (Lorenzetti, 1993).

The effects of water stress on assimilate partitioning during seedfill are better documented in forage legumes than previous stages of development. Sink demands may be altered away from reproductive development by severe water stress and generally the greatest effect occurs during early seed development. For example in white clover (*Trifolium repens*) both moisture shortage and excessive moisture result in partitioning towards the vegetative rather than reproductive growth (Clifford, 1987). Water stress, and subsequent redistribution of assimilate during reproductive growth of Western Australian grown narrow-leafed lupins (*Lupinus angustifolius*) is thought to cause a failure to set pods of up to 93% on the main stem axis (Pate and Farrington, 1981; Greenwood *et al.*, 1975; Farrington and Gladstones, 1974). Factors contributing to decreased seed yields in lupin crops stressed during reproductive development include decreases in pod number per plant and seeds per pod (French and Turner, 1991). Similarly water stress during the reproductive development of *Glycine max* also results in lower seed yields as a result of decreased seed numbers per unit area (Heatherly, 1993). Seed weight is often reduced by water stress but is less important than seed number (Heatherly, 1993). There are no reports on the effects of water stress on the expression of seed yield potential or seed quality in desmanthus.

2.5.4 SOIL

Legumes often have very specific soil requirements and are generally more sensitive to soil factors than other crop plants. Important soil properties include:

(a) fertility - both deficiencies and toxicities for plant development (Russel, 1978)

(b) drainage - most thrive on free draining sandy soils whereas poor drainage is often associated with higher incidences of disease and machinery problems (e.g. harvest traffic) (Hopkinson, 1988)

(c) pH - acid soils are common in tropical areas and legumes differ in their abilities to tolerate low pH (Hopkinson, 1988).

Correcting soil nutrient deficiencies of forage plants can be approached from two directions:

(a) determining methods of providing limiting nutrients to the species in question

(b) selecting plants on an edaphic basis (Russell, 1978).

The former is economically more feasible in seed production systems than in pasture production and most nutrient deficiencies can be corrected by the application of an appropriate fertiliser or alteration of soil pH. Generally, differences in tolerance to deficiencies occur between genera (and to a lesser degree between species in the same genus, Andrew, 1978) rather than between cultivars (Russell, 1978).

The presence of minerals within soils at levels toxic to plant development also limit the usefulness of soils for crop production. The two main toxicities found in Australia are associated with salinity (high Na and often Mg levels particularly with depth leading to a decrease in exchangeable Ca) and low pH (notably high Al and Mn concentrations). Attempts to overcome these problems through amelioration and liming have had limited success (Russell, 1978). Generally desmanthus is 'best suited' to, and is more likely to be produced on, alkaline clay soils which do not usually have these toxicities.

Selection of desmanthus types for cultivar release has occurred on soil types for which desmanthus is to be used as a forage. This edaphic selection should ensure that the types selected for release ('Marc', 'Bayamo' and 'Uman') have fertility requirements which generally match the soils on which they are sown. Although this may provide adequate growth, these soils may not be optimal for desmanthus seed production.

2.5.4.1 Nitrogen

Strategic application of N has been shown to increase both herbage (Scateni, 1981) and seed yield (Hampton, 1987) in grasses, but generally has little benefit when applied to legume seed crops. Symbiotic N-fixation by *Rhizobium* spp. (either native or applied to

the crop as a specific inoculum) appears to generally provide adequate N for legume seed crop development and has been shown to be more readily taken up by the plant than soil N (Henzell *et al.*, 1968).

Rhizobium inoculum (CB3126) effectively nodulates desmanthus and contributes to vigorous growth (Date, 1991). This infers that successful nodulation of desmanthus will probably provide plant available N at levels adequate for at least moderate levels of seed production. Whether seed production can be raised by the application of strategically applied N is unknown.

2.5.4.2 Phosphorous

Phosphorous is a key element for legume growth (Lorenzetti, 1993) and is the most limiting nutrient to legume growth in Australia (Russell, 1978). Soil phosphate availability to plants is dependent on a number of soil processes (Barrow, 1978) and content varies widely even on a localised basis (Fox, 1978). Pasture plants appear to have a greater requirement for P when they are at growth stages where the plant has a high P content. This is usually during vegetative development (particularly during establishment) and during regrowth after cutting (Yaptenco, 1963 as cited Fox, 1978). Phosphorous deficiency may affect seed production by restricting growth of the vegetative canopy, and therefore reducing the number of reproductive sites, and delaying floral development (Robinson and Jones, 1972; Shelton and Humphries, 1971). Application of P to soybean (*Glycine max*) has resulted in a three-fold yield increase through increased numbers of seeds per pod, pod retention and seed size (Grabau and Blevins, 1989).

Phosphorous application effects on vegetative growth in legumes are often a result of P effects on nodulation and subsequent changes in N supply to the plant (Cadisch *et al.*, 1989; Maasdorp and Gutteridge, 1986). Phosphorous application may also increase N content in legumes through enhanced root development and plant metabolism (Andrew and Robins, 1969).

Vegetative growth and leaf crude protein content of desmanthus has been shown to respond to P and K application on near neutral soils. Optimum levels of P and K were 6.4 and 37.8 kg/ha respectively (Vasanthi *et al.*, 1994). More vigorous vegetative growth would imply that the establishment of an adequate framework on which seed production is based is more likely.

2.5.4.3 Sulphur

Sulphur is limiting to legume growth in many areas of sub-tropical and tropical Australia (Jones *et al.*, 1975 as cited by Russell, 1978), particularly areas of medium rainfall (Barrow, 1978). Native pastures grown on cracking clay soils in Queensland have responded to S applied as superphosphate and interacted with N (Scateni, 1981).

Chlorosis of desmanthus plant material in both pasture and seed crops has been attributed to S and / or Mo deficiencies (Hopkinson pers. comm. 1995). A S and Mo subtraction trial found that removal of both of these elements caused chlorosis and poor plant vigour (Hopkinson pers. comm., 1996). This suggests that a basal application of S (probably as superphosphate or S prills) in desmanthus crops is required if soil tests indicate low sulphur content.

2.5.4.4 Potassium

Application of K has been shown to affect desmanthus vegetative performance. At P applications of 13.2 and 26.4 kg/ha increasing rates of K (12.6 to 37.8 kg/ha) resulted in increased green matter yield. However, at the highest rate of P application increasing rates of K decreased herbage yield (Vasanthi *et al.*, 1994). Interaction between the effects of the two nutrients implies that the optimal combination of K and P must be provided for maximum crop growth.

2.5.4.5 Calcium

Different tropical legume species have been shown to have different Ca-response thresholds (Bell *et al.*, 1989) with deficiency resulting in thickening of root tips, blackening of roots, stunting of lateral roots and necrosis and a failure to expand in leaves. Raised Ca concentrations in nutrient solution has also resulted in a two- to three-fold increase in Ca and decreased Mg concentration in the tops of a number of temperate and sub-tropical pasture legumes (genera = *Desmodium, Glycine, Lotononis, Macroptilium, Stylosanthes* and *Trifolium*) although concentrations did not increase as much in the roots (Andrew and Johnson, 1976). Selected tropical legume species have been shown to be more tolerant to Ca deficiencies than temperate species although it was suggested that this was due to species differences rather than ecotype (Andrew and Norris, 1961).

Levels of Ca considered sub-optimal for legume growth also generally result in reduced and delayed nodulation (Bell *et al.*, 1989). Application of $CaCO_3$ has been associated with an increase in N percentage in the tops of plants and is similarly thought to be due to greater nodulation in the presence of higher levels of Ca (Andrew and Norris, 1961).

In a series of trials evaluating desmanthus in Queensland, persistence was generally better on clay sites than on other soil types. Cook (1996) suggested that this was possibly due to higher Ca levels in the clay soils rather than soil pH. Many of the original collections of desmanthus were obtained on clay soils and desmanthus has a moderate Ca content compared to other forage legumes. This suggests that application of Ca may be beneficial if desmanthus seed production occurs on soils of low Ca content.

2.5.4.6 Trace Elements

Trace elements refer to elements required by plants in small amounts but which are necessary for normal development and function of the plant. Trace element deficiencies (because of low concentrations in the soil, redox state or ion interactions) can interfere with both plant development and function and nodulation in legumes. Molybdenum is

probably the most important trace element affecting legume growth and its availability can be manipulated by changing soil pH e.g. liming has been shown to decrease Mo response of *Macroptilium atropurpureum* (Russel, 1978) indicating that raising pH increases levels of Mo available to the plant. In Queensland Mo deficiency is common in areas of higher rainfall (Barrow, 1978). In Australia many legumes have been found to respond to Mo usually through increasing symbiotic N-fixation, hence Mo deficiency is often apparent in pastures to which N fertiliser has been applied. Clover plants deficient in Mo often have more, smaller and paler (and less efficient N-fixing) nodules than do normal plants. Ion interactions also occur with Mo. Responses to applied Mo are reduced if P, S and B supply is limiting to growth so deficiencies should be avoided (Andrew, 1978).

Copper, Ca and possibly P are considered to be specifically involved in symbiotic N-fixation (Robson, 1978) as correction of deficiencies of Co, Mo, Ca and Cu in a range of legumes has resulted in greater concentrations of N in the tops of the legumes. Calcium and B are thought to be heavily involved in infection and nodule development whereas Mo, Co, Cu and Ca strongly influence nodule function. Although Fe and S are found in relatively high amounts in nodules, deficiencies have a greater effect on plant function than nodulation (Andrew and Kamprath, 1978) although when incorporated at sowing Fe has been found to increase nodulation in *Cajanus cajan* grown on alkaline vertisols in New South Wales (Herridge and Holland, 1993).

The presence of trace elements in soil solution at levels toxic to plants is more common on acid soils. The most common toxicities are Al and Mn. Where Al and Mn are present in the substrate at toxic levels legume growth declines logarithmically (Helyar, 1978). Soil pH regulates the amount of Al in soil solution and the effects of the two on plant growth and nodulation are difficult to separate out in the field (Andrew, 1978). Certainly tolerances to Al can vary widely between legume genera (Andrew *et al.*, 1973). Generally legumes are more sensitive to Mn excesses than non-legumes (Lohnis, 1951; Peech and Bradfield, 1948) with temperate legumes being more susceptible to Mn toxicity than tropical legumes (Andrew and Hegarty, 1969).

As desmanthus seed production is likely to occur on soils of near neutral or alkaline pH Al or Mn toxicity is not likely to be a problem. Molybdenum deficiency is more likely to be a concern and may contribute to the chlorosis observed in some seed crops in Queensland (Hopkinson pers. comm., 1995).

2.6 Crop Management and Seed Production

2.6.1 INTRODUCTION

Genotype-environment interactions determine the ultimate potential of a crop to produce seed. Crop management practices are used to enhance environmental effects on crop development such that development and expression of PSY are maximised. Synchronisation of flowering is also desirable in the destructive, single pass harvest systems most commonly used in Queensland. Seed quality is another consideration particularly if poor quality seed significantly reduces establishment potential.

Literature available on management of the desmanthus seed crop is virtually non-existent, a reflection of limited research on desmanthus seed production. This review will cover key aspects of seed crop management and provide suggestions on which areas are likely to greatest impact on desmanthus seed production. It has been necessary to extend the literature base to other sub-tropical / tropical forage species and a few temperate legume species to discuss most issues.

2.6.2 SITE

Site selection is a fundamental step for successful seed production. The area chosen must fulfil the requirements of the crop, notably in regard to thermal growing season, photoperiod and solar radiation (Section 2.5). Strong specificity for species or cultivars to certain environments are common (Ferguson *et al.*, 1981). In the case of short and long day plants variation in daylength must be sufficient to induce development, notably flowering. Within a given area (as defined by climate and general soil type) there is generally enough soil type variation to satisfy the requirements of many legume species. Therefore selection of a good general area for seed production is based primarily on climatic variables (Hopkinson, 1988). The identification of geographic regions where high legume and grass seed yields are consistently achieved can act as a useful guide when predicting the performance of crops in geoclimatically similar regions (Ferguson *et al.*, 1981).

Other site related factors can be manipulated by farm management practices. These include moisture supply, topography and soil fertility and development. Other considerations include the prevalence of pests, diseases and weeds which may either act as hosts to pathogens or produce seed which may contaminate seed lots and be expensive to remove. Clearly the target market is another important consideration. Although poor choice of environment is the key cause of failure of seed crops, seed can be produced in marginal environments at the expense of economy and reliability (Hopkinson, 1988).

The requirement for an adequate support and marketing infrastructure for the grower is important. Seed production requires the same services as any other farming enterprise particularly cropping including production, cleaning and marketing facilities (Hopkinson 1988). Hopkinson (1988) demonstrated that although rainfall and frost limit tropical seed production in substantial areas of Queensland, a lack of infrastructure limits seed production within these areas. Because of this, tropical forage seed production is limited to a small area near Katherine, NT and along Queensland's coastal strip, notably the Atherton Tableland and Gympie areas.

2.6.3 SEEDBED

An aerated seedbed of adequate moisture and temperature are required for germination and subsequent establishment. Optimum conditions will minimise the time required for the plant to start providing its own energy reserves separate from the seed and are particularly important in small seeded plants such as desmanthus. In developing an appropriate seedbed, attention should also be paid to the control of weeds which will later compete with the crop plant and to the removal of plant residue which can carry pests and diseases.

For reliable seed production (although not necessary for establishment) desmanthus seed crops should be grown on neutral to alkaline clay soils. If soils are acid, lime should be added as a basal application to raise soil pH. Sowing into a well cultivated seedbed is recommended for desmanthus seed production (Loch, 1994) and has been shown to

benefit establishment of other sub-tropical legumes (McIvor, 1983). Over-cultivation should be avoided as excessive tillage (secondary tillage) has been associated with decreased mycorrhizal activity and decreased root development and plant growth due to soil compaction (Mulligan *et al.*, 1985).

Commercial production history and edaphic adaptation of desmanthus indicates that seed production is likely to occur on clay soils. Characteristics of clay soils include poor drainage and aeration, root impedance and root disruption (due to swelling and cracking) (Keating and Mott, 1987; Greacen and Gardner, 1982) with differing clay soils requiring differing approaches to tillage (Johnson *et al.*, 1982). Although these are problems encountered during crop development prevention usually occurs prior to sowing of the crop. Techniques include incorporation of gypsum (Greacen and Gardner, 1982), sand or organic matter and deep cultivation (Lines-Kelly, 1992).

2.6.4 SOWING METHOD

Desmanthus is typically slow to establish relative to other forage legumes and, in an untreated state, high hardseed content results in uneven establishment. No information is available on spatial effects on desmanthus seed production and where information on establishment is present, it is limited and rarely the result of formal trials.

2.6.4.1 Sowing Date

Factors to consider when recommending a sowing date for a specific crop include: temperature restrictions for germination and effects on the rate of seedling emergence, photoperiod and temperature requirements for reproductive initiation and pattern of seasonal rainfall to match crop requirements for vegetative and reproductive development and allow crop management practices e.g. stress induction of flowering and pollination and harvesting.

Legumes often have a longer pre-reproductive phase (developmental stage required for floral initiation) than grasses and this may prevent certain herbage species (e.g. *Vigna parkeri*) initiating reproductive growth if planted late in the season (Loch, 1993).

It appears that the early flowering 'Marc' should be sown in November / December (southern latitudes) in sub-tropical areas in order to produce a sufficient vegetative structure over the humid summer period. Crops sown too early tend to be slow growing probably due to lower than optimum soil temperatures for establishment and are more susceptible to weed competition (Loch, 1994). Cultivars 'Bayamo' and 'Uman' appear to be short-day flowering plants and are generally not ready for harvest until June or July. Again November / December sowings are probably beneficial to make use of humid summer conditions during vegetative growth and to reduce the risk of cool winter temperatures which may reduce reproductive development.

2.6.4.2 Sowing Technique

Traditionally, row planting has been used in seed crops to facilitate roguing of off-types and allow inter-row cultivation. With the advent of more effective herbicides, inter-row cultivation has become uncommon suggesting that there is less reason to plant in rows. However, with some forage legumes row spacing has been shown to have a positive effect on seed yield (Loch, 1993; Kowithayakorn, 1978). Row spacing is used in desmanthus seed crops in Queensland (Cox pers. comm., 1994).

On clay soils in India sowing on raised beds or ridges has resulted in higher crop yields because excess water is removed from around the seed allowing greater aeration (Krantz *et al.*, 1978 as cited by Unger, 1982). However, in Queensland moisture is usually limiting and sowing into furrows or depressions can increase the time the seed is exposed to water. Mulches, furrow blocking and minimum tillage are other options. Enhancement of seed / soil moisture content in conventionally prepared seedbeds can be achieved by rolling after sowing (Loch, 1993).

2.6.4.3 Sowing Rate

There has been no research on the effect of population density on desmanthus seed yield. A sowing rate of 5 to 10 kg treated (scarified and inoculated with *Rhizobium*) seed/ha sown in 25 to 30 cm rows has been recommended (Loch, 1994). The justification for this is uncertain, although it is possible that rates have been increased to compensate for inconsistent levels of hardseededness after scarification and to reduce the likelihood of weed competition.

2.6.4.4 Sowing Depth

Because of its small seed size it is generally recommended that desmanthus be sown no deeper than 1 cm (Loch, 1994). Broadcast sowing is not recommended as this results in greater evaporative loss from both the soil surrounding the seed and the seed itself (Cook, 1980).

2.6.5 SEED QUALITY

Successful establishment of a homogenous and weed-free crop of a desired plant population requires seed of adequate quality (i.e. high vigour) in a state ready for rapid germination. For desmanthus seed production hardseeded inhibition of germination must be overcome. Hardseed content of a seedlot is determined to a large extent by ambient conditions during seed development and after abscission and as such is often variable, commonly exceeding 60% (Loch and Harvey, 1992).

Desmanthus seed coats are extremely hard and unlike other papilionaceous species hardseededness does not readily break down during threshing or while in the ground (Hopkinson and English, 1993). For forage production the requirement is for the presence of germinable seed in the soil at levels sufficient for a good initial stand. Hardseededness in the remaining seed should have been partially reduced for subsequent staggered germination as conditions become favourable for germination. Seed production, however, requires seed emergence to be uniform and reliable.

In order for homogenous establishment to occur, desmanthus seed-coats are artificially damaged to allow the entry of water either through the testa or the strophiole. In a comparison of methods of treating seed to induce artificial softening in *Desmanthus virgatus* CPI 78382 and two other sub-tropical forage legumes (*Cassia rotundifolia* cv. Wynn, and *Vigna parkeri* cv. Shaw) Hopkinson and English (1993) found significant treatment interactions. Hardseededness in all species was most effectively broken by immersion in concentrated sulphuric acid (5 to 25 minutes) followed by thorough rinsing in cold water. The use of hot water (60 to 90°C for 2.5 to 20 minutes) and dry heat (60 to 90°C; 1 to 24 hrs) gave variable results for desmanthus and it was proposed that these methods would need careful application to seed lots of varying hardseed levels. Placing seed in boiling water for a few seconds has been shown to work well although there may be some heat damage to seed (Hopkinson and English, 1993). Interestingly, mechanical scarification was unsuccessful in reducing hardseededness of desmanthus. This is probably because the method used (dropping seed onto a rotating coarse grade sanding disc at 2900 rpm) was too gentle to damage the seed coat sufficiently to allow water entry (Loch and Harvey, 1992).

The testa of legume seeds provides protection from pathogens and premature entry of water vapour which contribute to decreased seed life expectancy. 'Breaching' of the strophiole does not interfere with testa structure suggesting that methods of hardseed treatment which breach the strophiole are superior to methods which involve damage to the testa (Hopkinson, 1993). Hot water and dry heat treatments tend to breach the strophiole (Hopkinson and English, 1993) whereas acid and mechanical scarification damage the seed coat. Both hot water and acid treatments have been shown to be successful in reducing hardseededness but with the former being less useful in seed lots containing lower levels of hardseededness. However, both methods are impractical for treating large volumes of seed. Trials involving gentle scarification with a rice whitener significantly raised germination of seedlots without increasing the number of dead seeds. This process did little damage to the testa and in many cases breached the strophiole by impact with a sensitive part of the testa. Because the process is effective, gentle and can handle large quantities it appears to be suitable for commercial practice (Hopkinson, 1994).

2.6.6 IRRIGATION

Generally irrigation is used in legume seed crops to produce vigorous vegetative growth and (often) to manipulate reproductive development (Hill and Loch, 1993). Water stress of legume seed crops during establishment and vegetative development limit PSY by lowering plant population and restricting the development of an adequate vegetative framework. This limits the number of reproductive sites per plant. Although seasonal rainfall in Queensland is highest over the periods coinciding with establishment and vegetative production of desmanthus, rainfall is often unreliable. In addition, strong evaporative forces in the key commercial production areas at these times (Hopkinson, 1993) mean that regular irrigation is required to minimise the risk of water stress. The effects of these stresses are discussed in Section 2.5.3. Irrigation is used on all commercial desmanthus seed crops although the effects of irrigation volume and frequency are unknown, with applications being based on the avoidance of wilting.

Soil type influences irrigation frequency required for optimum plant development (McCown, 1973) with shallow rooting species (e.g. *Trifolium repens*) being more susceptible to soil moisture deficits than deeper rooting species (e.g. *Medicago sativa*) (Lattimore *et al.*, 1994). Desmanthus has a root system similar to *M. sativa* and is known to be tolerant of low rainfall (Cook *et al.*, 1993). This implies that greater irrigation intervals are probably sufficient for optimal desmanthus development than are required by other forage species.

2.6.7 PLANT GROWTH REGULATORS (PGR)

Plant growth regulators are chemicals which affect the growth and development of particular plant species. Typically PGR are registered for use in high value production systems such as fruit production and less commonly to reduce lodging in certain graminaceous grain and seed crops (Leonard *et al.*, 1985).

Herbage species are often indeterminate or have a prolonged flowering season, shed seed easily, or present seed in a form difficult to harvest. There is considerable potential to increase either presentation yield or harvested yield in seed crops of herbaceous species through chemical manipulation of plant development. Research into the application of PGR to seed crops of herbage species and the evaluation of these chemicals purely on a 'seed yield component' basis has been fairly recent. Experience has been limited to a few more economically significant herbage species, these being typically of temperate origin. The use of a PGR was considered a possible means of increasing seed yields in desmanthus and was evaluated in this study. A detailed review of literature on this topic is presented in Section 5.1.2.1.

2.6.8 WEEDS

Productive management of the seed crop requires effective weed control. In the past, conventional cultivation and hand weeding techniques have been prevalent in most seed crop species but, owing to greater constraints on labour and time (particularly in more developed countries), chemical control of weed species has increased. This has resulted in the development of a considerable range of selective herbicides. Literature on the control of weed species in desmanthus crops is limited to two papers (Loch and Harvey, 1990; Mastrocola *et al.*, 1983) and personal communications. Weed control in desmanthus seed crops has been identified as an area requiring urgent attention, particularly the control of broadleaved weeds (Loch pers. comm., 1994; Loch and Harvey, 1990). Therefore an entire chapter (Chapter 4) of this study has been devoted to weed control, and a detailed review of relevant literature is presented in Section 4.1.

2.6.9 PLANT HEALTH

2.6.9.1 Introduction

Pest and disease problems in sub-tropical or tropical regions are greater in legume than grass crops. Field pest and disease prevalence in seed crops contribute to decreased seed

yield potential due to impaired development of the vegetative framework and destruction of reproductive sites.

2.6.9.2 Pests

Little has been published on the impact of insects on seed crops in comparison with herbage crops (Labruyere, 1980) although insects are reported to significantly reduce both seed yields and quality (Lorenzetti, 1993).

Pests which significantly affect the production of tropical and sub-tropical grain legumes include butterfly caterpillars, pod borers, moth larvae, aphids, weevils, leaf hoppers, thrips and beetles (Purseglove, 1974). Common insect pests of sub-tropical forage legume seed crops include a number of butterfly and moth caterpillars which feed on pods and flowers, sucking bugs which affect pods and flowers, psyllids and root eating weevils (Loch, 1993). Insect pests of some pasture legumes released in Queensland are listed in Appendix 2.1.

A psyllid (*Heteropsylla cubana*), probably introduced from the Caribbean and first identified in Queensland in April 1986 has been associated with widespread and substantial damage to leucaena (*Leucaena leucocephala)* stands in Australia (Davidson, 1987) and a number of other South-East Asian and Pacific countries (Moog, 1992). Desmanthus has been proposed as a pest-free alternative to leucaena and was developed as such (Burt, 1993a; Gardiner, 1992). Prior to the release of desmanthus in Queensland reports of pest incidence in the *Desmanthus* genus were scarce. In studying *D. illinoensis* Latting (1961) noted that a bruchid beetle (*Acanthoscalides* sp.) caused significant damage to seeds and seed heads in late summer. Both adults and larvae were present in large numbers with larvae found within seeds. Minor damage by spittle bugs in Belize and some infestation by red-spider mite (*Tetranchus*) in shade-house conditions in Queensland have also been reported. In all cases damage has been slight and of short duration. Other insects observed included: *Lachesilla nibilis*, *Phylobaenus* sp., *Melanophthalama* sp., *Blissus leucopterus* and Noctuidae spp.

(Saunders, 1968)

In a review of literature to 1985 Burt (1993a) reported observations of damage to meristems of *D. fruticosus* by an unnamed insect in Townsville which paralleled work by Latting (1961) who reported that a chrysomatid beetle (*Anomoea laticlavia*) similarly damaged shoots of *D. illinoensis.*

A psyllid was first observed in small desmanthus stands in the late 1980s (Loch pers. comm., 1996) and since then has been sporadically associated with some stands causing yellowing and even death of some plants. Psyllid damage usually occurs late in the growing season (February-June) mostly in coastal areas (Wrightson Seeds Ltd., 1994a). This psyllid has not been identified, however, and control measures are unknown. No other reports of insect pests on Queensland grown desmanthus exist.

Measures are available for the control of most insect pests (Hill and Loch, 1993). These usually involve insecticidal sprays although a number of biological controls have been developed for the control of specific species. Concerns regarding the effects of insecticides on non-target insect species is resulting in a movement towards biological controls in some areas (Sepswasdi, 1985; Wongkae, 1985). Breeding for resistance to given pests and diseases is another way to avoid this problem (Lorenzetti, 1993) and selection for psyllid (*Heteropsylla cubana*) tolerance has been used within the *Leucaena* genus (Shelton *et al.*, 1991).

2.6.9.3 Disease

Damage to the seed crop by disease can be considerable and disease incidence is a key consideration in site selection (Hill and Loch, 1993) and in plant breeding and selection (Lorenzetti, 1993). As an example about one tenth of the United States lucerne crop is lost annually to disease (Graham *et al.*, 1972).

Diseases of some pasture legumes released in Queensland are listed in Appendix 2.2. In herbage legume seed crops grown in Queensland the key economically important disease types include rhizoctonia leaf blight, anthracnose of stylos (*Stylosanthes* spp.), puccinia on siratro (*Macroptilium atropurpureum*) and botrytis flower blight (Loch, 1993).

Burt (1993a) found no reference to fungal or bacterial attack on any *Desmanthus* species in any country. In fact, in Antigua, *D. virgatus* has been observed to flourish in a season when *Stylosanthes hamata* and *Macroptilium atropurpureum* were severely affected by anthracnose and rust respectively (Keoghan, 1982 as cited by Burt, 1993a).

Fusarium has been found in the roots of 3 to 5 year old 'Marc' plants grown in a red kraznozem soil under weedmat near Gympie, South-East Queensland (Loch pers. comm., 1995). Presence of the fungus was associated with poor growth and in some cases death of plants. Over the period of the trial soil pH dropped to below 5.0. No reports of this infection have been made under field conditions.

Widespread use of chemical treatments is often expensive and not economically feasible. Prevention of disease is generally better than treatment and includes site selection, breeding, and the removal of vectors such as herbage matter by cultivation. Seed treatments to reduce disease damage during establishment are also common and include dehulling of infected seed, seed coats or dressings and heat treatment (Davis, 1994).

2.6.10 DEFOLIATION

Strategic defoliation either by grazing or mechanical cutting is commonly used by seed growers of herbage species to synchronise flowering or remove competition effects which reduce final seed yield. Defoliation is more common in grasses than legumes although is routinely used in some temperate herbage legume species (e.g. *Trifolium repens* and *T. pratense*).

In legumes a vegetative framework with a closed canopy is required prior to flower initiation (Hopkinson, 1988). Some legumes close early and develop gradually through the growing season (e.g. *Macrotyloma axillare*) and require little or no cutting or grazing (Loch, 1985a as cited by Hill and Loch, 1993). Other crops however can produce excessive vegetative growth (e.g. *Stylosanthes guianensis* var. *guianensis*) which needs to be cut back prior to initiation (Loch *et al.*, 1976). Indeterminate creeping

legumes need exposure of their axillary buds to light to flower vigorously (Hopkinson, 1988).

Desmanthus has a similar growth habit to lucerne (*Medicago sativa*) and probably responds similarly to cutting. Timing and severity of cutting have been shown to reduce seed yields in New Zealand grown lucerne. Cutting of plants prior to seeding results in weakening of the plants, severely depressed reproductive potential, delayed flowering time and subsequently affected flower and seed production. Cutting plants at full bloom resulted in much lower seed yields than when cut at the appearance of green reproductive buds (Kowithayakorn and Hill, 1982). Similar reports have been made by Lorenzetti (1993) in a review of temperate herbage species seed production. Cutting height is also important having a greater reduction on final seed yield when cuts are lower (1.0 cm as opposed to 7.5 cm) and it is recommended that lucerne plants should not be cut in the establishment year (Kowithayakorn and Hill, 1982). In other species (red and white clover), cutting before anthesis is also recommended with delayed grazing generally decreasing yields (Lorenzetti, 1993). This can impart a temporary dormancy particularly in hot weather resulting in slower regrowth (Lattimore *et al.*, 1994).

Investigations into the regrowth characteristics of desmanthus after defoliation are limited, with emphasis being on herbage production and recommendations for cutting height and interval when used as a browse shrub have been developed (Battad, 1993). Desmanthus has been reported to be tolerant to four mowings per year and that constant mowing results in the production of as many as 50 slender stems from the crown (National Research Council, 1979) in a manner similar to lucerne.

Decreased frequency of cutting (1, 2 or 3 cuttings) of desmanthus is associated with increased annual DM production and a decline of leaf content from 50 to 10% dry matter but an increase in *in vitro* organic matter digestibility (IVOMD). The latter effect is surprising and has been attributed to the dilution of tannins (which reduce IVOMD) by later growth (Adjei and Pitman, 1993).

Muir and Pitman (1991) found that defoliation of pot grown *D. virgatus* by clipping (23, 22, 18 and 12 cm) every 2 weeks during autumn for three or six clipping cycles reduced root mass and non-structural carbohydrate concentrations in roots and stem bases. However this did not affect later spring regrowth because a critical total non-structural carbohydrate (TNC) concentration had been achieved prior to cutting which was estimated to be between 2 and 7% TNC (unpublished data as cited Adjei and Pitman, 1993). Winter (3 cm) defoliation reduced growth only if there had been no prior autumn cutting. Michaud *et al.* (1989) also found poor regrowth in desmanthus plants defoliated when mature. Generally, spring herbage production was correlated with carbohydrate levels at the end of autumn and these levels were reduced by prior clipping. It was concluded that while most clipping regimes will not reduce TNC below critical levels required for regrowth, the ability of a plant to accumulate TNC may be a good indicator of spring regrowth (Muir and Pitman, 1991). It has also been suggested (Keoghan pers. comm. as cited by Adjei and Pitman, 1993) that defoliation tolerance of plants browsed at an earlier stage is due to increased activity / viability of basal buds i.e. basal buds senesce over extended periods exposed to apical dominance. This infers that

(a) if defoliation is found to synchronise flowering (in indeterminate types), it may be a useful tool for increasing yields and

(b) desmanthus may have problems perennating if harvested conventionally.

2.6.11 ENHANCING POLLINATION

Low pollinator populations, low humidity and low temperature are associated with poor seed set (Humphreys and Riveros, 1986). In many non-selfing species considerable increases in seed set can be achieved by increasing pollinator populations usually by the introduction of bee (*Apis* sp.) hives. For example, effective pollination using bees can increase seed yields 31-fold in white clover (*Trifolium repens* cv. Haifa) over covered plants (Goodman and Williams, 1994). White clover is largely self-incompatible (Atwood, 1940), however, and therefore requires cross-pollination. Self-compatible species have a lesser requirement for pollinators. Nevertheless pollinators can increase seed yields in self-compatible species (Girardeau and Leuck, 1967).

Interestingly, Hopkinson (1988) has commented that insect pollination does not seem important in herbage legumes introduced to Queensland. Whether this is because most species introduced are adequately self-compatible or native populations of pollinators provide sufficient pollination is uncertain. It is likely, however, that some species will respond to the introduction of pollinators especially as wild populations are generally declining because of destruction of habitat (Kleinschmidt, 1993). Whether desmanthus is one of these is uncertain.

2.6.12 HARVESTING

Harvest losses are also significant however and in temperate forage grasses and legumes can range from 20 to 75% (Hampton, 1991; Elgersma 1990; Horeman, 1989; Simon, 1987; Meijer, 1985; Clifford and McCartin, 1985; Andersen and Andersen, 1980; Foster *et al.*, 1962). Losses at harvest of up to 60% in sub-tropical herbage seed production are common (Hill and Loch, 1993).

Considerations of appropriate harvesting technique include synchrony of development, pod dehiscence / proportion of seed on the ground and seed texture and size (Hill and Loch, 1993). The 'wild type' (indeterminate growth habit, extended flowering period and poor retention of mature seed on the standing crop) characteristics of many forage legume species means that presentation time for harvest is often extended whereas the optimum period for harvest is reduced. Even within closely synchronised crops seeds often vary in the time taken to mature. Combined with a progressive production of flowers, this results in a prolonged period of presentation for harvest. If conventional single pass harvest methods are to be used, it is crucial to identify the 'window' in which maximum presentation of high quality seed (at an appropriate moisture content for harvest and minimising drying costs) occurs. Failure to do so will result in substantial losses of seed yield.

Alternative methods include:

(a) progressive recovery of seed (e.g. by brush harvesting or multiple destructive harvests) over the prolonged presentation phase. In species in which active flowering

can be induced more than once a season (e.g. *Macroptilium atropurpureum*) multiple destructive harvests can be made (Hopkinson, 1988). Non-destructive methods such as brush harvesting are less common in legume production and are generally better suited to the harvesting of chaffy grasses (Loch, 1993).

(b) collection of seed after is has been shed This method is well suited to the harvest of many legume crops because premature germination or aging of the seed is prevented by the hard seed coat. Vacuum harvesting has the potential to recover large amounts of seed compared to conventional means in poorly synchronised and dehiscent crops but is expensive and damaging to the existing crop, making further harvests unlikely.

(c) prolong the time the seed is held in the pod Glues applied at, or just prior to, seed maturity have been used to extend retention time of some sub-tropical grasses (*Chloris gayana*) but is dependent on the amount of penetration into the seed head (Loch and Harvey 1983). This approach is not common in legume seed production but shows promise in some vegetable species even on a commercial scale (Williams, 1978). Retention time can also be increased by submerging ripe pods in vegetation (e.g. *M. atropurpureum*, Hopkinson, 1986), by frequent light irrigation, or by harvesting in cooler weather (Hill and Loch, 1993).

(d) reduce the spread of flowering by chemical (e.g. PGR, fertiliser), stress (moisture) or mechanical (defoliation) means.

Accurate identification of optimum harvest time is required in single pass destructive harvest systems (combine harvester). Even when 'successful' commercial (combine harvester) harvests of desmanthus seed have been achieved a large proportion of seed have been left on the ground (Murat pers. comm., 1995). It is possible that the alternative systems presented above can increase recovered seed yields.

A considerable part of this study (Chapter 5) involves investigation into the effects of pre-harvest and harvest techniques on seed yields of desmanthus. Methods used in the study are reviewed in more detail in Sections 5.1.2, 5.1.3 and 5.1.4.

CHAPTER THREE
THE EFFECT OF POPULATION DENSITY ON REPRODUCTIVE DEVELOPMENT OF 'MARC' DESMANTHUS

3.1 Introduction

Plant population density is a fundamental consideration in both forage and seed production. Alteration of the number of plants per unit area affects the local environment of plants within the crop. This is typically through the limitation of light (intensity), moisture or soil nutrients to individual plants (Donald, 1963). These limitations result in stresses to the individual plant which are widely interpreted as 'competitive effects'. Plants often show extreme phenotypic plasticity when exposed to changes in population density (Donald, 1963). Rate of development and form are affected in both the vegetative and reproductive phases. At the individual plant level this manifests itself in changes in both seed yield and yield components and the conversion of these to realised seed yield.

Competition within a crop may be intra- or inter-specific. If weed species are controlled, the former is more common, particularly in seed production systems where the need to reduce post-harvest cleaning usually necessitates monocultures. In forage legume seed production systems, the vegetative framework regulates the number of potential reproductive sites per plant. In desmanthus these are located in the leaf axils (Cox, pers. comm., 1995) and so potential yield per plant is expected to depend on the number of leaves and branches on an individual plant. If moisture and soil nutrients are non-limiting, high population densities result in an increase in plant height as plants compete for light (Donald 1963). This is often associated with lodging as stem diameters decline. In branching herbage legume species this can also be associated with a decline in branch number per plant e.g. *Medicago sativa* (Askarian, 1993; Kowithayakorn, 1978). Similarly leaf number and area per plant are typically reduced by increased plant population density with early senescence and abscission usually occurring in leaves which are shaded either by structures of neighbouring plants or from the plant itself (Donald,

1963). Thus leaves located at the bases of stems tend to abscise before those typically younger leaves located further up the stem.

The degree to which reproductive development of the individual plant is affected by population density and therefore competition is particularly important for seed production systems. Increasing population density has been shown to significantly ($P<0.05$) reduce numbers of flower buds, open flowers and harvestable racemes per plant in lucerne (*Medicago sativa*) a similar branching forage legume to desmanthus (Askarian, 1993). These reductions are related to the decreased number of reproductive sites arising from the reduced vegetative framework of plants growing in high population densities. Seed set has also been found to be higher when *M. sativa* is grown at lower population densities (Kowithayakorn, 1978). This means that as well as establishing a greater potential seed yield per plant, a greater proportion of this potential is converted into actual seed yield when *M. sativa* plants are grown at low population densities. In *M. sativa*, pods per raceme and seeds per pod have been shown to be generally insensitive to changes in plant density whereas thousand seed weight slightly declined at higher plant populations (Askarian, 1993). The similar growth habits of *M. sativa* and desmanthus suggests that similar responses to population density are likely to occur.

In forage seed production maximisation of seed number per unit area is usually associated with high seed yields (Hampton, 1988b). Thus reductions in population are typically associated with increases in potential and actual seed numbers per plant. However when converted to per unit area values this effect is reduced because, although per plant seed yields decline with increasing plant population, the numbers of plants per unit area compensate for this effect. Usually there is a limited range of population densities at which large numbers (both potential and actual) of seed is produced per unit area, this reflecting a combination of seed produced per plant and plants per unit area. This is commonly termed the 'optimum' population density and is the targeted level for established populations. These optimal population densities are often species specific although they have been shown to vary with cultivar in some species e.g. *Glycine max* (Wilcox, 1974). Considering the differences in plant size between cultivars 'Bayamo',

'Marc' and 'Uman' it is possible that different population densities may be optimal for these different cultivars.

Another consideration is the spatial arrangement of plants at a given plant density. Most crop species are sown in rows. This is recommended for most annual seed crops of forage species because adequate row sowing facilitates:

(a) a reduction in required seeding rate enabling greater areas to be sown for multiplication with (often) limited and expensive early generation seed

(b) off types being more easily identified

(c) weed control by inter row cultivation

(d) a more even supply of nutrients

(e) a more appropriate light environment supplied to the plant particularly when sowing rates are low (Humphreys and Riveros, 1986).

However, row spacing as opposed to sward systems are more prone to erosion, have less unit area forage for grazing and can provide conditions which make heavy machinery transport more difficult in wet weather (Humphreys and Riveros, 1986). In row systems per unit area population density is a product of row number per unit area and plant numbers per unit of row. In some species (e.g. *Phaseolus vulgaris*) the type of spatial arrangement is less important than population density per unit area (Field and Nkumbula, 1986) while in others row spacing requires more consideration. For instance in *M. sativa* row spacing has been shown to affect first season seed yield while sowing rate had no effect. In the second year however this relationship was reversed, sowing rate being more influential (Askarian, 1993).

Generalisations on the effects of plant density on per unit area crop vegetative and reproductive yields have been put forward by a number of authors and are well reviewed by Willey and Heath (1969). Generally forage yield per unit area (usually measured as dry matter) follows an asymptotic relationship with increasing population density although some authors have reported removal from this trend at very high populations (Campbell and Viets, 1967; Bleasdale, 1966; Bruinsma, 1966). Reproductive yield, as in seed production, has been generalised to have a parabolic relationship with population density. In some instances an asymptotic relationship is observed but these are

exceptions and a parabolic relationship is generally accepted for reproductive yields. The implications of this relationship is that there will be a range of densities at which there are marked changes in seed yield and that after some point further increases in population density will have little further effect. Certainly there will be no gain in sowing at very high population densities in seed crops. A number of equations have been developed to model the effects of density on vegetative and reproductive yields of crop plants. After evaluation of these equations Willey and Heath (1969) conclude that although many may be useful to 'smooth over' data in many species they are often limited to a restricted population density range. Of those equations listed, reciprocal types are seen to be superior to other types because they have a greater biological basis (Willey and Heath, 1969). Mead (1979) agrees that the reciprocal model is superior to others in predicting practical yield-density relationships adding that Bleasdale's and Nelder's model is also useful. These equations are:

(a) Reciprocal model

$$w^{-1} = a + bp + yp^2$$

(b) Bleasdale (1967) and Nelder (1962) model

$$w^{-x} = a + bp$$

where w = yield per plant

p = plants per unit area

a, b, x and y = constants

As far as trial design is concerned, investigation into the effects of population density on cropping monocultures is much less complex than, say, pasture communities where several species may be involved. In crop situations interest is usually on the effects of differing distances of neighbours on the individual plant within the crop. Also of consideration is the number of equidistant neighbours from the individual plant (Mead, 1979). When considering the effects of plant density on a crop, either at the plant level or the per unit area level, trial designs tend to fall into two categories:

(a) those that have specific objectives and are (usually) targeted at a limited range of population densities or spatial arrangements (response models) e.g. complete randomised block.

(b) systematic designs which are based more on statistical benefits rather than agronomic practices (Mead, 1979) e.g. radial design.

Systematic designs for plant spacing studies have a number of advantages over response models. These include a minimum of wastage of materials and surface area in order to obtain a wide range of population densities and having no set objectives which may bias results or mean that important aspects are overlooked. The key disadvantage is that the opportunity to sample may be limited and randomisation can be difficult. This means that the number of assumptions which need to be made in order for analysis of variance to be successful can be easily violated. These include problems of heterogeneity within the crop, effective randomisation of sampling and the requirement for yield errors to be normally distributed and independent (Mead, 1979). The advantages of systematic designs, however, make them particularly useful in species where very little is known about the population density behaviour. This approach was seen as the best option for the study of the effects of population density on the development of seed yield indices in desmanthus.

Systematic designs initially developed by Nelder (1962) and modified by Bleasdale (1967) have been widely adopted by agronomists. They involve the establishment of a an almost rectangular area around the individual plant, the area of which is variable being defined by either straight lines or arcs of concentric circles. The design most often chosen is a 'radial' type where areas around any given plant (except in the outer or inner arcs) is created by a series of arcs (concentric circles of increasing radial dimensions centred on a fixed point) bisected by radians separated by a fixed angle (4.5°). For more detail the reader is referred to Bleasdale (1967).

Because information available on desmanthus plant development seed crop production is so limited it was necessary to take a broad approach in the early stages of the study. The use of a density trial was seen as imperative because of the extent of the effect that differences in population density have on the establishment and expression of seed yield potential in most plant species. Conducting of trials without prior determination of optimum population density would risk the commercial validity of results i.e. maximum

seed yields for specific conditions may not be achieved because of sub-optimal levels of inter-plant competition. The use of a density trial also provided the opportunity to quantify the vegetative and reproductive development of the plant with particular emphasis on seed yield components. The information generated from this trial was used to identify further areas of research which in turn provided the basis for further work.

The use of a radial design allowed the establishment of a wide range of population densities (2 to 185 plants/m^2) while minimising the effort required to maintain the trial. This was considered important because of the lack of previous work in this area. Also, at the beginning this trial, herbicide screenings had not been conducted under field conditions. As such it was preferable to hand weed a small area, as facilitated by the radial design, than to attempt to control weeds by chemical means with the risk the chosen chemical might adversely affect desmanthus development. The use of a full circle allowed sufficient numbers of plants (80 at each density) for the destructive sampling used in this trial.

The objectives of this study were to determine the effect of population density on desmanthus in South-East Queensland with particular emphasis on:

(a) vegetative development
(b) reproductive development
(c) flowering pattern
(d) the generation of potential seed yield
(e) the contribution of various seed yield components to potential seed yield.

Cultivar 'Marc' was used as it has been identified as the cultivar with the greatest potential for increased seed yields (Loch pers. comm., 1994).

3.2 Materials and Methods

3.2.1 DESIGN

The population (91 plants/m^2) typical of commercial practice was estimated using current commercial sowing rates (4 kg seed/ha; TSW = 3.50g; 80% plant establishment and survival) and was used centrally in the logarithmic density scale of the trial. Extreme plant densities (2 and 216 plants/m^2), although presumed to be inappropriate for commercial seed production, were also included to ensure a full evaluation of the extent of the seed production response to intra-specific competition in South-East Queensland under irrigation.

The trial consisted of 80 radians bisecting 31 arcs (Figure 3.1, Plate 3.1). The innermost and outermost arcs were excluded to avoid edge effects. The remaining 29 arcs were divided into seven density groups separated by barrier arcs which were excluded from measurements (Table 3.1). Every second arc was used for plant sampling within each density group.

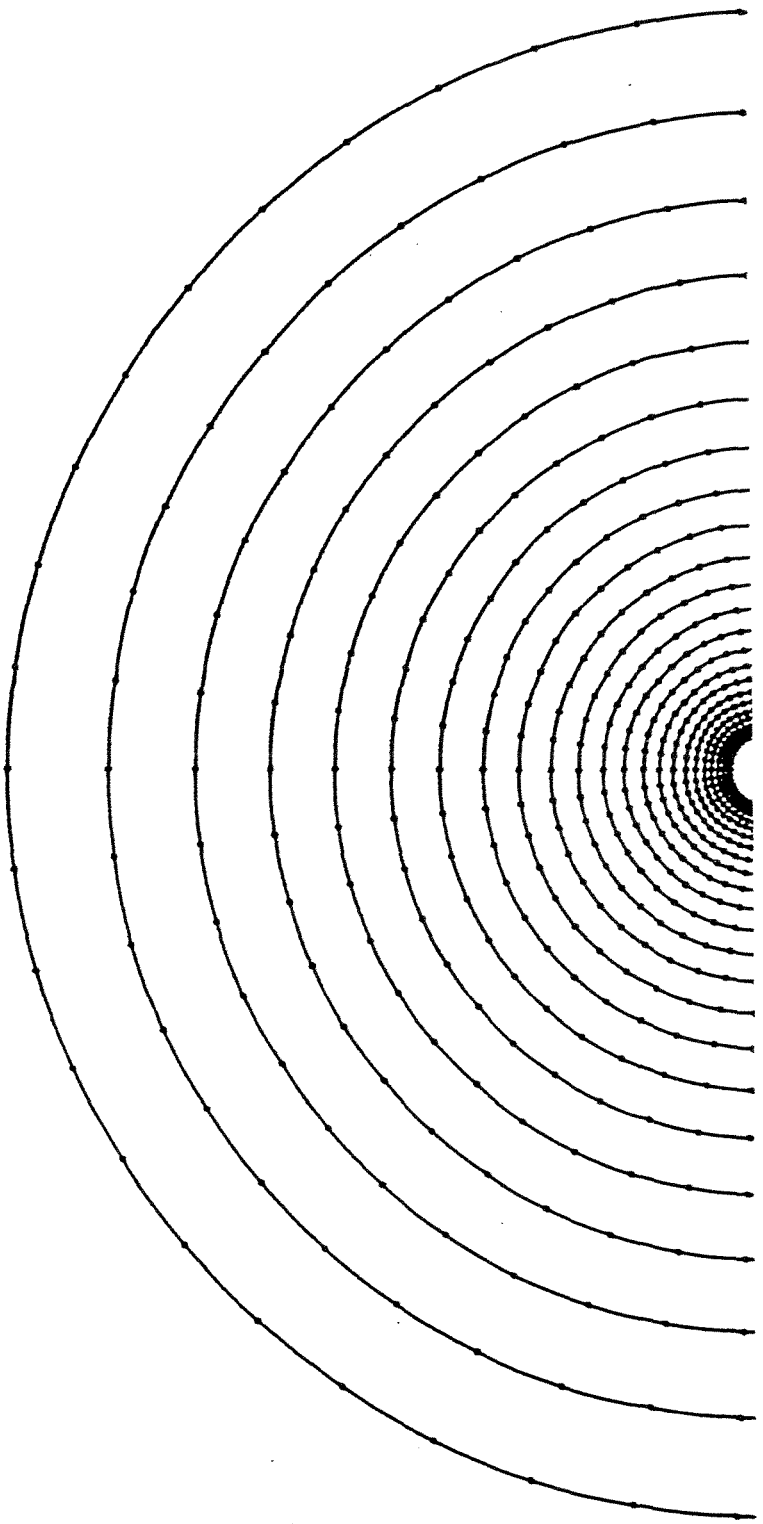
Table 3.1 **Allocation of density groups and specifications of the radial trial.**

Density group	Arc number	Distance along radii (m)	Area per plant (cm^2)	Population density (pl/m^2)	Mean sampled population density (pl/m^2)
	1[1]	0.83	46.15	216.68	
1	2[2]	0.90	54.07	184.95	
	3	0.98	63.35	157.85	159.85
1	4[2]	1.06	74.21	134.75	
	5[1]	1.15	86.92	115.05	
2	6[2]	1.25	101.80	98.23	
	7	1.35	119.22	83.87	84.93
2	8[2]	1.47	139.61	71.62	
	9[1]	1.59	163.48	61.16	
3	10[2]	1.71	191.29	52.28	
	11	1.86	223.87	44.67	45.22
3	12[2]	2.01	262.06	38.16	
	13[1]	2.18	306.90	32.58	
4	14[2]	2.35	359.35	27.83	
	15	2.55	420.70	23.77	24.07
4	16[2]	2.76	492.51	20.30	
	17[1]	2.98	577.51	17.35	
5	18[2]	3.23	674.89	14.82	
	19	3.49	790.05	12.66	12.81
5	20[2]	3.78	925.02	10.81	
	21[1]	4.09	1083.01	9.24	
6	22[2]	4.42	1267.78	7.89	
	23	4.79	1484.30	6.74	6.82
6	24[2]	5.18	1737.65	5.76	
	25[1]	5.60	2034.22	4.92	
7	26[2]	6.06	2381.51	4.20	
	27	6.56	2788.14	3.59	
7	28[2]	7.10	3263.75	3.06	3.17
	29	7.68	3821.16	2.62	
7	30[2]	8.31	4474.18	2.24	
	31[1]	8.99	5238.30	1.91	

[1] Border arc

[2] Sampled arc

Figure 3.1 Layout of the radial trial (after Nelder, 1962).



3.2.2 CROP MANAGEMENT

The site, previously in irrigated lucerne (*Medicago sativa*), was located on a slightly alkaline black cracking clay soil (Kraznozem) near Kilkivan, South-East Queensland (26°03'S 152°15'E). Soil tests conducted in early October 1994 are presented in Appendix 3.1. Existing vegetation was sprayed with glyphosate (2.2 kg ai/ha) 3 weeks prior to rotary hoeing (two passes) to 20 cm depth on 11 November 1994. This resulted in a fine weed-free seedbed.

Seed was acid scarified (Appendix 3.2) prior to sowing and a sample germination tested (Appendix 3.2). Seed was of good quality (mean normal germination = 86% after 10 days). Seed was inoculated (Appendix 3.2), pre-germinated (TP: 20/35 °C 14/10 hr) and sown into plastic establishment tubes after two days (13 November, radicle emergence). The tubes were placed in racks (each containing 100 tubes) and transferred into a glasshouse (~25 °C constant) for 24 days after which poor vigour plants were discarded, tube numbers were reduced to 50 per tray and the trays placed outside for the seedlings to 'harden'.

The trial was pegged out and sown on 20 December (39 days post-germination). A metal spike was hammered into the ground at the centre of the trial. A chain, on which sowing sites had been marked, was attached to the spike by a ring and the outer arc pegged by moving the chain forward by a set distance resulting in an angle between successive radians of 4.5°. Once the outer pegs were in place, seedlings were planted as marked on the chain between the outer peg and the central spike. A 10 cm deep soil corer was used to form planting holes and the plants simply removed from their tubes and slipped in. Conditions at sowing were hot (~35°C) and dry. Irrigation water was applied immediately after planting and the trial was irrigated weekly over the following 6 weeks. Establishment was effective and only 37 reserve plants (of the same age) were planted into the radial trial on 24 January.

Plate 3.1 **Radial trial at Kilkivan, South-East Queensland, 11 January 1995. The population density of prostrate plants (foreground) is between 6 and 24 plants/m^2 whereas erect plants (mid-ground) are planted at rates up to 217 plants/m^2 (central border arc).**

Irrigation was used to supplement low rainfall particularly during vegetative development (November to March) (Appendix 3.3). In the 1994/1995 season water applied to the crop was approximately 6 mm/day during the November to February period, declining to 4.5 mm/day and 2 mm/day in March and April respectively. Mean total water applied thereafter was approximately 0.5 mm/day. Poor regrowth in the second year (Appendix 3.4) led to the premature cessation of the trial in January 1996 and irrigation was not applied thereafter.

Grass control was achieved by spraying with haloxyfop (0.15 kg ai /ha, 400 l H_2O/ha) on 24 January, 23 March and 12 April. Broadleaved weeds were controlled by regular (weekly) handweeding.

A psyllid (*Acizzia* spp.) infestation was observed on 7 March and controlled by spraying dimethoate (0.03 kg ai/100 l H_2O and soaking vegetation until runoff) on 23 March, 30 May and 11 June. Psyllid damage to stem tips and leaf fall was noted between identification of the psyllid and treatment. The only other insect present with the potential to impair plant development was the green vegetable beetle (*Nezara viridula*). This was only occasionally sighted however.

3.2.3 MEASUREMENTS

3.2.3.1 Vegetative Development

Destructive harvests of three randomly selected plants from each selected density group were conducted every 2 weeks between 60 and 212 days after germination. Plant height and breadth were recorded prior to cutting just below the crown. Each plant was then divided into branching tiers and the following components recorded:

- branch number
- branch length - from the top of the crown (primary tier) or base, to the tip

- branch mass - dried to constant weight (48 hours at 70°C)
- leaf number
- leaf mass - dried to constant weight (48 hours at 70°C)
- node number - node where no leaf was present

3.2.3.2 Flowering Pattern

Five plants per density group were randomly selected and tagged with a marked peg. Inflorescence numbers were recorded on these plants twice a week over the entire flowering period. Inflorescences were removed immediately following counting to avoid the possibility of double counting. Flower counts were recorded by branching tier. Categories of branching tier were:

- Tier one (primary branch): main stem arising from the crown
- Tier two (secondary branches): branches originating from a primary branch
- Tier three (tertiary branches): branches originating from a secondary branch, etc.

3.2.3.3 Reproductive Development

The same harvested plants were examined for reproductive indices and the following components recorded by plant and by branching tier:

- mean number of reproductive sites (leaf axils)
- mean number of inflorescences, immature umbels (pods are fully expanded, not abscised) or mature umbels (pods have abscised, as evidenced by an abscission line on the peduncle) but not dehisced. See Plate 3.2 for examples.
- mean number of florets per inflorescence
- mean number of pods per umbel
- mean number of seeds per immature or mature pod

One harvested plant per density group was selected and a structural diagram produced which included the number and location of vegetative (branches, leaves, nodes) and reproductive (inflorescences, immature, mature and dehisced pods) structures.

It was originally intended to count ovule numbers in ovaries selected from all density groups at two weekly intervals over the season. Failure to adapt a promising, time saving ovary staining technique (Herr, 1971) to desmanthus cv. 'Marc' meant that a more time consuming technique of ovule dissection was used. As a result sampling was reduced to two times (7 March and 4 April) when plants were actively flowering and to three density groups (2, 4 and 6). Pre-anthesis inflorescences were collected, individual ovaries were dissected from randomly selected florets and ovules dissected from them. Ovules were counted under a microscope after mounting in water.

3.2.3.4 Seed Quality Indices Over the Season

Seed was collected periodically (every two weeks) over the season from each selected density group by gently shaking plants and catching falling seed in a bucket. The seed was evaluated for standard germination, hardseededness and thousand seed weight (Appendix 3.2) during August 1995.

Monthly germination tests (Appendix 3.2) were conducted on seed samples collected during the season to check for any storage deterioration which could affect comparisons between seed collected early or late in the season. There were no significant (P=0.05) changes in standard germination characteristics.

3.2.3.5 Harvested Seed

Seed was 'harvested' on 20 June 1995 using a quadrat (0.1 m^2) and sampling at 5 quadrats per density group. Mature seed remaining on the plant was collected by cutting all plants within the quadrat, drying and hand threshing. Seed recovery by this method was very high, no seed being found in the post-cleaning residue after threshing.

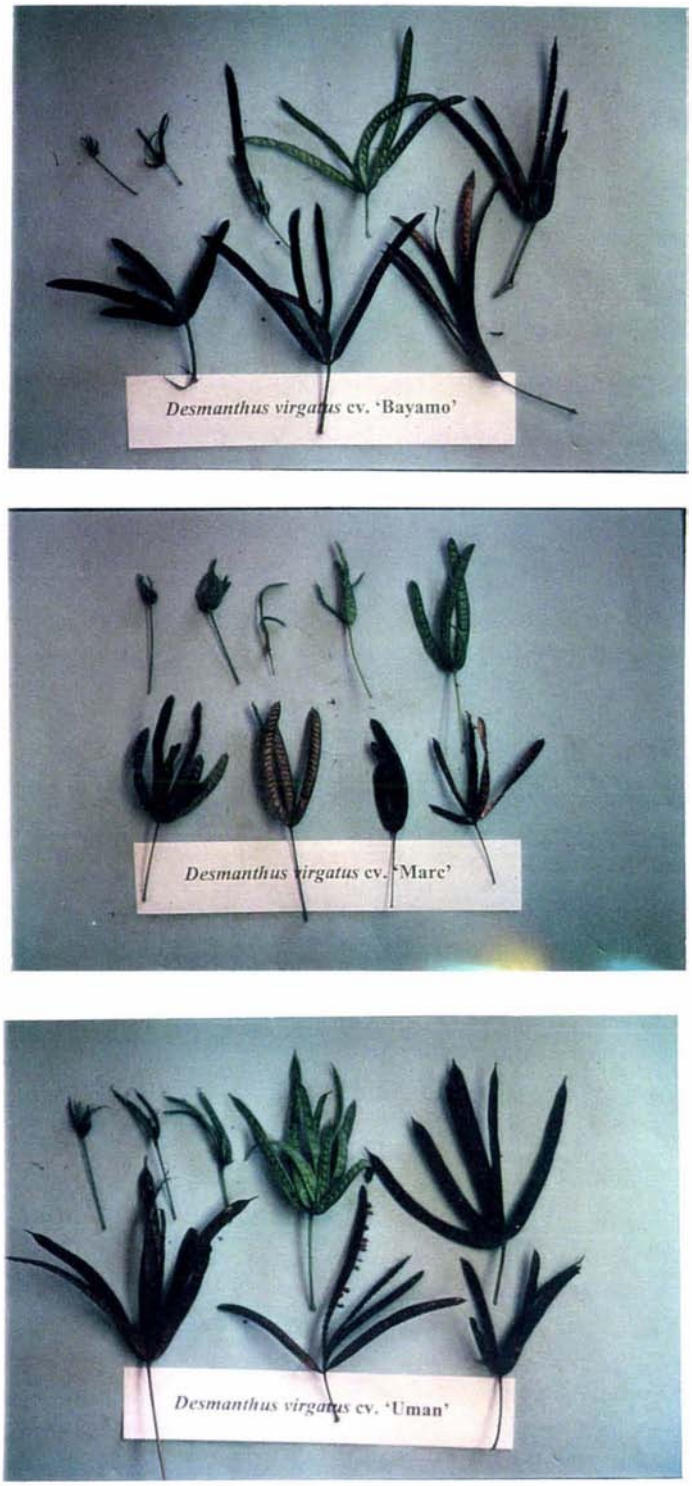


Plate 3.2 Pod development sequences of *Desmanthus virgatus* cvs. 'Bayamo', 'Marc' and 'Uman' shortly after anthesis until pod dehiscence (left to right by row). Immature pods as classified in this study are represented by the fourth umbel in cvs. 'Bayamo' and 'Uman' and the fifth umbel in cv. 'Marc'. Mature pods are represented by the fifth umbels in cvs. 'Bayamo' and 'Uman' and seventh umbel in cv. 'Marc'.

Fallen seed in each quadrat was collected by brushing, along with the top 2 cm of topsoil, into polythene bags. Seed and soil was separated by 'floating off' seed as the seed-soil mixture was slowly poured into 100% perchlorethylene solution. Again, seed recovery was very high with no seed being found in the soil fraction after perchlorethylene treatment. All harvested seed was further cleaned using a combination of screens and air separation. Standard germination, seed weight and hardseed (Appendix 3.2) tests were conducted in August 1995.

3.2.3.6 Climate Data

Rainfall and irrigation were measured on site over the season. Minimum and maximum temperature data was obtained from the nearby DPI research station at Gympie. Long term rainfall and temperature data was obtained for Gympie from QDPI in Indooroopilly, Brisbane (Appendix 3.3).

3.2.4 STATISTICAL ANALYSIS

Data was converted on SAS statistical software. Means and standard errors were generated for all vegetative and reproductive indices and graphed to identify trends. Variables were calculated to determine the contribution of various components to final yield.

Means of all time independent data were generated and compared using analysis of variance and generalised linear model procedures. Treatment mean values of variables with a significant F value were compared with the Fischer's protected least significant difference test (P=0.05). Correlation coefficients were generated between measured and calculated variables.

3.3 Results

3.3.1 PLANT DEVELOPMENT

3.3.1.1 Vegetative

During establishment one main stem (tier 1) was produced with bipinnate leaflets arising from buds located towards the stem apex. Early formed leaves were observed to have fewer pairs (1 or 2) of pinnae than later forming leaves (3 or 4 pairs of pinnae). Up to 10 nodes are produced in this early main-stem elongation phase. In many cases the more basal nodes did not produce leaflets. The first branches (tier 2) arose from basal nodes on the main stem with successive branches initiating progressively from younger buds located higher on the main stem. Early formed secondary branches tended to arise from nodes carrying no leaflet. This was not always the case in secondary branches produced further up the main stem. Where a leaf was present the branch arose between the leaf and the apical portion of branch to which the leaf was attached. The number of secondary branches was typically less than 15 per plant and was dependent on population density. Tertiary branches arose from secondary branches in a similar fashion to secondary branches from the main stem. Again total tertiary branches rarely exceeded 15, the number being strongly influenced by population density. Leaf production in the secondary and tertiary branches was similar to that of the main stem. In the conditions of this trial secondary and tertiary branches first arose 46 to 60 and 60 to 74 days after germination respectively.

3.3.1.2 Reproductive

Flowering

The first fully expanded inflorescences were observed 46 days after germination when either no or few secondary branches had formed. The first inflorescences were produced in the axils of leaves (usually fourth to tenth formed) located on the main stem and typically contained 3 to 6 florets. Later formed inflorescences were produced from younger nodes closer to the stem apex. As the main stem lengthened, progressively

more inflorescences were produced with later inflorescences containing more (7 or 8) florets. The period between successive inflorescences fully expanding was between 1 and 6 days with there often being 2 adjacent inflorescences fully expanded at the same time on the main stem. The period of full expansion was 1 to 2 days. Nodes forming branches did not form inflorescences. Up to 15 inflorescences formed on the main stem over the season. Flowering on the main stem was generally completed by 128 days although the occasional flower occurred on the main stem after this in low population densities. Flowering on secondary and tertiary branches followed a similar pattern to that of the main stem. The first inflorescences in the secondary and tertiary branching tiers formed after 74 days. Most plants which produced tertiary inflorescences began to do so between 74 and 96 days.

Pollination / Seed set

Key pollinators observed on fully expanded inflorescences included native (*Trigona* sp.) and honey (*Apis* sp.) bees which were numerous particularly during the mornings when the trial was most often visited. All branching tiers were accessible to pollinators in all population densities. Pollination was followed by browning and shrivelling of the inflorescence and subsequent pod emergence. The period between inflorescence expansion and the emergence of pods was not measured precisely but did not appear to exceed 5 days.

Pod Development

The first pods arose from inflorescences on the main stem and were recorded 60 days after germination. Immature pods on secondary and tertiary branches were first observed after 74 days although were not present in large numbers until 96 days in tier three. The number of immature pods per umbel were substantially lower (about half) than the number of florets per inflorescence indicating high levels of abortion within individual inflorescences. There was no evidence of abortion between the stages of 'immature' and 'mature' pod, a period in which pod width and seed size was observed to increase. The period taken for pods to reach immature and mature pod status was not recorded because individual reproductive sites were not tagged and monitored. The

number of seeds per immature pod declined over the season from approximately 24 to 17 seeds per pod.

Pod dehiscence was first recorded after 114 days in all branching tiers but was more common in the main stem and secondary branches at this time. The period between anthesis and pod dehiscence of pods arising from inflorescences produced early in the season was approximately 40 days.

3.3.1.3 Effects of Psyllid Infestation on Plant Development

Mean leaf number per plant increased with decreasing plant density (Figure 3.2). Prior to 96 days after germination increases in mean leaf number per plant were apparently linear but increased at different rates. As a result leaf number per plant at 96 days ranged from approximately 60 (density group 1) to 350 (density group 7). However in all density groups mean leaf number declined from 114 days to less than 75 per plant by 184 days. This decline occurred in all density groups but was greatest in density groups 5 and 7. This was attributed, at least in part, to psyllid infestation. Leaf mass showed a similar decline to leaf number (Appendix 3.5).

Schematic diagrams were used to assist visualisation of plant density effects on plant structure. Symbols used in these diagrams were:

- ● crown
- | stem
- ⊢ node with leaf
- ⊢ node with no leaf
- •7 inflorescence // number of florets
- ▫7 immature umbel // number of pods
- ▪7 mature umbel // number of pods
- ▪△ mature umbel // at least one dehisced pod

Typical plants at 156 days are presented in Figures 3.3 and 3.4. A comparison with younger plants (Figures 3.5 and 3.6) reveals considerable leaf loss particularly at stem tips where necrosis of stem tissue was observed. This decline in leaf numbers (114 to 184 days) was recorded 2 weeks after the decline in inflorescence number (96 to 128 days) (Figures 3.2 and 3.7). Although psyllids were first observed 114 days after germination it is likely that they had been present for some time. It is possible therefore that psyllid damage contributed to the decline in inflorescence number before a significant reduction in leaf number was observed.

3.3.2 THE EFFECT OF POPULATION DENSITY ON PLANT STRUCTURE

Population density greatly affected plant structure principally through altering branching and therefore the number of reproductive sites.

3.3.2.1 Plant Size

Plant size is a combination of plant height and breadth. Mean individual plant height generally followed a near linear pattern of growth reaching a plateau after 96 to 114 days after germination. Plant height was not affected by population density until 74 days after germination (Appendix 3.6) when mean plant height ranged between 0.13 and 0.28 m. After this time density effects became more apparent with increasing population density resulting in increased plant height. This was due to an extended period of height increase in plants grown at higher population densities compared to lower densities. Plants in groups 5, 6 and 7 showed no appreciable increase in plant height after 96 days post germination. Plant height in groups 1, 2 and 3 continued to increase until 114 days after which growth ceased. Typically plants in groups 1 and 2 had mean plant heights of between approximately 0.55 and 0.80 m. Plants in groups 6 and 7 were generally less than 0.40 m in height with groups 3, 4 and 5 being intermediate.

Mean individual plant breadth (Appendix 3.7) showed a similar pattern of increase followed by a levelling off between 96 (density groups 1 and 2) and 114 days (all other

Figure 3.2 **Effect of population density on mean leaf number per plant of *Desmanthus virgatus* cv. 'Marc'.**

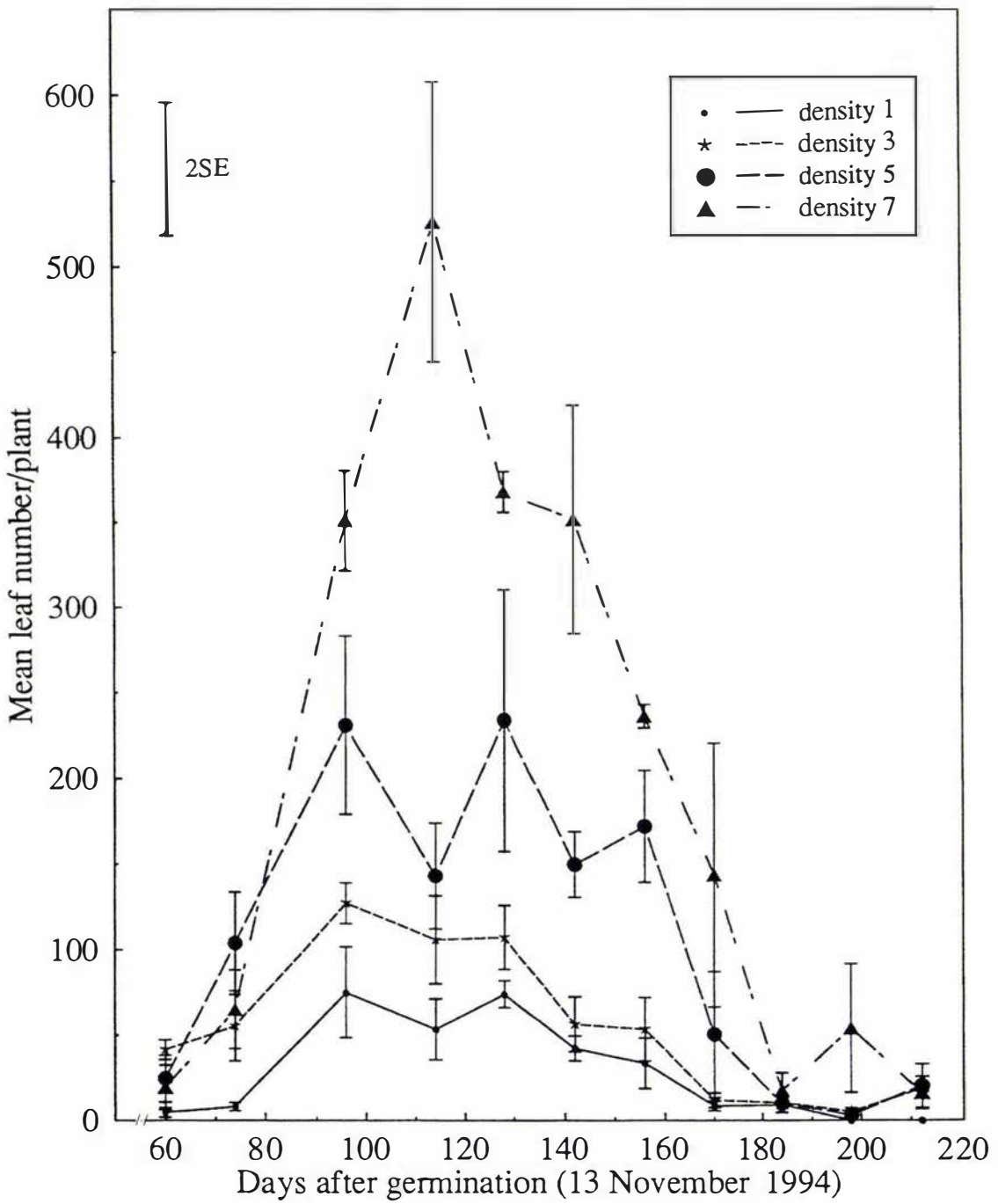


Figure 3.3 Schematic diagram of *Desmanthus virgatus* cv. 'Marc' 156 days after germination grown in a population of 160 plants/m^2.

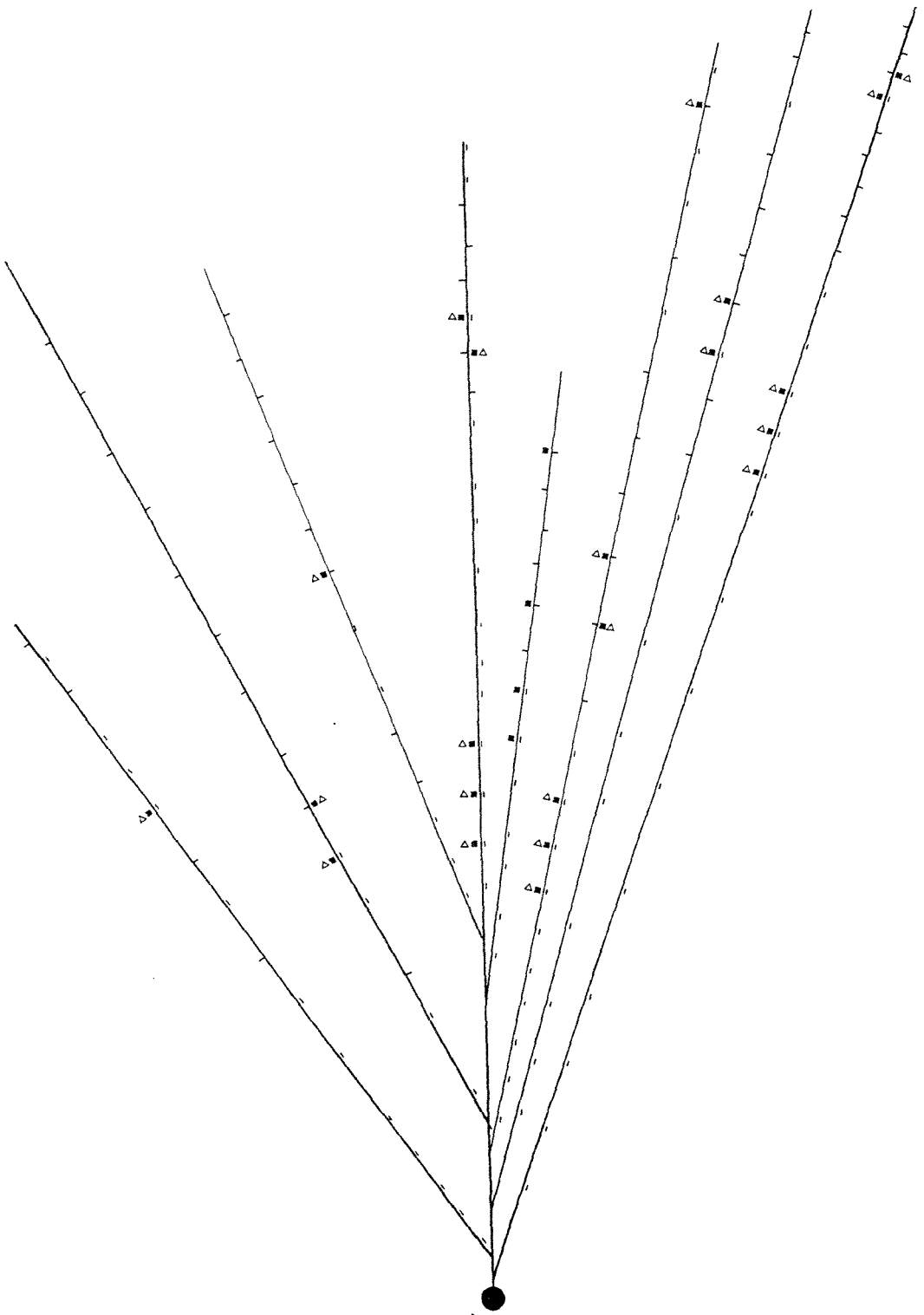


Figure 3.4 Schematic diagram of *Desmanthus virgatus* cv. 'Marc' 156 days after germination grown in a population of 3 plants/m^2.

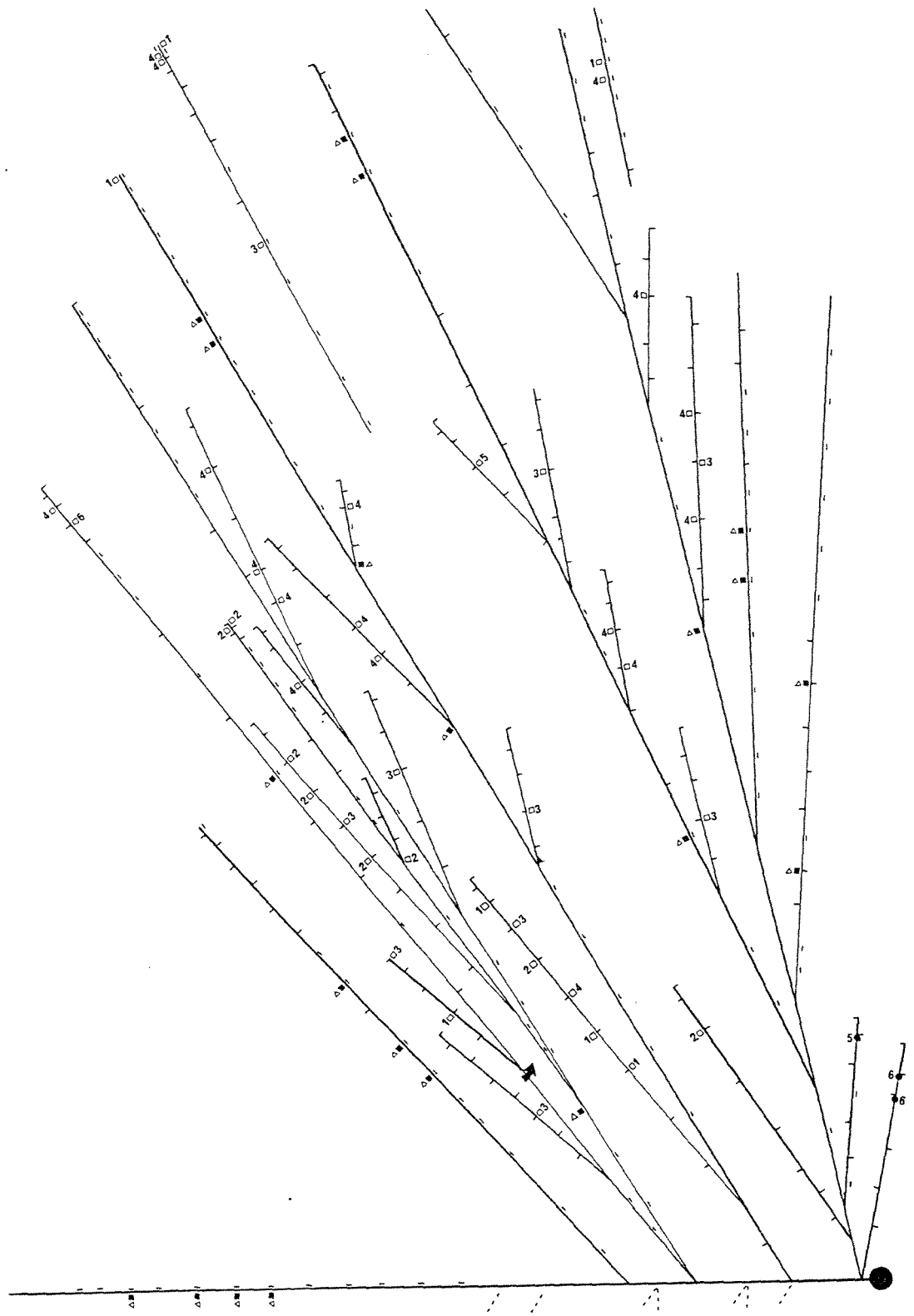


Figure 3.5 Schematic diagram of *Desmanthus virgatus* cv. 'Marc' at peak flowering (96 days after germination) grown in a population of 160 plants/m^2.

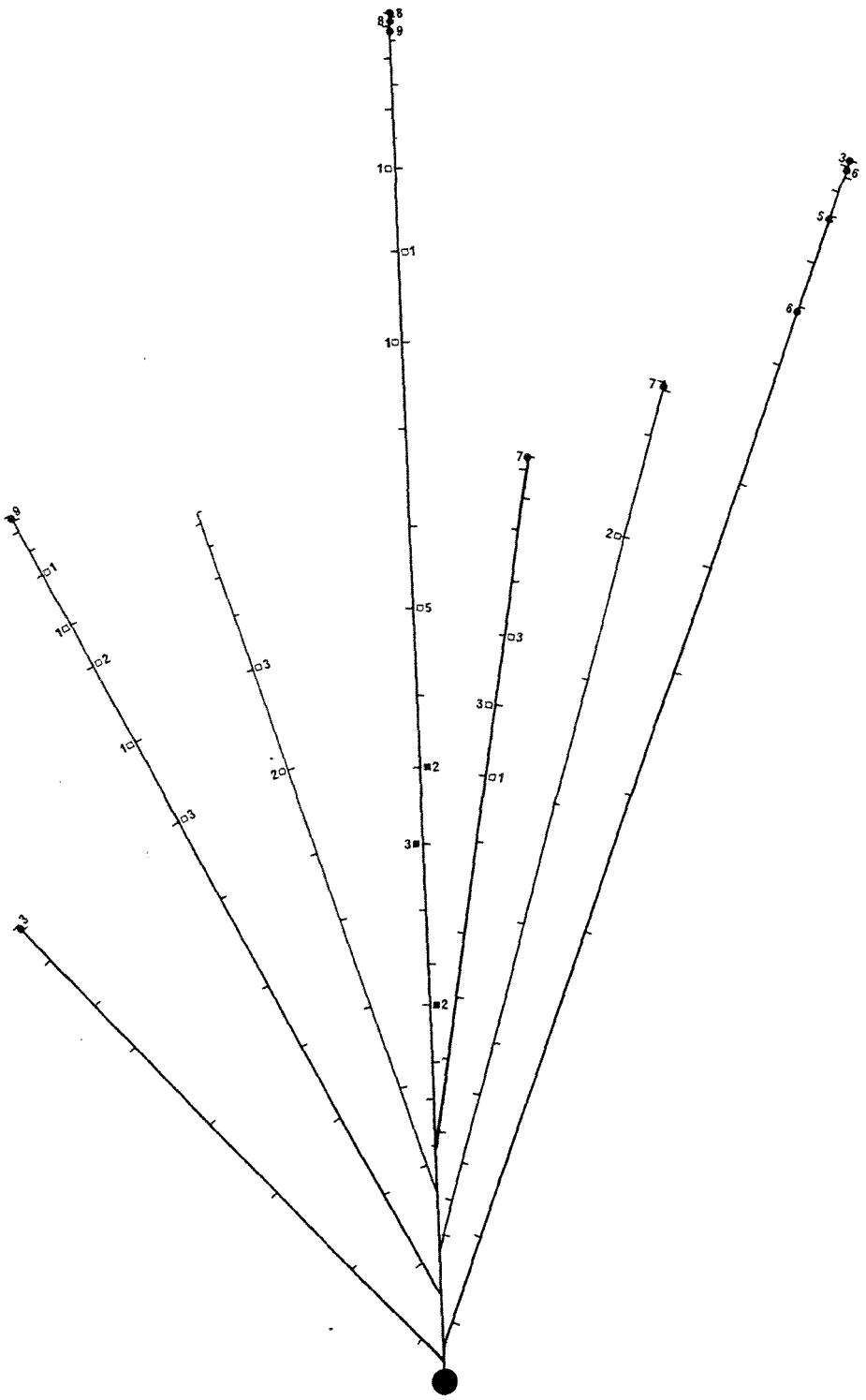
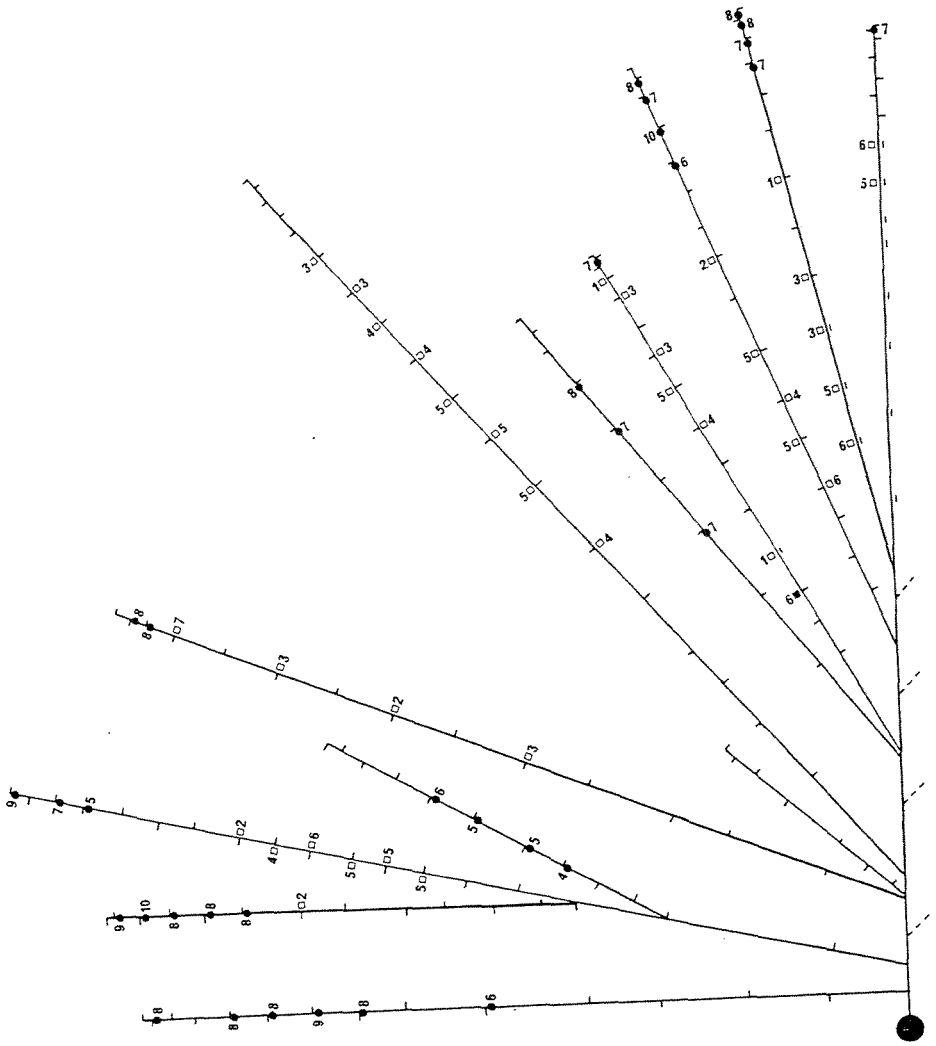


Figure 3.6 Schematic diagram of *Desmanthus virgatus* cv. 'Marc' at peak flowering (96 days after germination) grown in a population of 3 plants/m^2.



groups). There is some evidence of continued increase in plant breadth to 128 days in density groups 5, 6 and 7 but the data is not consistent. Differences in plant breadth after 128 days vary widely with population density. At high population densities (density groups 1 and 2) mean plant breadth does not exceed 0.75 m whereas in groups 6 and 7 mean plant breadths range between 1.15 and 1.91 m.

3.3.2.2 Branching

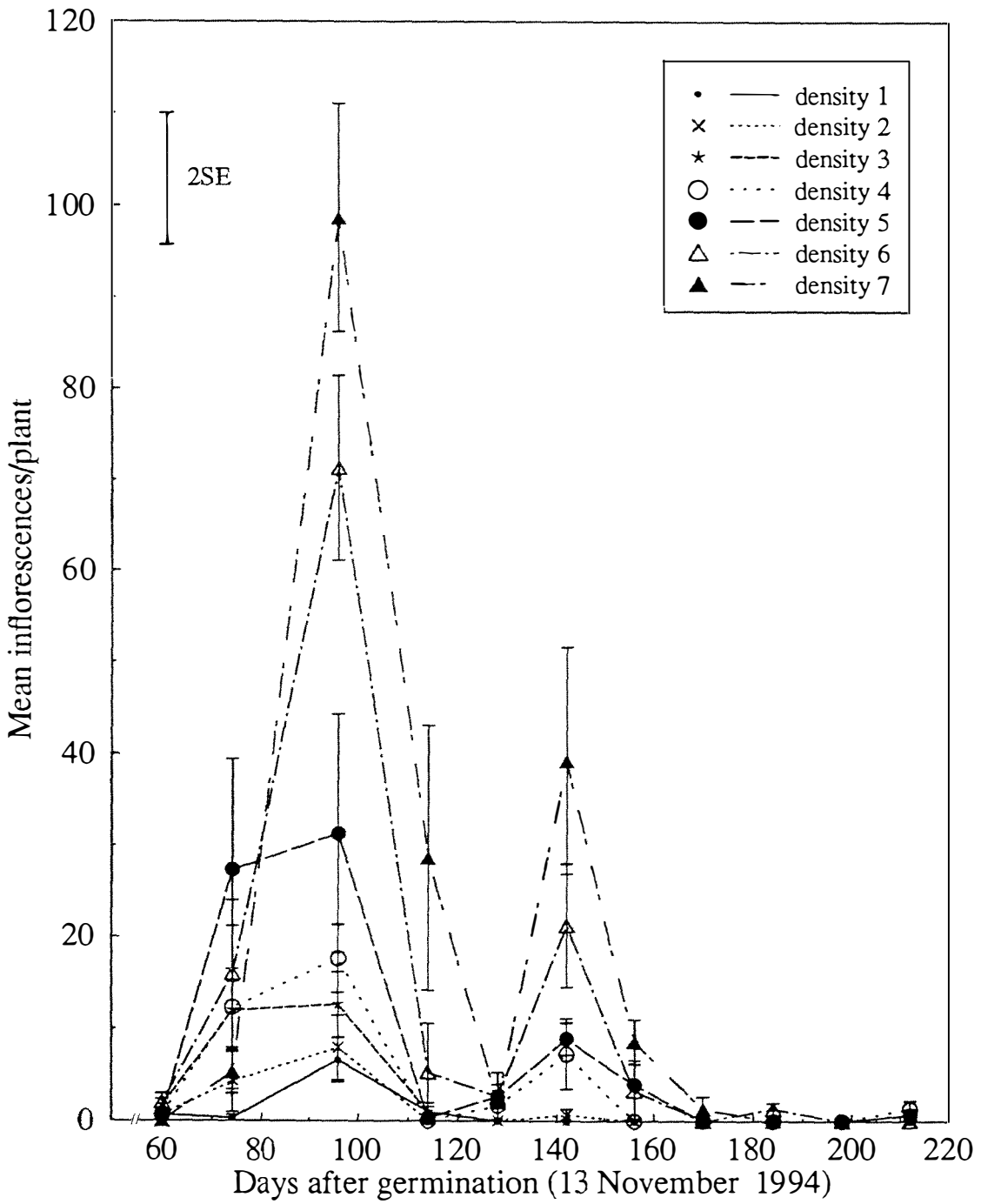
Branching was described by recording branch number, length and dry weight (mass). Mean branch number per plant was strongly affected by population density (Appendix 3.8). Plants in density group 1 showed no branching at 74 days whereas all other density groups showed branching by 60 days. Branching had ceased by 74 days in groups 2, 3 and 4 but continued until 96 days in groups 5, 6 and 7. The continuation of branching accounted for (mostly) significant differences in branch number after 114 days between groups 1, 2 and 3 (mean number per plant ranges 2.0 to 6.3) and groups 6 and 7 (14.3 to 46.0). Density groups 4 and 5 were intermediate. The effect of population density on mean branch length (Appendix 3.9) and branch mass (Appendix 3.10) was similar to mean branch number.

3.3.3 THE EFFECT OF POPULATION DENSITY ON FLOWERING PATTERN

Mean inflorescence number per plant decreased markedly with increasing population density (Figure 3.7). Flowering in all density groups began approximately 60 days after germination and peaked at 96 days. However plants in density groups 1 and 2 virtually stopped flowering after 114 days whereas all other groups continued to flower producing a second smaller peak at 142 days.

In the first peak inflorescence numbers ranged from less than 20 inflorescences per plant (density groups 1, 2, 3 and 4) to more than 90 inflorescences per plant (density group 7). Density groups 5 and 6 were intermediate.

Figure 3.7 **Effect of population density on mean inflorescence number per plant of *Desmanthus virgatus* cv. 'Marc'.**



The sharp decline in mean inflorescence number per plant between 96 days and 128 days occurred at the same time as an abrupt decrease in leaf number per plant (Figure 3.2). It is likely that the psyllid infestation contributed to both the onset and the speed of this decline.

3.3.4 THE EFFECT OF POPULATION DENSITY ON OVULE NUMBER

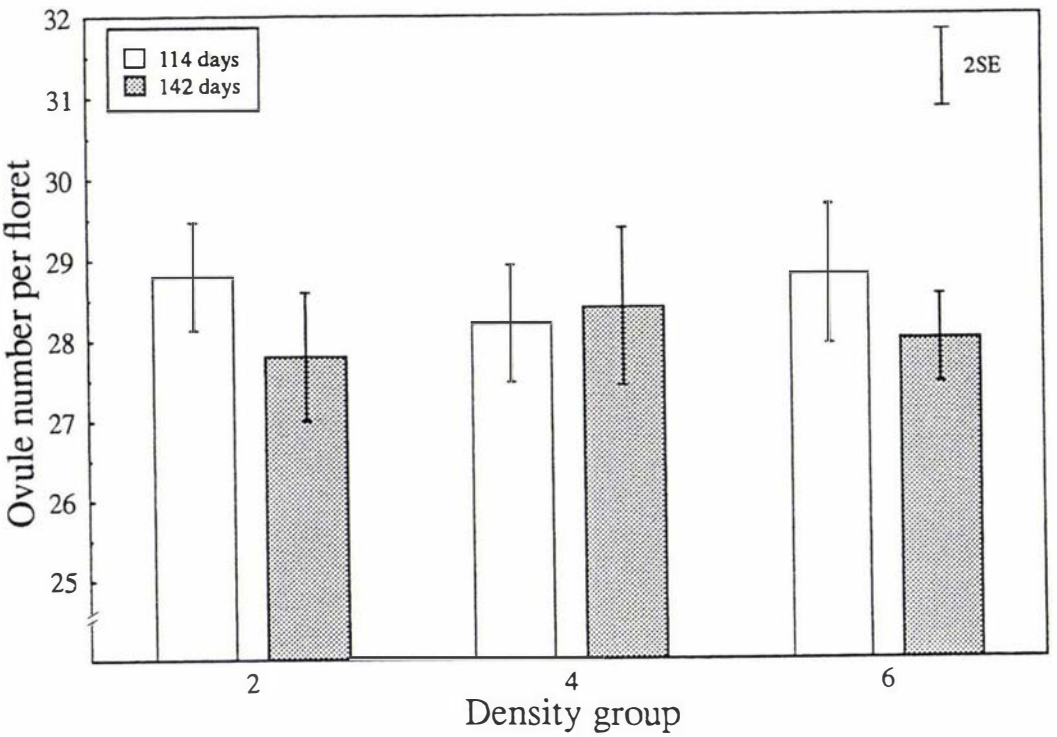
Population density had no effect on the mean number of ovules in (perfect) 'Marc' florets sampled 114 and 142 days after germination (Figure 3.8). Ovule number per floret ranged from 25 to 31 with means across all densities of 28.6 and 28.0 at 114 and 142 days respectively. The method (Section 3.2.3.3) used to count ovules was susceptible to error, particularly in isolating the small translucent ovules from the ovary. It is possible that a few ovules may have been undetected reducing mean ovule numbers.

The ovule sampling dates of 114 and 142 days coincided with the end of the first, and the middle of the second flowering peaks respectively. Thus it can be assumed that ovule numbers per floret remain effectively constant while desmanthus is actively flowering.

3.3.5 THE EFFECT OF POPULATION DENSITY ON OVULE ABORTION

In this study ovule abortion during seed set is represented as the mean number of seeds per immature pod as a proportion of the mean number of ovules present at anthesis. It was necessary to count seeds at full pod expansion (immature pod stage) because, until this point, some seed sites (located at the distal end of the pod) are not developed sufficiently to allow reliable seed counts to be made. Thus ovule abortion during 'seed set' is considered over an approximately two week period beginning at anthesis.

Figure 3.8 **Effect of population density on mean ovule number per floret of *Desmanthus virgatus* cv. 'Marc'.**



Population density did not affect the mean number of seeds per immature pod at any time (Appendix 3.11). When pooled across densities the mean number of seeds per immature pod declined from 23.8 (96 days) to 14.22 (184 days) (Appendix 3.12). Small declines in seed number per pod over time have been recorded in other species and are probably due to competition for assimilate during flowering and early seed development (Habekotte, 1993). It is also possible, however, that psyllid damage may have contributed to the decline in seed number per pod by reducing assimilation through reduced leaf area. Timing of flowering may also be a factor with later inflorescences being exposed to a shorter photoperiod therefore reducing assimilation.

The number of ovules per floret was counted on plants sampled from density groups 2, 4 and 6, 114 and 142 days after germination. Determination of 'seed set' was conducted by comparing these results and ovule numbers which developed from these inflorescences and were present as immature pods two weeks after 114 and 142 days. When pooled by density the mean number of ovules per floret at 114 and 142 days was

28.6 and 28.0 respectively (Section 3.3.4). The mean number of seeds per immature pod (pooled by density) at 128 and 156 days was 21.8 and 20.2 respectively. Therefore the proportion of ovules remaining at full pod expansion was estimated to be 76.2 (114 days) and 72.1% (142 days). Whether similar levels of seed set occurred at other times of the season is unknown.

The mean number of seeds per mature (abscised) pod was not influenced by density (Appendix 3.13). After 142 days, widespread pod dehiscence and lower numbers of mature pods made the counting of seed in mature pods difficult. As a result few data points are available over this period. The average number of seeds per mature pod between 96 and 142 days ranged from 19.2 to 22.6 suggesting that virtually no seed / ovules were aborted between the immature pod and mature pod stages.

3.3.6 THE EFFECT OF POPULATION DENSITY ON ABORTION OF REPRODUCTIVE SITES

The population density distribution of mean number of immature umbels (Appendix 3.14) and mature umbels (Appendix 3.15) simply mirrors inflorescence numbers (Figure 3.7). Two peaks of immature pods were observed at 96 to 114 and 156 days after germination indicating the period between anthesis and immature pod was approximately 14 days. A clear peak of mature umbels at 128 days indicates that the period from anthesis to mature pod was approximately 32 days.

The number of immature umbels per plant were higher than the number of inflorescences from which they originated. This is because inflorescences were only ever counted once while immature pods may have been counted more than once (i.e. sampling occurred every 14 days). This 'double-counting' possibility means that estimations of the abortion of entire reproductive sites were not made. Tagging studies are required to quantify this information.

3.3.7 THE EFFECT OF POPULATION DENSITY ON ABORTION OF REPRODUCTIVE COMPONENTS

The mean number of florets per inflorescence ranged from 4.0 to 9.1 (Appendix 3.16) and mean number of pods per umbel ranged from 0.7 to 6.0 (Appendix 3.17). Neither were influenced by population density. When pooled across densities both mean florets per inflorescence and pods per umbel were found to decline over time (Appendix 3.12).

A comparison of mean (pooled by density) florets per inflorescence and pods per umbel (sampled two weeks after sampling florets) shows that between 38 and 50% of florets form pods (Appendix 3.12). Although three exceptions occurred arising from disproportionately low number of florets per inflorescence present at 60, 170 and 184 days this is not considered to be biologically significant. During the main flowering period (74 to 156 days) the overall percentage conversion of florets to pods was 45%.

3.3.8 DENSITY EFFECTS ON SEED QUALITY

3.3.8.1 Seed Collected Off the Ground

There were no density effects on seed quality parameters (% normal seedlings, % abnormal seedlings, % dead seed, % hardseeds and % fresh ungerminated seed) or seed weight (data not presented). Values which have been pooled by density are presented in Table 3.2. They indicate that seed recovered from the soil was of good quality and that the majority was impermeable to water at the time of testing. Some slight damage, perhaps due to the hydrochloric acid treatment used to scarify the seed coat, may have contributed to the number of abnormal seedlings (~16%).

3.3.8.2 Seed Collected Off Plants Over the Season

No density effects were observed in seed quality parameters of seed collected over the season (data not presented). Values pooled by density are presented in Table 3.2. If hardseeds are assumed to have normal germination these results are very similar to those for seed collected at harvest. There was little, if any, germination loss in seed lying on soil, even though levels of hardseededness and thousand seed weight were substantially lower in harvested seed. Hardseededness may have been reduced whilst lying in the soil. This might be explained by more extreme temperature and moisture conditions at the soil surface. These conditions have been shown to reduce hardseededness in *Trifolium subterraneum* (Quinlivan, 1966). The reason for the lower thousand seed weight is less certain. It may be partially explained however by the 20% decrease in thousand seed weight observed in seed harvested at different times over the season (Figure 3.9).

Table 3.2 **Seed quality indices of *Desmanthus virgatus* cv. 'Marc' seed collected off the ground at the end of the season and from plants during the season.**

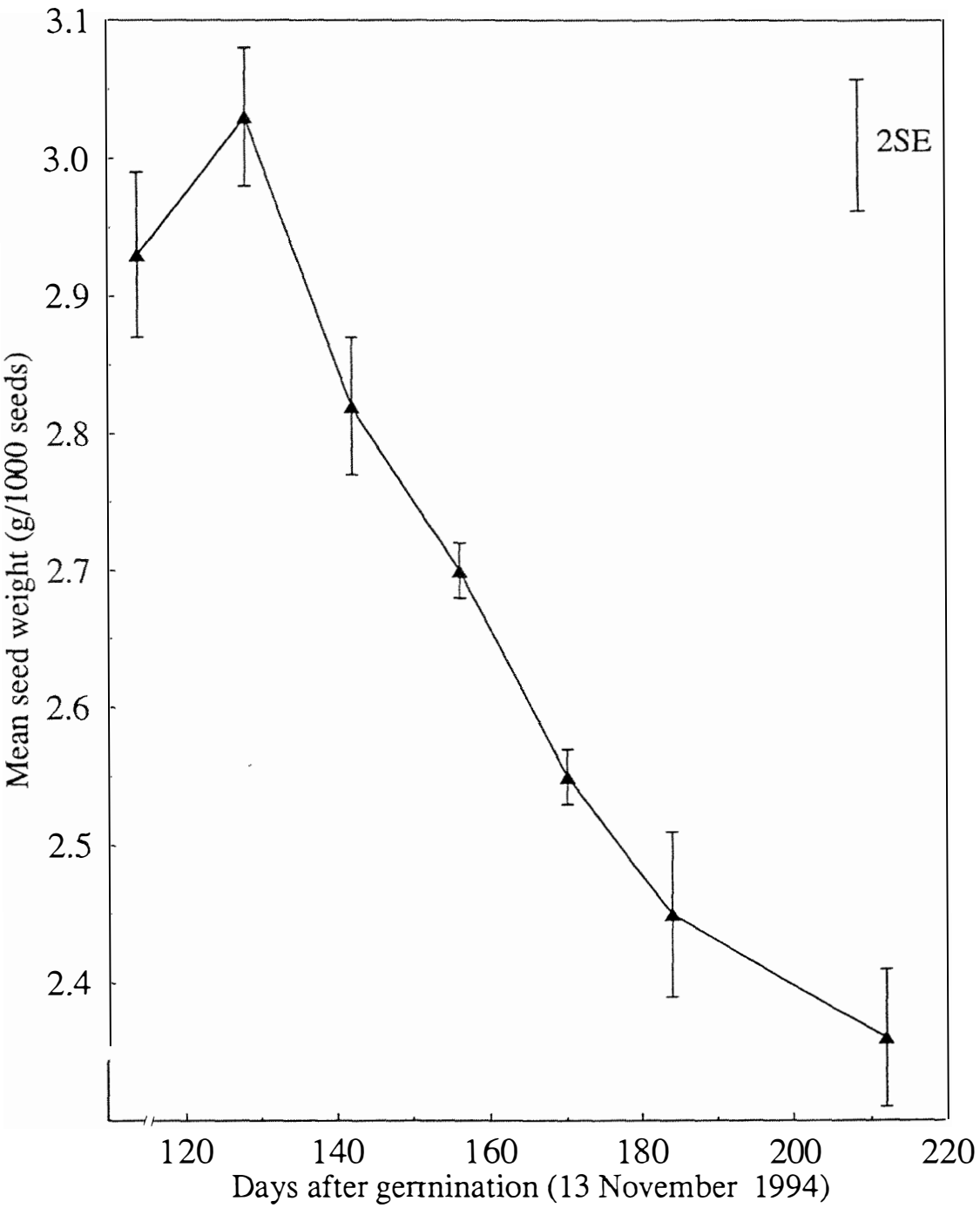
Quality index	Seed collected off ground	Seed collected from plants over season
normal seedlings (%)	**74.6** 1.9	**56.9** 3.5
abnormal seedlings (%)	**16.2** 1.7	**14.9** 1.9
hardseed (%)	**5.3** 0.7	**26.1** 3.8
fresh ungerminated (%)	**0.6** 0.5	**0.3** 0.3
dead (%)	**3.3** 0.6	**1.4** 0.5
thousand seed weight (g)	**3.06** 0.03	**2.71** 0.04
hardseededness (%)	**97.6** 0.5	**90.4** 2.0

standard germination test

0.00 mean (n=35)

0.00 standard error (n=35)

Figure 3.9 **Mean thousand seed weight of *Desmanthus virgatus* cv. 'Marc' seed collected over the season and pooled across densities.**



3.3.9 HARVESTED SEED YIELDS

Total (fallen and unfallen) seed yields produced over the entire season ranged from 1081 to 1355 kg seed/ha but were not influenced by density (Figure 3.10). The absence of population density effects on per unit area seed yield is surprising because of the large range of population densities used (~3 to 159 plants/m^2). It was decided to calculate potential seed yields (PSY) using data collected in this study and to compare these with the harvested seed yields. Calculation of PSY is presented in Section and 3.3.11.

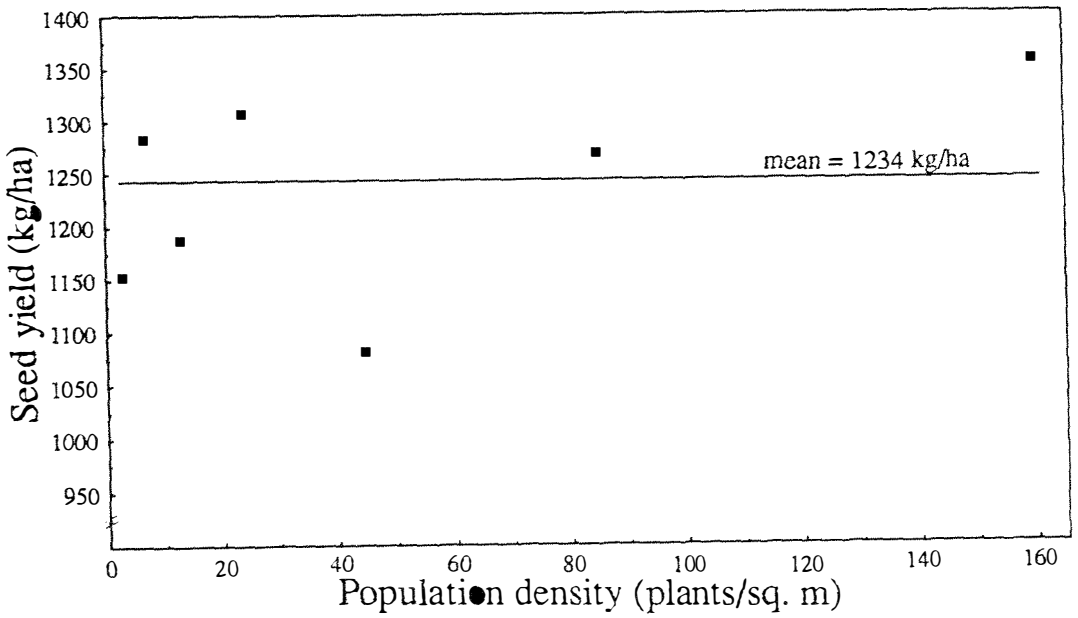
3.3.10 CONTRIBUTION OF PEAK FLOWERING TO SEED YIELD

Harvested seed yields represented volumes of seeds collected over the entire season (Section 3.3.9). An estimation of how much of this seed is presented for a single destructive harvest (e.g. combine harvester), and the effect of population density on this, is preferred as combine harvesters are used to commercially harvest desmanthus. It has been established that most inflorescences are produced over a limited period and that this 'peak' of flowering contributes to subsequent peaks of immature and mature umbels respectively. It is likely that population differences in the number of inflorescences present at peak flowering contribute most to seasonal seed production because density differences in ovule number (Section 3.3.4), abortion rates (Sections 3.3.5, 3.3.6 and 3.3.7) and seed size (Section 3.3.8) are limited.

3.3.10.1 Vegetative Structure

Vegetative indices at peak flowering are presented in Table 3.3. Plants at low population densities were prostrate, many branched and, because of this, bore more leaves and inflorescences than plants grown at high population densities. Thus high branch numbers of plants grown at low population densities provided greater numbers of potential (leaf axils) and actual (inflorescences) reproductive sites which later formed greater numbers of pods. Mean number of branches per plant and mean total branch mass per plant were both strongly correlated (coefficient value = 0.96: P = 0.05) with mean inflorescence and mean leaf number per plant (Appendix 3.18).

Figure 3.10 **Effect of population density on seed yield of *Desmanthus virgatus* cv. 'Marc' collected 20 June 1995.**



3.3.10.2 Reproductive Structures

Most inflorescences were produced during peak flowering 96 days after germination (Figure 3.7). At high population densities (groups 1, 2 and 3) more than 90% of total flowering occurred between 74 and 114 days after germination. Between 70 and 80% of total inflorescence numbers were produced in the same period at lower population densities. This difference is due to the contribution of the second flowering peak which only occurred in plants grown in lower population densities (Figure 3.7).

Between 74 and 114 days after germination, the number of inflorescences on plants grown at low population densities (group 7) was more than 16 times that of plants grown at the highest population densities (group 1) (Table 3.4). This represents considerable phenotypic plasticity but is not unusual when compared to other legumes with similar growth habit (e.g. *Lotus corniculatus*, McGraw *et al.*, 1986).

Table 3.3 **Effect of population density on the vegetative structure at peak flowering (96 days after germination) of *Desmanthus virgatus* cv. 'Marc'.**

Density group	Plant height (m)	Plant breadth (m)	Branch number per plant	Total Branch length (m/plant)	Branch mass (g/plant)	Leaf number per plant	Leaf mass (g/plant)
1	**0.59**	**0.54**	**3.67**	**2.22**	**1.92**	**75.0**	**1.53**
	0.07	0.04	1.86	0.18	0.79	26.5	0.61
2	**0.59**	**0.49**	**6.67**	**2.92**	**4.26**	**93.3**	**3.60**
	0.01	0.09	1.33	0.59	0.46	26.5	0.24
3	**0.58**	**0.53**	**12.00**	**3.76**	**3.89**	**127.0**	**3.22**
	0.03	0.04	2.00	0.16	0.54	11.9	0.31
4	**0.48**	**0.98**	**8.33**	**4.51**	**5.83**	**133.3**	**4.71**
	0.04	0.19	1.45	0.32	1.26	**9.3**	0.90
5	**0.44**	**0.93**	**18.00**	**7.67**	**9.59**	**231.0**	**8.07**
	0.003	0.07	5.77	1.99	2.63	52.0	2.47
6	**0.52**	**0.93**	**24.67**	**9.62**	**11.09**	**345.0**	**12.86**
	0.10	0.25	1.67	1.01	0.93	25.2	1.32
7	**0.34**	**1.12**	**27.33**	**9.15**	**10.64**	**351.0**	**14.40**
	0.03	0.04	3.38	1.07	1.76	29.5	2.62
	0.00	mean (n=3)					
	0.00	standard error (n=3)					

Table 3.4 **Effect of population density on mean inflorescence number per plant at peak flowering and inflorescence number at peak flowering of *Desmanthus virgatus* cv. 'Marc' as a percentage of total inflorescences.**

Density group	Mean inflorescences per plant			Percentage of total inflorescences per plant	
	Season total	96 days	74-114 days	96 days	74-114 days
1	8.7	6.7	8.0	76.9	92.7
2	13.7	8.0	12.3	58.5	90.2
3	27.3	12.7	25.7	46.3	93.9
4	41.0	17.7	30.0	43.1	73.1
5	76.0	31.3	59.0	41.2	77.6
6	123.3	71.3	92.7	57.8	75.1
7	184.7	98.7	132.7	53.4	71.8

Conversion of inflorescence number per plant totalled over the season to values per unit area resulted in greater inflorescence numbers at lower population density (Table 3.5, Figure 3.11). Values ranged from 585 inflorescences/m^2 (3.17 plants/m^2) to 1386 inflorescences/m^2 (159.85 plants/m^2). The relationship between population density and total inflorescences produced over the season is curvilinear and is similar to legumes of similar growth habit e.g. *Lotus corniculatus* (McGraw *et al.*, 1986). The effect of population density on inflorescence number per unit area during peak flowering (74 to 114 days) was similar to total inflorescences produced over the season (Table 3.5).

The number of umbels per unit area during peak pod presence (96 to 128 days) and over the entire season also showed a positive response to increasing population density (Table 3.6). Once pods had been formed it is expected that most, if not all, then produced mature pods. Thus the distribution of mature umbels with respect to population density is not presented.

Table 3.5 **Effect of population density on inflorescence number per unit area over the entire season and at peak flowering of *Desmanthus virgatus* cv. 'Marc'.**

Density group	Mean inflorescences per m^2		
	Total	96 days	74-114 days
1	1385.9	1066.2	1278.8
2	1161.0	679.4	1047.2
3	1236.3	572.9	1160.8
4	986.9	425.2	722.1
5	973.6	401.3	755.1
6	841.0	486.5	632.0
7	585.4	312.8	420.6

Table 3.6 **Effect of population density on mean immature umbel (IU) number per plant and per m^2 at peak pod presence and IU number at peak flowering as a percentage of total IU number of *Desmanthus virgatus* cv. 'Marc'.**

Density group	Mean IU per plant		Percentage of total IU per plant	Mean IU per m^2	
	Total	96-128 days		Total	96-128 days
1	23.3	23.3	100.0	3729	3729
2	31.0	25.7	82.8	2633	2179
3	33.3	26.3	79.0	1507	1191
4	64.7	57.0	88.2	1595	1406
5	146.0	107.0	73.3	1870	1370
6	251.3	196.0	78.0	1714	1337
7	375.3	213.0	56.8	1190	675

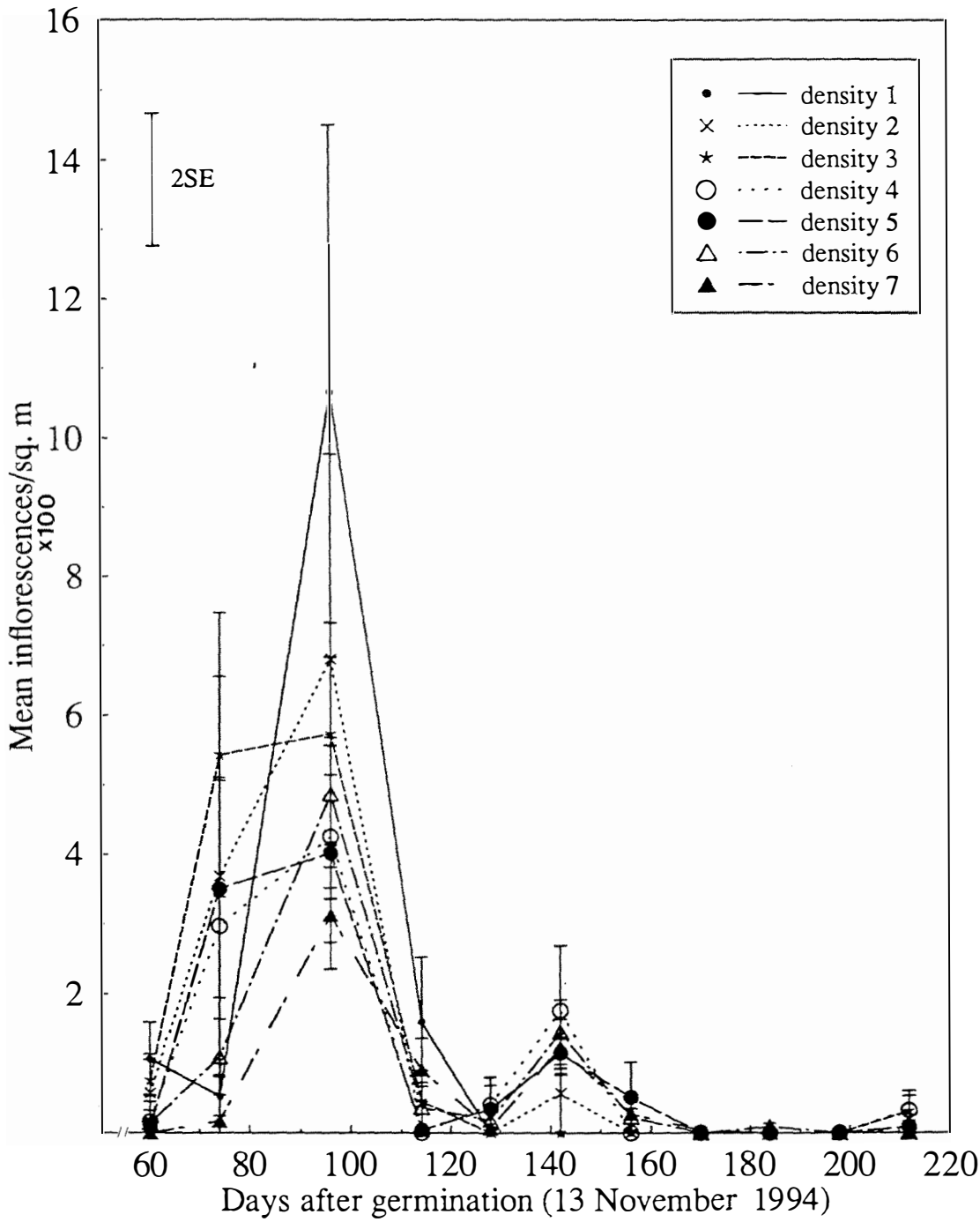
3.3.11 POTENTIAL SEED YIELD

3.3.11.1 Calculation of Potential Seed Yield

Components used to calculate potential yield arising from inflorescences present 96 and 142 days after germination are presented in Appendix 3.19. Potential seed yields are presented in Appendix 3.19 and Figures 3.12 and 3.13.

Potential seed yield per plant calculated from the first flowering peak decreased more than 15-fold with increasing population density (Figure 3.12). Most of the PSY per plant was a result of the first flowering peak. The highest mean value achieved was 18.75 g/plant which was a result of the first flowering peak at the lowest population density. The same value calculated for the second flowering peak was less than 5 g/plant. Differences in PSY per plant between the first and second flowering peak was mainly due to differences in inflorescence number per plant although lower mean values in the second flowering peak of pods per umbel (79% that of the first flowering peak), seeds per immature pod (92%) and thousand seed weight (90%) also contributed to the differences.

Figure 3.11 **Effect of population density on mean inflorescence number per m^2 of *Desmanthus virgatus* cv. 'Marc'.**



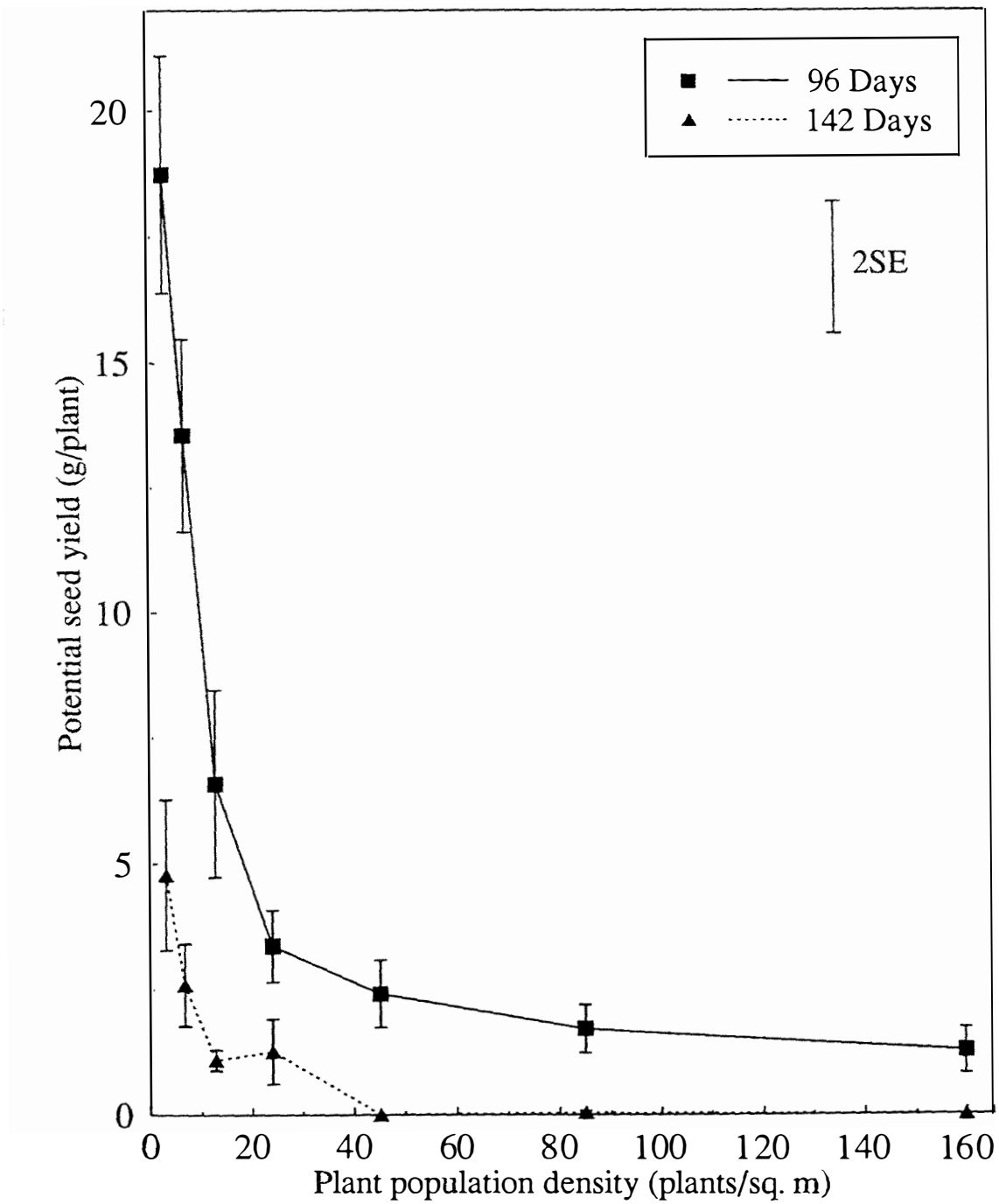
For both flowering peaks incremental increases in PSY became larger as plant population decreased (hyperbolic function). Low amounts of seed were produced per plant in the first flowering peak, and virtually no seed was produced in the second flowering peak, by plants grown at population densities of greater than 45 plants/m^2. This was because very few, or no, inflorescences were present on plants at these population densities. As a result the influence of second peak inflorescences on PSY was only of significance at low population densities.

Conversion of PSY calculated from the first flowering peak to per unit area values tripled PSY with increasing population density (to approximately 2000 kg/ha) (Figure 3.13). As expected, PSY calculated from the second flowering peak were much lower with mean densities below 24 plants/m^2 producing only 200 kg/ha and higher population densities producing virtually no seed. Addition of PSY derived from both peaks reduced the influence of population density because flowering period was extended at low population densities. However, this was not enough to offset the effect of plant density (which increased 50-fold). As a result total PSY per unit area continued to rise with increasing population density (Figure 3.13). The relationship between total PSY and plant density was tested using the least squares procedure for quadratic or linear function. The linear form provided the best significant (P=0.05) fit of the data (higher r^2 value).

3.3.11.2 Contributions of Branching Tiers to Potential Seed Yield

The variable which most affected PSY was inflorescence number per plant (Section 3.3.10) which was influenced by population density effects on vegetative structure. The contribution of different branching tiers to inflorescence number per plant and other seed yield components, and subsequently to PSY, is presented in this section.

Figure 3.12 **Effect of population density on potential seed yield per plant of *Desmanthus virgatus* cv. 'Marc'.**

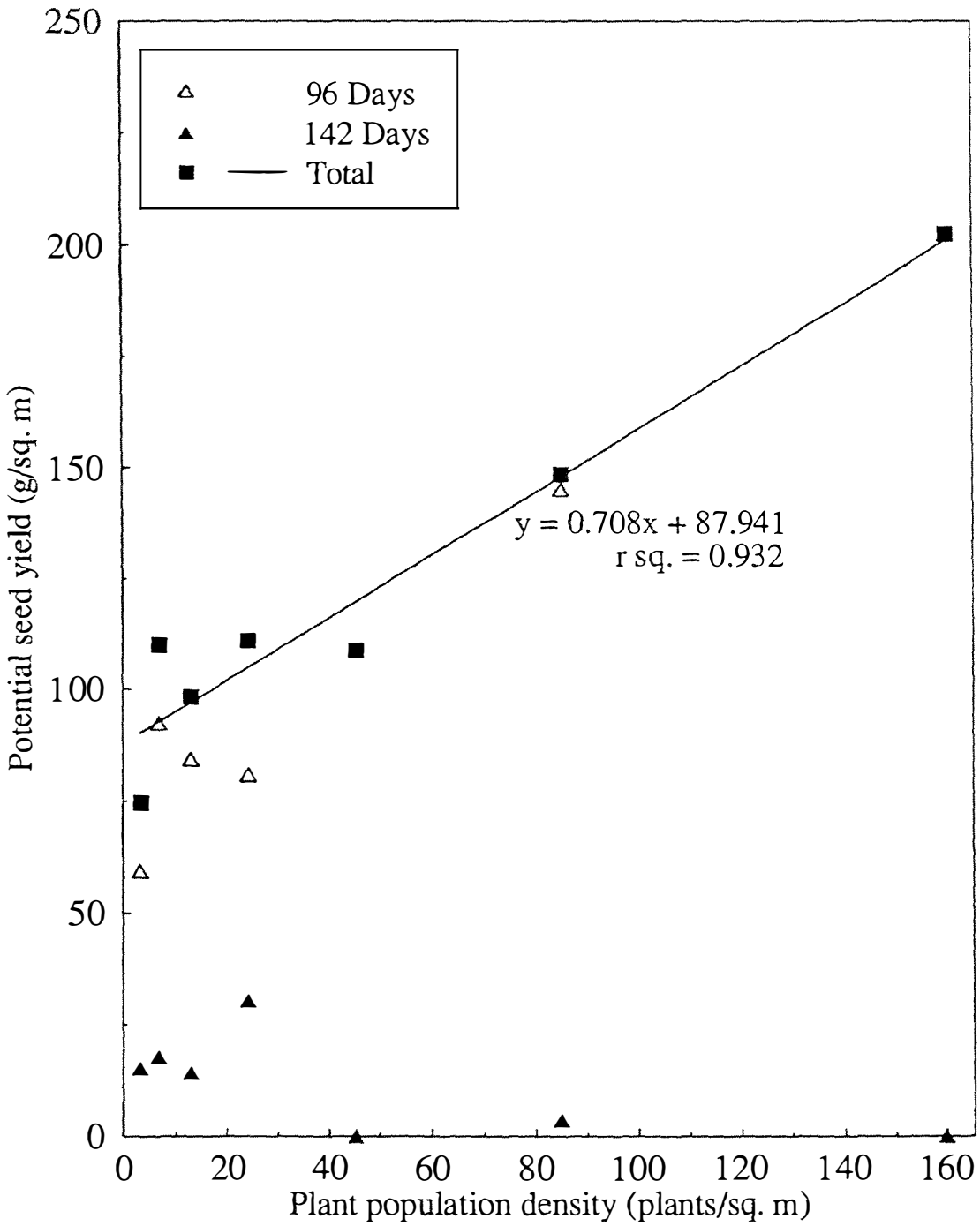


Branch number per branching tier consisted almost entirely of secondary branches at high population densities (density groups 1, 2 and 3) (Appendices 3.20 to 3.26). Most branching occurred before 60 days after germination with no significant increase in branch number in density groups 1, 2 and 3 thereafter. At lower populations (density groups 4 to 7) tertiary branches contributed an increasing proportion of total branch numbers. Although secondary branch numbers did not increase after 74 days tertiary branches did continue to develop beyond 74 days (Appendices 3.20 to 3.26).

As expected, secondary branches were the main contributors to total leaf number per plant at high population densities (density groups 1, 2 and 3)(Appendices 3.20 to 3.22) and increased from 60 to 128 days after germination (density groups 1 and 3) and 142 days (density group 2) but declined thereafter. Leaves from tertiary branches were uncommon in density groups 1 to 3 reflecting the general absence of tertiary branches. In lower population densities (density groups 4 to 7) leaves on tertiary branches began to be produced from approximately 74 days (Appendices 3.23 to 3.26). At extremely low population densities (density groups 6 and 7) tertiary branch leaves contributed similar numbers to those of secondary branches by 114 to 128 days after germination.

The main stem produced few inflorescences which were generally recorded only before 114 days after germination. Despite this, main stems were important contributors to total inflorescence numbers at high population densities (density groups 1 and 2). Secondary branches were, however, the main contributors to total inflorescence number in all population densities until just after peak flowering (Appendices 3.20 to 3.26). No inflorescences were found on tertiary branches in density groups 1 to 3 or were reported before 96 days in the other density groups. Decreasing population density thereafter was associated with an increase in the numbers of inflorescences on tertiary branches. At the lowest population density (density group 7) tertiary branches contributed the most inflorescences 114 days after sowing.

Figure 3.13 **Effect of population density on potential seed yield per m^2 of *Desmanthus virgatus* cv. 'Marc'.**



3.4 Discussion

3.4.1 SEED CROP DEVELOPMENT

The sowing date (13 November) used appeared to be suitable for 'Marc' seed production. Mean air temperatures during establishment ranged from 17 to 32°C and moisture supply was high. Although soil temperatures were not measured it is reasonable to assume that soil temperatures fitted into this range or, because the soil was a black cracking clay and therefore had high heat retention, were higher. This suggests that soil temperatures would have been near optimum (26 to 33°C, Njarui *et al.*, 1992) for most of the establishment period. Early season growth was rapid with no apparent limitations to growth.

Total water application (rainfall plus irrigation) was between 180 and 200 mm per month in the growing period prior to 114 days after germination (7 March) and is not thought to have limited vegetative growth. Lower total water application during March (103 mm) and April (60 mm) did not appear to stress plants i.e. there was no sign of wilting. However it is possible that the reduced water application may have stressed plants sufficiently so that they became more susceptible to psyllid attack which occurred during this period.

The most important feature of herbage seed crops is usually flowering pattern (Section 2.4.2). Two peaks in mean inflorescence number per plant (96 days and 140 days) were observed, the former contributing most of the inflorescences of individual plants. The intensity of the 96 day peak strongly suggests that the inflorescences produced at this time would contribute most to crop yield. Whereas inflorescence number per plant before 114 days is the result of normal crop development, it is likely that flowering after this period was affected by other factors. Possible reasons for the sharp decline in mean inflorescence number per plant between 96 and 128 days include psyllid damage, moisture stress or photoperiodic control of inflorescence number. Of these, psyllid damage is the most likely factor considering the changes in vegetative indices, particularly mean leaf number per plant, observed during this period. Moisture supply to

the site was still high during this period and is not thought to have contributed to the decline in inflorescence number.

As there are apparently no photoperiodic controls of flowering in 'Marc', an early summer sowing seems most appropriate. This better guarantees optimal soil temperatures and establishment rainfall reducing the requirement for irrigation. A different situation may apply for 'Bayamo' and 'Uman' which appear to have short-day requirements for floral initiation and / or induction (Graham *et al.*, 1991b). There is the possibility that moisture stress induces more vigorous flowering in 'Marc' as occurs in some indeterminate forage legumes such as *Macroptilium atropurpureum* (Hopkinson, 1988). If this is the case moisture stress could be used to produce a stronger flowering peak which in turn can enhance yields in single harvest systems. This seems unlikely, at least in early (before 96 days) crop growth because vigorous flowering was produced under moist soil conditions. It is more probable that moist soil conditions are required to produce adequate vegetative growth in order to maximise light interception and provide a framework on which reproductive development can occur. The irrigation regime used in this trial used the assumption that moisture application was less important once vegetative growth was completed i.e. that dry (but not moisture stressed), cool (but frost-free) and settled conditions during late pod development would be conducive to pod development, delay of pod dehiscence and a reduction in diseases. Cool, dry and settled conditions during pod development were provided by the early summer sowing. It is not known whether the virtually complete (practically useful) cessation of flowering was due solely to natural development, psyllid damage or a combination of the two. Partial recovery of flowering indicates that the psyllid was influential. However, the recovery was only partial which could point to rundown towards the end of the season. Thus it seems likely that both factors played a part.

Peaks in mean immature (96 to 114 and 156 days) and mature (128 and 184 days) pods per plant indicated that the inflorescences present at 96 days contributed mostly to seed yield. They also indicate that the periods taken to reach immature and mature pod status are approximately 18 days and 32 days respectively. If the second peaks are taken into consideration the periods taken to reach immature and mature pod status is 14 and 42

days. The decrease in late season pod development rate is probably related to decreasing temperatures and / or water supply.

Pods appeared to dehisce when they had reached a certain stage of maturity, senesced and dried. Most pods dehisced between 128 days and 156 days most probably because they represented maturation of umbels involved in peak flowering. Psyllid damage could also have been influential by increasing premature pod abscission. This is supported by the decline in seed weight observed over the season which may also have been caused by pre-mature pod abscission. Although 'Marc' flowered over an extended period, a large proportion of pods dehisced between 128 days and 156 days. Because most seed was presented at one time emphasis is placed on the importance of recognising the correct time of harvest if a single pass harvest system is to be used. This may not be as important in 'Bayamo' and 'Uman' seed crops as pods of these cultivars do not appear to dehisce as readily (Cox pers. comm., 1995).

In addition to seed yield, seed quality is also important. Mean normal germination was consistently over 80% if hardseeds are assumed to produce normal seedlings. Mean abnormal and dead seeds were consistently around 15% and 2% respectively. Whereas germination characteristics did not change significantly over the season there was a significant decline in seed weight. This indicates that maximisation of seed number per unit area is more important than maximising seed weight (at least for the seed weight range observed) if high yields of viable seed are to be achieved.

3.4.2 IMPLICATIONS OF PSYLLID DAMAGE FOR COMMERCIAL DESMANTHUS SEED PRODUCTION

The psyllid was identified (Entomology Division of CSIRO, Indooroopilly, Queensland) as being a member of the *Acizzia* genus. It seems likely that this psyllid is the same as that observed on nearby desmanthus stands in the 1980s (Loch pers. comm., 1996). The psyllid is native to Australia being of the same family (Pysllidae) as the (introduced) *Heteropsylla cubana* which has been so damaging in leucaena (*Leucaena leucocephala*) stands in Queensland (Bray and Woodroffe, 1991) and other countries (Austin *et al.*,

1996; Berhe and Tothill, 1995). *Acizzia* are commonly found on native or naturalised species including *Acacia*, *Dodonea*, *Apophyllum*, *Hakea*, *Eremocritus* and *Leptospermum* (Carver *et al.*, 1991). It seems that low population densities of desmanthus in pasture based field trials have meant that *Acizzia* has preferred other hosts. However, when higher population densities are used, as is the case for seed production, desmanthus crops may be a more suitable host. It is possible that *Acizzia* may be a serious pest for future desmanthus seed production in South-East Queensland. The apparent lack of psyllid damage in desmanthus seed crops grown commercially on the Atherton Tablelands indicates that the area may not host the pest. This geographic isolation is clearly advantageous considering the obvious impact that the psyllid can have. Emphasis should be on the side of caution, however, and it should be assumed that the psyllid has the potential to damage all seed crops in Queensland. Within this trial regular applications of dimethoate (0.03 kg ai/100 l H_2O) applied every two weeks was found to be effective in controlling the psyllid presumably through reducing the psyllid population to non-damaging levels. Residual declines in leucaena productivity after complete eradication of leucaena-psyllid with 0.04% dimethoate have been reported (Bray and Woodroffe, 1991). Thus early eradication of psyllid is important. Identification of psyllid damage should be through regular monitoring. I found it reasonably easy to collect the psyllid by rubbing randomly selected branch tips between cupped hands. About twenty samples is recommended. If any psyllids are found it is time to spray.

3.4.3 ANNUAL VERSUS PERENNIAL SEED CROPPING

Although desmanthus is recognised as a perennial plant (Hacker, 1990) it recovered poorly from late season cutting agreeing with previous results (Adjei and Pitman, 1993). Muir and Pitman (1991) found that defoliation of desmanthus early in the season had little effect on new season growth but late (winter) defoliation results in poor spring regrowth. The suggested mechanism was that defoliation during vegetative development increases activity of basal buds but that these senesce over extended periods of apical dominance (Keoghan pers. comm., as cited by Adjei and Pitman, 1993). Thus regrowth after cutting during reproductive growth is limited by the number of basal buds present. Results from this trial support this theory and indicate that if 'Marc' is destructively

harvested its use as a second year crop is limited. An alternative may be to use a number of harvests during the season as this will encourage basal bud production.

3.4.4 EFFECTS OF POPULATION DENSITY ON PLANT DEVELOPMENT

3.4.4.1 Vegetative Development

Density effects on mean plant structure were characteristic of similar legumes such as *Medicago sativa* (Askarian, 1993; Kowithayakorn, 1978) and *Lotus corniculatus* (McGraw *et al.*, 1986). Increasing population density was associated with an increase in mean plant height but declines in mean branch and leaf number and plant breadth. Some density effects occurred by 60 days after germination but by 96 days larger differences occurred. Density differences in mean plant height were due to an extended period of stem elongation (~18 days) in plants sown at high densities, notably density groups 1 and 2 (> ~85 plants/m^2). Similarly density differences in mean plant breadth were due to continued horizontal expansion (~18 days) by plants sown at low (especially < ~13 plants/m^2) population densities. By 114 days after germination plant size (as determined by plant height and breadth) and structure (branch number, length and mass) was at a maximum in all density groups. Although branching was complete 96 days after germination, psyllid damage (rapid leaf fall 128 to 142 days after germination) may have reduced branch elongation.

3.4.4.2 Reproductive Development

Increasing population density decreased inflorescence number per plant. Plant branching structure regulated inflorescence distribution on the individual plant. As a result secondary inflorescences were present in all density groups whereas tertiary inflorescences were only present at population densities lower than 24 plants/m^2. Density strongly affected the numbers of secondary and tertiary inflorescences per plant e.g. at peak flowering plants experiencing low levels of competitive stress had an average of 70 and 27 inflorescences per plant on secondary and tertiary branches respectively, whereas stress affected plants had less than 5 (density groups 1 and 2). These results are

similar to those found in species with similar growth habit (e.g. *Medicago sativa* (Askarian, 1993; Kowithayakorn, 1978) and *Lotus corniculatus* (McGraw *et al.*, 1986)).

Density differences in the numbers of umbels mirrored inflorescence number per branching tier and per plant implying that either most inflorescences formed at least one immature pod (the entire inflorescence was not aborted) or that the rate of whole-inflorescence abortion is similar between density groups. The possibility of 'double-counting' of umbels means that comparisons between total numbers of inflorescences and umbels can not be used to determine which is correct. Individual inflorescences need to be tagged in order to accurately monitor development of individual reproductive sites.

Mean number of florets per inflorescence and pods per umbel showed no evidence of being affected by population density or changing over the season. Similarly, population density had no significant effects on seed quality (standard germination characteristics, hardseededness and seed weight). Again these results agree with results obtained for similar species e.g. *Medicago sativa* (Askarian, 1993; Kowithayakorn, 1978) and *Lotus corniculatus* (McGraw *et al.*, 1986).

3.4.5 DENSITY EFFECTS ON COLLECTED SEED YIELD

Measured seed yields ranged between 1081 to 1355 kg/ha with no clear trend for population density (Section 3.3.9). If these results are to be accepted, a 50-fold increase in population was associated with no change in seed yield. Although seed yield per plant often increases with decreasing population density, responses of this scale are unusual in legumes. Typically increasing population density of legumes (particularly of this scale), over which there are changes in competitive stress, results in increasing seed yield per unit area in a curvilinear (usually a parabolic or asymptotic) form e.g. *Lotus corniculatus* (McGraw *et al.*, 1986), *Vigna unguiculata* (Craufurd, 1996), *Vicia faba* (Aguilera-diaz and Recalde-manrique, 1995), *Lupinus angustifolius* (French *et al.*, 1994) and *Glycine max* (Ablett *et al.*, 1991; Parvez *et al.*, 1989). Thus the relationship between population density and seed yield per unit area obtained in this study was unexpected.

The two most likely reasons for the low collected seed yields and lack of density effects are:

(a) damage to the seed crop so that reproductive development is impaired

(b) poor sampling of seed.

Inflorescence number per unit area is generally the most important contributor to seed yield in herbage seed crops (Bullitta *et al.*, 1989; Evans *et al.*, 1986; Marshall, 1985) and this study indicates that desmanthus is no exception. Psyllid damage markedly decreased inflorescence number (Section 3.3.3) thereby decreasing PSY in this trial. The extent of this decrease cannot be measured because all density groups were affected.

It has also been widely hypothesised that stresses on the mother plant can result in reduced assimilate supply to the ovule and consequently increased ovule abortion (Evenari, 1984). For example, seed yields of semi-leafless peas (*Pisum sativum*) have been shown to be relatively insensitive to population density (Martin *et al.*, 1994) when affected by water stress during reproductive development. The psyllid damage (leaf shed and cessation of flowering) (Sections 3.3.1.3 and 3.3.3) indicate that plants were under considerable stress shortly after 'peak' flowering. Thus total season seed yield was probably affected by decreased assimilate supply to developing pods / ovules which most likely resulted in abortion of pods / ovules arising from peak flowering. The decline of seed number per pod (Section 3.3.5) and seed weight (Section 3.3.8.2) over the season supports this.

The possibility that an inappropriate density range, in which no seed yield response to plant density occurred, was chosen is considered unlikely because, at one end of the scale, plants appeared under no competitive stress (neighbouring plants did not touch), whereas at the other end of the density continuum plants showed considerable density effects (Sections 3.3.2 and 3.3.3).

The seed collection method used (Section 3.2.3.5) is similar to that employed successfully in plant persistence trials in South-East Queensland (Clem and Hall, 1994). However, in this study seeds were observed in the quadrat areas after the soil had been removed particularly in high population densities where the greater number of plants interfered with sweeping. This is considered a likely source of experimental error. Other factors possibly interfering with seed collection include loss of seed down cracks in the soil or removal by birds, rodents or ants but there was no direct evidence of these. Migration of seed from one density group to a neighbouring group during pod dehiscence is a possible explanation. However, pod dehiscence in 'Marc' desmanthus is not explosive and the seed is relatively dense meaning that wind dispersion is unlikely to have an effect. Movement of seed down the 5% slope during storm rainfall is also a possibility but again there was no evidence of this. Cleaning of the soil-seed mixture is not expected to have contributed to experimental error.

3.4.6 DENSITY EFFECTS ON POTENTIAL SEED YIELD (PSY)

Potential seed yields were calculated to verify seed yields collected off the ground. Because most inflorescences were produced in a short period, which in turn contributed to a contracted presentation period, PSY were calculated with SYC arising from flowering peaks (96 and 142 days) (Appendix 3.19).

Mean PSY increased from 4.8 to 19.5 g/plant with decreasing population density (Figure 3.9). When converted to per unit area values, this resulted in an increase of seed yield from 745 to 2020 kg/ha equivalent. The yield component which had the greatest influence on PSY per plant was inflorescence number (96 days) which increased 14-fold with decreasing population density. The other components (pods/umbel (114 days), seeds/immature pod (114 days) and thousand seed weight (212 days)) used in the calculation showed no significant trend with density. The number of reproductive sites present at peak flowering (as either leaf axils, inflorescences or umbels) was dependent on the size of the vegetative structure particularly the number of secondary and tertiary branches. This is highlighted by strong (> 0.85), significant (P=0.05) correlations

between branch number per plant and inflorescences and immature pods per plant at 96 and 114 days respectively (Appendix 3.18).

Potential seed yield was also affected by density differences in flowering duration which were again a result of density effects on plant structure. Flowering duration was shorter at high population densities (groups 1, 2 and 3) and as a result fewer inflorescences per unit area were produced after 128 days in these densities compared to the other density groups. Thus plants sown at high population densities produced less seed later in the season (the second flowering peak). Mean seed weight declined by approximately 20% between peak flowering and the end of the season. This interacted with density differences in flowering duration to reduce population density differences in PSY i.e. although plants grown in low population densities produced proportionately more inflorescences in the second flowering peak than plants in high population densities, this effect was partially offset by declining seed weight over the season.

The distribution of PSY per plant with population density was typical of similar legume species e.g. *Medicago sativa* (Askarian, 1993) and *Lotus pedunculatus* (McGraw *et al.*, 1986). Incremental changes in PSY were greatest at the lowest populations used in this trial indicating that competitive stresses occurred at all population densities. Population densities above 24 plants per m^2 resulted in very low PSY per plant.

The relationship between total PSY/m^2 and plant density was linear. Usually the relationship between seed yield per unit area and plant density is parabolic (e.g. *Medicago sativa*, Kowithayakorn and Hill, 1982) or sometimes asymptotic (e.g. *Lotus corniculatus*, McGraw *et al.*, 1986) with a linear phase occurring at a range of plant densities at which reductions in seed yield per plant do not compensate for increases in plant density (Willey and Heath, 1969). However, a linear (but negative) response between seed yield per unit area and plant density has been reported in *Lotus pedunculatus* over a wide range of plant densities (22 to 133 plants/m^2) (Hare, 1984). Generally in legumes the linear phase occurs within the range of plant densities used in this study. However, there are exceptions e.g. *Stylosanthes humilis*, another sub-tropical forage legume exhibiting extensive branching, shows a clear linear phase between 10 and

250 plants/m^2 and does not reach maximum yields until 850 plants/m^2. As with desmanthus in this study, other SYC of *S. humilis* (other than inflorescence number) were not affected by plant density in the linear phase (but were affected at higher plant densities) (Shelton and Humphries, 1971).

Results from this study indicate that the point where increasing plant density was compensated by decreasing seed yield per plant (optimum plant density) was not achieved despite the wide range of plant densities used (3 to 160 plants/m^2). Optimum plant density for seed production of lucerne (*Medicago sativa*), a plant with similar growth habit to desmanthus has been reported to be less than 60 plants/m^2 (Askarian, 1993; Kowithayakorn and Hill, 1982). This study suggests, however, that desmanthus behaves like *S. humilis* and that the optimum plant population of desmanthus grown at a high fertility site and under irrigation is at least 160 plants per m^2 (7 kg seed/ha; TSW = 3.50g; 80% field emergence). The ability to continue to flower and for seed or pod abortion not to increase at high population densities is responsible for this.

3.4.7 COMPARISON OF COLLECTED AND POTENTIAL SEED YIELDS

Potential seed yields showed a more typical response to population density than collected seed yields. Total mean PSY per plant increased from 4.8 to 19.5 g per plant with decreasing (approximately 150 to 3 plants/m^2) population density. The response curve was curvi-linear and biologically sound. Conversion to per hectare values resulted in a linear increase of PSY from approximately 745 to 2020 kg/ha equivalent with increasing population density. The positive relationship between population density and PSY per unit area was similar to reports for other plant species although an asymptote was not reached (Section 3.4.6).

Also there is reason to question the effectiveness of seed recovery by quadrat. Collected seed yields showed no trend with density unlike with PSY (Figure 3.10) and seed was observed on the ground after quadrat sampling particularly at high population densities. Collected seed yields were similar to PSY at low population densities but were much lower than PSY at plant densities above 45 plants/m^2. The presence of seeds in soil after

quadrat harvest at these high population densities indicates that sampling was not as efficient, this being a result of the difficulty of sweeping around greater numbers of plants. Thus quadrat collection of seed, as used in this study, is considered to be accurate at lower population densities but less so when increasing numbers of plants interfere with sweeping up seed and that this influenced collected seed yields.

3.4.8 RECOMMENDED SOWING RATES

The PSY suggest that increasing plant density to 160 plants/m^2 (7 kg seed/ha; TSW = 3.5g; 80% field emergence) will benefit seed yield. However, these results should be treated with caution until a further field evaluation is conducted in a psyllid-free stand. It is not recommended that sowing rates be higher than this because declines in seed yields as observed in similar crops (e.g. *Medicago sativa*, Kowithayakorn and Hill, 1982) may occur thereafter.

Seed costs are not expected to influence sowing rates because the benefit to the grower of sowing at rates required to establish populations up to 160 plants/m^2 outweigh the extra cost of seed required e.g. the benefit of sowing one extra kilo of seed is 162 kg of increased PSY (TSW = 3.5g, 80% field emergence).

Other benefits of high sowing rates will be increased weed control because canopy closure will occur earlier and ease of direct heading because plants will be more erect than when sown at lower population densities. Also a greater proportion of seed is presented in a shorter period at high plant densities. Thus (combine) harvest efficiency should be greater if higher population densities are used.

3.4.9 FURTHER RESEARCH

There is a need to study seed production of desmanthus at higher plant densities than used in this study in order to confirm similarity of the response to *S. humilis* and to determine whether further increases in seed yields can be achieved at higher plant densities. The use of a randomised complete block design using combine harvestable

plots, each containing a separate plant density, is preferable to a radial design as the effect of plant density on combine harvest efficiency can also be evaluated.

The two-weekly destructive sampling technique used in this trial did not completely document SYC, particularly rates of inflorescence abortion and development of florets and umbels. Tagging studies are required to fully document reproductive site development over the season. These should be extended to at least one of the short-day flowering responsive cultivars.

Calculation of PSY enabled the estimation of inefficiencies in the conversion of florets to immature pods (seed set). At populations recommended in this trial, less than 40% of florets formed pods. Possible reasons for this are:

(a) poor pollination because of few suitable pollinating insects

(b) high levels of pod abortion just after anthesis.

There is a need to investigate self-pollination rates and the potential to increase pod-set by introducing pollinators.

In this trial decline in seed weight over the season combined with a relatively contracted flowering period indicated that a single pass harvest system was most appropriate. 'Marc' has displayed the ability to produce inflorescences over an extended period, however, (although in low numbers) and it is possible that the flowering 'peak' may have been extended if psyllid was not present. The decline in thousand seed weight over the season reduced the yields of late season seed although the decline in seed weight had no effect on seed viability suggesting that reductions in seed weight of this magnitude are not important for establishment. Thus late season seed, if successfully and economically, collected will be useful. There is a need to compare different harvest systems, particularly those collecting seed in one destructive harvest with those collecting fallen seed produced over the entire season. The latter system is likely to be useful for 'Marc' seed because this cultivar has a long flowering period and pods dehisce easily. This investigation should be extended to one of the short-day cultivars, however, as these have been observed in casually monitored plots to have an extended flowering period and exhibit some pod dehiscence.

3.5 Conclusion

It has been demonstrated that 'Marc' has the ability to produce moderate seed yields under irrigated conditions in South-East Queensland even when damaged by psyllid (*Acizzia* sp.). Although 'Marc' flowered continuously over an extended period most of the seed was presented in a relatively short time arising from peak flowering. Ready pod dehiscence further reduced the period of seed presentation for harvest highlighting the need to identify the correct time of harvest.

The seed yield component which was most responsive to plant density was the number of inflorescences per plant which was related to the size of the vegetative framework. Plant seed yields were much higher when plants were sown at low (3 plants/m^2) population densities. However, when converted to per hectare values, high population densities (160 plants/m^2) resulted in highest PSY. Thus population density is more influential on PSY than seed yield per plant. This suggests that high sowing rates (e.g. 6 to 7 kg seed/ha; TSW 3.5g, 80% establishment) will result in optimum population densities although there is the possibility that even higher sowing rates may further increase seed yields.

Loss of PSY occurred during anthesis and early pod development with less than 50% of florets forming fully expanded pods at all population densities. Whether this is due to poor seed set / pollination or subsequent abortion is uncertain and requires investigation. Losses of potential after the immature pod phase were limited to a 20% decline in seed weight over the season.

Under the trial conditions experienced (psyllid damaged) a single-pass destructive harvest was the most appropriate harvest method as most seed was presented over a contracted period. However, ready pod dehiscence and a prolonged flowering period suggest that alternative harvesting techniques which collect seed over a prolonged period may be useful.

Subsequent trialwork should place emphasis on:

(a) tagging studies of reproductive sites to accurately determine rates of development and abortion.

(b) pollination studies to evaluate the potential of increasing seed set through the introduction of pollinators. This should also give an indication of selfing rates.

(c) evaluation of harvesting techniques both destructive and non-destructive.

Investigation should be on 'Marc' and one of the late-flowering cultivars as this will allow comparison of data already collected on 'Marc' and facilitate detailed yield component analysis on either 'Bayamo' or 'Uman' which has not yet been completed to date.

CHAPTER FOUR
CHEMICAL CONTROL OF WEEDS IN DESMANTHUS SEED CROPS IN SOUTH-EAST QUEENSLAND

4.1 Introduction

Effective control of weeds within a seed crop is necessary to minimise costs associated with lost production (competition effects and interference with harvesting) and seed lot contamination by weed seeds. In Queensland most weed control in high value crops involves herbicides because labour costs are high and effective, relatively inexpensive, chemicals are readily available to the grower.

The weed control programme, usually a combination of mechanical or chemical means, must effectively control the weed spectrum present whilst not reducing the seed yield potential of the cropped species. With herbicide use consideration must also be made of local restrictions (availability and registration), and the future use of the site. As with all factors of seed crop management the method used must give a positive return on investment.

There is virtually no published information on weed control by herbicides in *Desmanthus virgatus*. Of the information available most comes from unpublished sources. This is presented in Section 4.1.1. In order to identify potentially useful herbicides for use in desmanthus seed production reference has been made to a taxonomically closely related tropical forage legume (*Leucaena leucocephala*), a temperate legume with similar growth habit (*Medicago sativa*) and also other tropical and sub-tropical legumes of economic importance. This material is presented in Sections 4.1.2 to 4.1.4. This information was used to identify herbicides for use in the trials included in this study.

4.1.1 DESMANTHUS SPP.

Herbicide screenings of desmanthus have been conducted in pot trials in Queensland (Table 4.1) (Loch and Harvey, 1990) and Nova Odessa, Brazil (Mastrocola *et al.*, 1983). Desmanthus seedlings are intolerant of the broadleaf targeting, hormone type herbicides 2,4-D, 2,4-DB and dicamba (Loch and Harvey, 1990) and MCPA and MCPB (Loch pers. comm., 1994).

Desmanthus seedlings are more tolerant to knockdown herbicides with other modes of action. Examples include bentazone, diclofop-methyl, dinoseb (now unavailable), MSMA and sethoxydim (Loch and Harvey, 1990; Mastrocola *et al.*, 1983). Tolerance to fluazifop-P was also noted although slight distortion and necrosis of emerging leaves was noticed (Loch and Harvey, 1990). These herbicides target broadleaved weeds, the exceptions being fluazifop-P and sethoxydim which target grass weeds. MSMA and diclofop-methyl control a range of broadleaved and grass weeds.

Only two (chloroxuron and oryzalin) residual herbicides have been tested on desmanthus seedlings. Oryzalin (1.5 kg/ha) applied 1 month after sowing and following pre-emergence weed control has been used effectively for long term control of weeds in *D. virgatus* in field trials at Gympie (Loch and Harvey, 1990). Desmanthus was also found to be tolerant to chloroxuron (Mastrocola *et al.*, 1983).

Weeds which have proven to be particularly troublesome in Queensland desmanthus seed crops include *Aechynomene, Chinopodia, Sida, Digitaria, Salvia, Urochloa* and *Verbena* species (Murat pers. comm., 1995). Current commercial desmanthus seed production relies on only one pre-emergence (trifluralin) and one post-emergence (bentazone) herbicide. These have not controlled all weed species present in desmanthus seed crops. A wider range of herbicides is required for desmanthus stands particularly for post-emergence control of broadleaved weeds. In addition to weed control during establishment, early spring weed management in established crops during,

Table 4.1 **Tolerance of 3 to 4 week old *Desmanthus virgatus* seedlings to eight post-emergence herbicides in a pot trial, Gympie, Queensland.**

Active ingredient	Product	Rate (g ai/ha)	Tolerance
2,4-D	Nufarm Amicide	500	No
		1000	No
2,4-DB	Nufarm Buticide	800	No
		1600	No
Acifluorfen	Blazer	448	No
		996	No
Bentazone	Basagran	1440	Yes
		2880	Yes
Dicamba	Banvel 200	150	No
		300	No
Dinoseb	Daturan	1600	Yes
		3200	Yes
Fluazifop-P	Fusilade 212	106	Yes
		212	Yes
Sethoxydim	Sertin 186EC	186	Yes
		372	Yes

(Adapted from Loch and Harvey, 1990)

and immediately after, dormancy is also expected to be important if weed populations are to be controlled to a satisfactory level.

4.1.2 HERBICIDE TOLERANCE OF LEUCAENA

Of the Mimosaceae, *Leucaena* spp., particularly *L. leucocephala*, are the most documented of the species taxonomically close to desmanthus and for which seed is commercially produced. Recent pot-based herbicide screenings conducted in Queensland (Hawton *et al.*, 1990; Loch and Harvey, 1990) have seen a number of herbicides evaluated on leucaena (*L. leucocephala*) (Appendix 4.1). These results indicate that leucaena seedlings have a greater degree of tolerance to herbicide treatment than desmanthus seedlings, particularly to hormone based post-emergence applications, notably 2,4-D and 2,4-DB.

Trial work, previous to that listed in Appendix 4.1, has concentrated on weed control during establishment of leucaena (Appendix 4.2). Of the herbicides not tested on desmanthus, cyanazine, dalapon (+2,4-D), flumeturon, imazaquin, MSMA, nitrofen, norflurazon, paraquat and PCP were shown consistently to have little effect on *Leucaena leucocephala*. Of these, imazaquin, nitrofen and PCP are not available in Australia. Assuming that desmanthus responds similarly to *L. leucocephala*, potentially useful herbicides in desmanthus seed crops are cyanazine, dalapon, flumeturon, MSMA, norflurazon and paraquat.

4.1.3 HERBICIDE TOLERANCE OF OTHER TROPICAL LEGUME SPECIES OF ECONOMIC IMPORTANCE

Moody (1979) has reviewed the tolerance of six other tropical legumes to selective herbicides. Species included, as cited by Moody (1979), are mung bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), asparagus bean (*Vigna unguiculata* ssp. *sesquipedalis*), pigeon pea (*Cajanus cajan*), peanut (*Arachis hypogaea*) and soyabean (*Glycine max*). Tolerances are listed in Appendix 4.3. In addition I have included fine stem stylo (*Stylosanthes guianensis* var. Intermedia) in recognition of its role in sub-tropical herbage production.

Information from Appendix 4.3 cannot be simply translated into herbicide recommendations for *D. virgatus* because of:

(a) variation in tolerance between species and

(b) the constant turnover of chemical products available on the market.

However this list has been used to identify which herbicides have been used in tropical legume cropping situations in the past and to help determine those most likely to have potential for use in *Desmanthus* spp. As such, information on rates and timing of application has been omitted. Of the 46 herbicides, or herbicide combinations, listed only half remained on the Australian market in 1993 (Badewitz-Dodd, 1993).

4.1.4 HERBICIDE TOLERANCE OF LUCERNE AND OTHER TEMPERATE LEGUME SPECIES OF ECONOMIC IMPORTANCE

Lucerne (*Medicago sativa*) has many similarities in morphology and development to desmanthus. Important similarities in the context of herbicide use include:

(a) the presence of a tap-root which can access nutrients from depth

(b) similar foliar branching patterns which ultimately arise from a 'crown' and which exhibit a degree of lateral branching

(c) relatively slow establishment

(d) similar growing season

(e) perenniality

(f) a 'dormant' period where little growth occurs.

Because of these similarities, and because considerable research has been conducted into herbicide use in lucerne crops, emphasis has been placed on lucerne in the selection of potentially useful herbicides for desmanthus. Herbicide types, rates and time of application as used in lucerne crops in New Zealand are listed in Appendix 4.4.

In order to include as many potentially useful herbicides as possible the search was extended to a number of commercially important temperate legumes other than lucerne. These, with recommended application rates and times, are listed in Appendix 4.5. Herbicides not already identified as being useful in the tropical crops or lucerne were added to the list of potentially useful herbicides for desmanthus seed production.

4.1.5 APPROACH TO THE IDENTIFICATION OF SUITABLE CHEMICAL WEED CONTROL STRATEGIES IN DESMANTHUS

Effective weed control is clearly important in commercial desmanthus seed crops. The identification of herbicides safe for use in desmanthus and which control the weed

species encountered in Queensland was also required if further experimental work in this study was to be conducted in the field. Two periods in which weed control in desmanthus seed crops was likely to be most influential were identified as:

(a) during establishment when seedlings of both desmanthus and weed species are present. This is a stage when desmanthus (which establishes slowly) is expected to compete poorly with faster growing weed species. Effective control of weed species prior to canopy closure is expected to be the most important period. Thereafter, desmanthus should compete effectively with most weed species.

(b) at the beginning of second season growth when desmanthus will become less competitive with some established weeds and weed seedlings. This assumes that desmanthus is to be grown as a perennial crop.

Priority was placed on the determination of effective herbicides for use in establishing desmanthus. Because few pre- and post-emergence herbicides had been trialed on desmanthus, and because so many are being used effectively on apparently similar crops, it was necessary to take a broad approach at first. Once promising herbicides were identified the focus was narrowed and eventually combinations of chemicals assessed in field conditions.

The study was divided into four parts:

(a) preliminary pot-based screening of selective herbicides on desmanthus seedlings

(b) field evaluation of selected selective herbicides on desmanthus seedlings

(c) field evaluation of combinations of selective herbicides on seedlings

(d) field evaluation of herbicides applied to mature desmanthus plants.

The initial trial involved the screening of 58 herbicide treatments (2 pre-plant, 22 pre-emergence, and 34 post-emergence) used in legume species in New Zealand or Australia on desmanthus seedlings. The large number of herbicides evaluated meant that this preliminary screening had to be conducted as a pot trial which also meant that the screening could be conducted out-of-season by using controlled environment conditions

thereby saving time and providing at least tentative information on weed control prior to the first season of field trials. The findings from the preliminary trial reduced the number of potentially useful chemicals to seven pre-emergence and nine post-emergence treatments. The effect of these herbicides on desmanthus and weed performance was evaluated in the field during the 1994/1995 season. Combinations of pre- and post-emergence herbicides which showed potential in the 1994/1995 field trials were evaluated in field trials in the 1995/1996 season. Recently released herbicides for use in lucerne seed crops were also incorporated in the 1995/1996 field trial.

The literature identified chemicals for use in dormant legume crops (such as lucerne). One screening of potentially useful herbicides identified was conducted on established (one year old) desmanthus plants. This was conducted during the 1995/1996 season in field conditions.

Cultivar 'Marc' was used in all trials for consistency and because literature indicates that 'Marc' is best suited to South-East Queensland conditions.

4.2 Preliminary Herbicide Screening of *Desmanthus virgatus* cv. 'Marc' During Establishment

4.2.1 INTRODUCTION

The objective of this trial was to identify selective herbicides which are non-damaging to desmanthus plants during establishment. A wide range of herbicides was screened on 'Marc' desmanthus with emphasis being placed on early post-emergence application. Results from this pot trial and information obtained from the literature was used to select treatments for subsequent field evaluation of herbicides.

4.2.2 MATERIALS AND METHODS

4.2.2.1 Pre-Spray Preparation

A Kiwitea loam soil (4.5% organic carbon) was adjusted to a pH of 7.0 by adding lime equivalent to 2 t/ha. Planter bags (1.8 l) were filled with the soil and seed of *Desmanthus virgatus* cv. 'Marc' was sown at a depth of 5 mm with ten seeds per pot. Five pots were used for each treatment and control. The pre- and post-emergence treatments were applied in separate experiments each using a completely randomised design with untreated controls. Pre-emergence treatments were further divided into those requiring soil incorporation of the herbicide (trifluralin and EPTC) and those directly applied to the surface. The seed was dormancy treated by scalpel excision of the non-embryonic end and stored dry at 20°C prior to sowing, resulting in a 98% germination (between paper, 12 hrs 20°C:12 hrs 30°C, 24 hrs light). Pots for the pre-emergence herbicide trial were sown on 4 July 1994 immediately prior to herbicide application. Post-emergence herbicide trial pots were sown on 30 June 1994 4 weeks prior to application and thinned to eight plants per pot after 2 weeks. Pots were placed on benches in a controlled environment glasshouse located at the Plant Growth Unit, Massey University, Palmerston North. The benches were fitted with capillary action sub-irrigation. Temperature and humidity were measured by a thermohygrograph and mean values for the entire experimental period were 21.9° (17 to 33°C) and 67.0% (48 to 90%) respectively.

4.2.2.2 Pre-Emergence Herbicide Application

The 22 pre-emergence treatments (Table 4.2) were applied at rates recommended for other legume crops (O'Connor, 1994; Badewitz-Dodd, 1993; Loch and Harvey, 1990) immediately after sowing. Where a number of rates were recommended lower doses were chosen. Soil incorporation (hand mixing of herbicide with the top 10 cm of soil) was used for EPTC and trifluralin. All five pots per treatment were sprayed in one application. Herbicide treatments were applied using a modified version of the pendulum laboratory sprayer described by Wiese (1977). Plants were placed below the pivotal centre of the swinging boom and herbicide was forced through two flat fan nozzles (35 cm apart) by compressed air. Spray pressure was kept constant at 200 kPa. The boom was released from the same height for each application and allowed to pass twice over each pot. A sheet of glass placed below the pivotal centre of the boom was used to calibrate the sprayer and water equivalent to 250 l/ha was applied. Calibration checks revealed a variation of less than 5%. Relative humidity and temperature at the time of spraying averaged 62% and 14.3°C respectively.

For the trifluralin and EPTC treatments, unsown pots were sprayed as above, emptied into a container and the herbicide mixed into the soil by hand. Seeds were sown immediately after herbicide application. Rates are given in Table 4.3. Pots of all treatments were placed in the glasshouse immediately after spraying.

4.2.2.3 Post-Emergence Herbicide Application

The 34 post-emergence treatments used (Table 4.4) were applied to 4 week old (three to four true leaf) plants at the lowest rate recommended for other legume crops. Application was as above and variation in spray weight applied was again less than 5%. Relative humidity and temperature at application averaged 71% and 15.1°C

Table 4.2 **Pre-emergence herbicide treatments applied on 4 July 1994 to pots sown with *Desmanthus virgatus* cv. 'Marc' seeds.**

Chemical	Product	Application rate (kg ai/ha)
acetochlor	Roustabout	2.10
alachlor	Lasso	1.44
aziprotryne	Brasoran 50WP	2.00
chloridazon	Chloronion	0.86
chlorpropham	Chloro IPC	2.40
chlorthal dimethyl	Dacthal 75W	4.50
cyanazine	Bladex 50SC	1.00
diflufenican +	Cougar	0.10
isoproturon		0.50
diuron	Karmex	0.80
ethofumesate	Nortron 500SC	1.50
hexazinone	Velpar L	0.80
linuron	Linuron 50	1.00
methabenzthiazuron	Tribunil	1.05
methazole	Probe 75WD	1.13
metribuzin	Sencor DF	0.38
norflurazon	Solicam DF	2.00
oryzalin	Surflan Flo	3.00
oxadiazon	Foresite 380	1.52
oxyfluorfen	Goal	0.72
pendimethalin	Stomp 330E	0.99
simazine	Gesatop 500FW	1.00
terbutryne	Topogard 500FW	0.26
untreated	-	-

Table 4.3 **Soil incorporated herbicide treatments applied on 4 July 1994 to pots which were subsequently sown with *Desmanthus virgatus* cv. 'Marc' seeds.**

Chemical	Product	Application rate (kg ai/ha)
EPTC	Eradicane Super	4.32
trifluralin	Treflan	0.80
untreated	-	-

Table 4.4 **Post-emergence herbicide treatments applied on 28 July 1994 to pots sown with *Desmanthus virgatus* cv. 'Marc' seeds.**

Chemical	Product	Application rate (kg ai/ha)
2,4-D amine	Dow Elanco 2,4-D Amine	0.80
2,4-DB	Dow Elanco 2,4-DB	2.40
asulam	Asulox	0.80
aziprotryne	Brasoran 50WP	2.00
benazolin	Cornox CWK	0.15
bentazone	Basagran	1.44
bromofenoxim	Faneron 50WP	0.30
bromoxynil	Bromoxynil 40	0.90
bromoxynil +	Combine	0.20
ioxynil		0.20
carbetamide	Carbetamex 70	2.80
chloridazon	Pyramin DF	1.17
chlorimuron	Classic	0.03
chlorpropham	Chloro IPC	2.40
chlorsulfuron	Glean	0.02
chlorthal dimethyl	Dacthal 75W	4.50
clethodim[1]	Centurion 240EC	0.12
cyanazine	Bladex 50SC	1.00
dalapon	Chemagro Dalapon	2.22
diflufenican +	Cougar	0.10
isoproturon		0.50
diquat	Reglone	0.60
ethofumesate	Nortron 500SC	1.50
flumetsulam	Broadstrike	0.04
glyphosate	Roundup	0.36
haloxyfop	Gallant	0.20
ioxynil	Totril	0.45
linuron	Linuron 50	1.00
MCPA	Dow Elanco MCPA	0.56
MCPB	Dow Elanco MCPB	1.16
methabenzthiazuron	Tribunil	0.60
metribuzin	Sencor DF	0.38
paraquat	Gramoxone	0.20
pendimethalin	Stomp 330E	0.99
propyzamide	Kerb Flo	0.52
terbutryn	Igran 500 FW	0.26
untreated	-	-

[1] Applied with 2 l/ha D-C-Trate

respectively. Oil (D-C-Trate) was applied at 2 l/ha with clethodim. No other surfactants were used. Pots were placed in the glasshouse immediately after spraying.

4.2.2.4 Data Collected

Pots were scored weekly on the basis of plant height, form and colour. Scores ranged from 1 to 10, '1' representing complete removal of green matter ('dead') and '10' representing the most vigorous growth (Plate 4.1). Plants with any green material were counted after the first week and at harvest for both trials. Harvesting was conducted on 26 August 1994 and 1 September 1994 for the pre- and post-emergence treatments respectively and consisted of cutting the growing plant at ground level and immediately measuring the fresh weights of shoots.

4.2.2.5 Statistical Analysis

Treatment mean values of score, fresh weight and plant number were generated and variables with a significant F value were compared with the Fischer's least significant difference procedure.

4.2.3 RESULTS AND DISCUSSION

4.2.3.1 Herbicide Performance Indicators

It was decided that plant fresh weight, final score and, in the case of the pre-emergence treatments, final plant number per pot should give the best estimate of how herbicide treatments affected subsequent seed production. Ultimately a full season field trial is required to evaluate treatment effects on seed production and quality rather than relying on simulation of field conditions using pots in a glasshouse. However pot trials were considered to be more practical than using field plots for the initial screening of large numbers of herbicides.

Plate 4.1 Plant vigour ratings used in the preliminary herbicide screening on *Desmanthus virgatus* cv. 'Marc'. Tags on pots denote vigour scores at harvest (53 days after sowing) of pots in pre-emergence herbicide treatments.

4.2.3.2 Pre-Emergence Herbicides

The difference between damaging and safe pre-emergence herbicides was readily apparent with all variables used to estimate herbicide damage (Table 4.5). Damage from pre-emergence herbicides was obvious within 1 week with scores and plant numbers changing little after the initial assessment 1 week after application. Near optimum temperatures and moisture supply for desmanthus growth probably contributed to this rapid effect. The pre-emergence trial was concluded after 6 weeks because of the stabilisation in results.

Untreated plants had a mean fresh weight of 1.30 g/pot 53 days after application. All plants except those treated with oryzalin and chlorpropham had significantly (P = 0.05) lower weights. A further three treatments resulted in final mean scores which were not significantly different (P = 0.05) from untreated plants. These were diflufenican + isoproturon, chlorthal dimethyl and terbutryn. Pendimethalin, aziprotryne, diuron, chloridazon, methazole and alachlor were moderately (vigour score = 5.0 to 5.8) damaging to desmanthus plants. Of these, pendimethalin had the highest fresh weight 53 days after application.

The need to control broadleaved weeds in seed crops of the slow establishing desmanthus has been identified (Loch pers. comm., 1994). The herbicides listed as having little effect on desmanthus growth all include broadleaved weeds in their target spectrum with diflufenican + isoproturon, oryzalin and pendimethalin having notably wide broadleaf target ranges (O'Connor, 1994). For general pre-emergence weed control it would appear, therefore, that oryzalin, pendimethalin, diflufenican and chlorpropham are the best options. Chlorpropham, however is not available in Queensland and is not expected to be registered for use there in the future. Although the least damaging chemical available in Queensland, oryzalin is expensive at the rates used in this trial. Pendimethalin, although found to be more damaging to desmanthus, controls a similar weed spectrum to oryzalin at half the cost, even when applied at similar rates (Appendix 4.6).

Table 4.5 **Effects of pre-emergence herbicides on germinating *Desmanthus virgatus* cv. 'Marc' seedlings grown in pots.**

Chemical	Initial count 15DAA[1,3] (plants/pot)	Final count 53DAA[1,3] (plants/pot)	Fresh weight 53DAA[1,3] (mg/pot)	Initial score 20DAA[1,2,3]	Final score 53DAA[1,2,3]
acetochlor	2.0	1.0	19	1.4	2.2
alachlor	3.8	2.6	272	3.8	5.0
aziprotryne	5.6	4.0	353	4.6	5.2
chloridazon	5.6	4.2	229	5.4	5.2
chlorpropham	6.6	6.4	1020	7.6	9.0
chlorthal dimethyl	6.2	5.0	798	6.6	7.4
cyanazine	5.4	2.0	98	3.2	3.4
diflufenican + isoproturon	6.0	5.2	767	8.0	8.2
diuron	4.6	3.6	210	5.4	5.2
ethofumesate	4.6	3.9	156	3.8	2.8
hexazinone	5.4	1.8	116	2.2	2.4
linuron	4.8	1.6	4	1.4	1.0
methabenzthiazuron	5.4	4.6	36	4.0	2.4
methazole	6.0	3.6	191	5.8	5.2
metribuzin	5.4	3.0	23	2.2	2.0
norflurazon	3.4	2.6	190	2.4	2.4
oryzalin	5.4	6.2	1042	8.0	8.6
oxadiazon	0.8	1.4	19	1.2	1.8
oxyfluorofen	0.6	0.8	2	1.0	1.0
pendimethalin	5.8	5.4	535	5.4	5.8
simazine	4.8	1.4	22	1.8	1.8
terbutryn	5.3	3.8	289	7.8	6.5
untreated	7.2	7.2	1298	9.2	9.0
$LSD_{0.05}$	2.3	2.2	310	2.4	2.6

1 Mean values for 5 pots

2 Scores range from 1-10 1 = no green material present, 10 = most vigorous growth

3 Days After Application

The triazines (aziprotryne, cyanazine, hexazinone, simazine and terbutryne) were poorly tolerated as evidenced by mean final fresh weights significantly (P=0.05) lower than untreated pots (Table 4.5). Metribuzin (not technically a triazine though structurally very similar) was also damaging to desmanthus. Increased solubility within the triazine family was associated with greater desmanthus tolerance to treatment. As irrigation was from the base of the pots, leaching is not expected to have removed enough of the more soluble triazines from the desmanthus root zone. Instead, physiological tolerance is expected to account for the observed differences. Although damaging to seedlings the depth control nature of the triazines may result in them having a place in broadleaf control in deeply taprooted established desmanthus crops. In addition to the triazines the ureas (diuron, linuron and methabenzthiazuron), amides (alachlor and acetachlor), ethofumesate, oxyfluorfen and oxadiazon are not recommended for use in legume seedlings. These were included to determine if *D. virgatus* seedlings were physiologically tolerant to the application of these herbicides. All were damaging. Application of the ureas and norflurazon resulted in reduced numbers and checked growth. In addition to checked growth, distorted foliage was observed with the amides (alachlor and acetochlor) and ethofumesate. Oxyfluorfen and oxadiazon treatments were two of the most damaging, but both control a very wide range of weed species at emergence in stone and pip fruit orchards so it was not surprising that they were damaging (O'Connor, 1994).

4.2.3.3 Pre-Sowing Herbicides

Both trifluralin and EPTC are volatile and so require incorporation into the soil to avoid losses (Ross and Lembi, 1985). Both treatments caused significant damage to germinating desmanthus (Table 4.6). Trifluralin was not as damaging as EPTC and at the end of the trial plants were checked in growth but otherwise appeared normal i.e. relatively high final vigour score of 6.0. The low mean fresh weight of trifluralin-treated pots was mainly caused by relatively low seedling numbers presumedly because of the herbicide. Trifluralin is recommended for pre-emergence grass and broadleaved plant control in a variety of leguminous crops (O'Connor, 1994) and has been used in commercial desmanthus seed crops. Results from this trial suggest that trifluralin may check growth of desmanthus in commercial seed crops.

Table 4.6 **Effects of soil incorporated herbicides on germinating *Desmanthus virgatus* cv. 'Marc' seedlings grown in pots.**

Chemical	Initial count 15DAA[1,3] (plants/pot)	Final count 53DAA[1,3] (plants/pot)	Fresh weight 53DAA[1,3] (mg/pot)	Initial score 20DAA[1,2,3]	Final score 53DAA[1,2,3]
EPTC	3.4	1.8	39	2.0	2.0
trifluralin	4.2	3.2	446	7.6	6.0
untreated	7.4	6.8	1749	9.2	9.4
$LSD_{0.05}$	2.7	3.1	619	1.3	2.0

[1] Mean values for 5 pots

[2] Scores range from 1-10 1 = no green material present, 10 = most vigorous growth

[3] Days After Application

4.2.3.4 Post-Emergence Herbicides

General effects

Treatment effects took longer to become evident than with the pre-emergence treatments although generally full effects had developed by the third week after application (Table 4.7). Partial recovery from initial damage subsequently occurred in some cases.

Propyzamide resulted in a significantly (P = 0.05) higher mean fresh weight than the untreated control plants although the final scores were not significantly different. It may be possible therefore that propyzamide had some form of growth promoting activity. In order of decreasing mean fresh weight, treatments not significantly different to the untreated control included carbetamide chlorthal dimethyl, asulam, chlorpropham, clethodim, bromoxynil and bromoxynil + ioxynil. In addition the final mean counts of propyzamide, carbetamide, haloxyfop, bromofenoxim, chlorsulfuron, ioxynil and chlorimuron were not significantly different to the untreated pots. Of the herbicides with final counts not significantly different to the untreated pots (Table 4.7) clethodim, chlorimuron, benazolin, carbetamide, dalapon and bromofenoxim are currently not available on the Australian market (Badewitz-Dodd, 1993).

Table 4.7 **Effects of post-emergence herbicides on germinating *Desmanthus virgatus* cv. 'Marc' seedlings grown in pots.**

Chemical	Initial score 5DAA[1,2,3]	Medial score 10DAA[1,2,3]	Final score 35DAA[1,2,3]	Final count 35DAA[1,3] (plants/pot)	Fresh weight 35DAA[1,3] (mg/pot)
2,4-D amine	5.0	2.4	1.2	0.6	33
2,4-DB	6.2	2.2	1.6	2.2	67
asulam	8.6	8.4	7.6	6.6	1519
aziprotryne	6.8	2.4	3.8	4.2	154
benazolin	7.6	7.8	7.6	6.0	1107
bentazone	7.4	6.0	5.8	5.0	448
bromofenoxim	8.4	7.4	7.0	5.8	780
bromoxynil	6.2	6.4	8.0	6.0	1281
bromoxynil + ioxynil	8.2	7.2	7.6	7.0	1279
carbetamide	7.4	8.6	9.0	6.0	1945
chloridazon	8.2	8.2	4.2	6.6	263
chlorimuron	5.8	6.0	6.0	5.4	779
chlorpropham	7.2	6.8	8.0	6.8	1513
chlorsulfuron	7.0	7.0	6.2	6.4	634
chlorthal dimethyl	7.4	8.4	8.6	6.8	1783
clethodim	8.2	8.2	8.2	5.8	1309
cyanazine	7.6	1.2	1.0	0.0	93
dalapon	7.4	7.2	7.8	5.8	1074
diflufenican + isoproturon	7.6	2.6	2.2	0.8	62
diquat	1.8	1.4	1.6	0.4	83
ethofumesate	7.6	7.0	3.2	6.2	425
flumetsulam	7.6	6.2	5.4	7.0	639
glyphosate	8.0	1.8	1.4	0.2	451
haloxyfop	7.2	6.8	7.4	5.2	924
ioxynil	7.2	5.2	6.2	5.6	581
linuron	6.2	1.0	1.0	0.0	39
MCPA	6.2	4.0	1.8	1.2	53
MCPB	5.0	2.8	2.0	2.4	75
methabenzthiazuron	6.0	1.0	1.0	0.0	39
metribuzin	5.0	1.0	1.0	0.0	35
paraquat	1.8	1.0	1.0	0.0	38
pendimethalin	6.4	6.4	5.2	5.6	411
propyzamide	8.6	9.2	9.6	7.0	2536
terbutryn	5.6	1.0	1.0	0.0	55
untreated	8.2	8.0	8.4	5.2	1675
$LSD_{0.05}$	1.6	1.5	1.2	1.8	499

[1] Mean values for 5 pots

[2] Scores range from 1-10 1 = no green material present, 10 = most vigorous growth

[3] Days After Application

Herbicides with predominantly broadleaved target species

The herbicides having relatively little effect on desmanthus growth included the nitriles, chlorthal dimethyl, benazolin and the carbamates. The nitriles screened included ioxynil, bromoxynil and a combination of the two. Ioxynil (0.45 kg ai/ha) controls a wider range of species than bromoxynil (0.90 kg ai/ha)(O'Connor, 1994) and this increased activity is reflected in a reduced plant tolerance as shown by the significantly lower (P = 0.05) fresh weight of plants treated with ioxynil compared with bromoxynil. The similarities between bromoxynil and the bromoxynil (0.20 kg ai/ha) / ioxynil (0.20 kg ai/ha) mixture suggest that the two products are potentially useful to control broadleaf weeds in desmanthus crops although the mixture should give control of a wider range of species (O'Connor, 1994). High (0.90 kg ai/ha) rates of bromoxynil were not very damaging to desmanthus seedlings. Therefore the bromoxynil / ioxynil mixture was probably less damaging to desmanthus seedlings because of the low proportion of ioxynil (0.20 kg ai/ha compared to 0.45 kg ai/ha when applied as ioxynil only).

Although chlorthal dimethyl had little effect on desmanthus growth either, it is limited in its target spectrum. Similarly the practical application of benazolin is limited by its target range (used mainly for chickweed (*Stellaria media*) control in leguminous crops) (O'Connor, 1994).

The carbamate herbicides which were tolerated well by desmanthus were asulam and chlorpropham. Of these chlorpropham would be more useful as it controls a much wider spectrum of broadleaved weeds and some annual grasses (O'Connor, 1994).

Bentazone only checked seedling growth when used at rates recommended for commercial practice (Loch pers. comm., 1994). It is likely therefore that it is safe for use in established stands, though it is expensive (Appendix 4.6). Similarly chlorimuron only checked growth. Post-emergence applications of flumetsulam applied at rates used in this trial are tolerated by some *Trifolium*, *Medicago,* and *Arachis* species (DowElanco, 1993). However in our trial it severely checked growth in desmanthus and caused some

necrosis. Although seedlings did appear to recover, their development was set back. Flumetsulam may be safe for use in more established stands.

Although the triazines (aziprotryne and terbutryne), pendimethalin and diflufenican were tolerated by desmanthus when applied pre-emergence, these herbicides caused substantial damage following post-emergence application. Ureas were very damaging to desmanthus with both post- and pre-emergence applications.

The broad spectrum herbicides paraquat, diquat and glyphosate were very damaging at the relatively low rates used in this trial. This was expected although paraquat is used to control grasses in *Trifolium repens* seed crops at the rate used in this trial (O'Connor, 1994).

The hormone herbicides were the most damaging post-emergence herbicides tested resulting in little or no green material left 1 week after application. Interestingly the phenoxyacetics (MCPA and 2,4-D) and phenoxybutyrics (MCPB and 2,4-DB) were equally damaging though normally the latter herbicides are much safer for legumes. This is probably because MCPB and 2,4-DB were applied at higher rates than MCPA and 2,4-D.

There is a need to identify a safe and effective range of herbicides for post-emergence broadleaved weed control. However this will be less important if effective, persistent, selective pre-emergence treatments are available. Of the least damaging post-emergence herbicides for broadleaved weeds only the nitriles (bromoxynil and ioxynil), chlorthal dimethyl and asulam are available in Queensland. Of these, the nitriles control the widest broadleaved weed spectrum. Asulam has a limited target range. It is uncertain whether these herbicides will effectively control the weed species present in desmanthus seed crops.

Herbicides for grass weeds

Herbicides designed to control grasses in dicotyledonous crops tended to be less damaging to the desmanthus seedlings. Haloxyfop checked growth though not significantly (P=0.05). Clethodim and dalapon are both registered for post-emergence control of grass weeds in many leguminous crops and both had little effect on desmanthus seedlings. Similarly the amides (carbetamide and propyzamide) were tolerated well. Ethofumesate was the only herbicide for grass weeds which caused damage resulting in considerable stunting and distortion.

Haloxyfop appears to be the best option for grass control in Queensland desmanthus crops because of its wide target range and the unavailability of dalapon, carbetamide and clethodim in Queensland. Propyzamide, although having a smaller target range, also has considerable potential.

4.3 Herbicide screening of *Desmanthus virgatus* cv. 'Marc' in South-East Queensland. 1. Seedlings

4.3.1 INTRODUCTION

The preliminary herbicide trial (Section 4.2) evaluated 22 pre-emergence and 34 post-emergence treatments for selectivity on desmanthus under environmentally controlled conditions. Pre-emergence treatments which appeared to be safe included chlorpropham, chlorthal dimethyl, diflufenican + isoproturon, oryzalin and pendimethalin. Post-emergence herbicides which were safe on desmanthus seedlings included asulam, benazolin, bromoxynil, carbetamide, chlorpropham, chlorthal dimethyl, clethodim, dalapon, haloxyfop, and propyzamide.

A field trial was conducted in the 1994/1995 season to confirm these results. All herbicides listed above were included in the field trial except benazolin, carbetamide, chlorpropham, clethodim and dalapon which are not registered for use in Queensland. Although the pot trial indicated that trifluralin and bentazone were moderately damaging to desmanthus these chemicals were included because they are used in commercial desmanthus seed crops. Three additional herbicides recently registered in Queensland for the control of broadleaved weeds in legume crops (imazethapyr, flumetsulam and a bromoxynil/diflufenican mixture) were also included.

4.3.2 MATERIALS AND METHODS

4.3.2.1 Pre-Treatment Preparation

The trial was located on a black cracking clay near Kilkivan, South-East Queensland (pH = 7.2). The site had grown lucerne (*Medicago sativa*) for the previous 5 years and soil tests showed that it was not deficient in any major elements. Existing vegetation was sprayed with glyphosate (2.16 kg ai/ha) 3 weeks prior to rotary hoeing on 11 November 1995. Pre- and post-emergence treatments were applied in adjacent trials, each with a randomised block design with four replicates. Plots were 2.0 m x 2.5 m and treatments were blocked by replicate down an eastern facing incline (approximately 5° slope). A distance of 0.5 m between plots was left to allow for spray overlap.

Desmanthus seed (cv. 'Marc') (1000 seed weight = 4.21 g) was scarified and inoculated (Appendix 3.2). Germination testing (Appendix 3.2) showed 83% normal seedlings after 10 days.

The seed was sown < 1 cm deep on 11 November 1994 in 0.25 m rows at rates of 7.6 and 7.8 kg seed/ha in the pre- and post-emergence trials respectively. Conditions at the time of sowing were hot (air temperature ~40°C maximum) and dry. Rainfall during the trial period was supplemented by regular irrigation to ensure rapid growth of seedlings.

4.3.2.2 Pre-Emergence Herbicide Application

Eight pre-emergence herbicides (Table 4.8) were applied at rates recommended for other legume crops. Where more than one recommended rate was available, the higher one was chosen so that weed control would be more effective. Additional hand-weeded and unweeded control treatments were also included. Herbicides were applied immediately after sowing, except for trifluralin and one pendimethalin treatment which were incorporated into the top 10 cm of soil using a rotary hoe immediately after spraying and prior to sowing. Herbicide treatments were applied using a propane pressurised 'Azo' chest-mounted boom sprayer at a constant spray pressure of 200 kPa. Sufficient chemical to cover 10 m of forward movement at recommended rates was made up to 1 l with water. Eight taper fan (Delavan LF2-80) nozzles offset at 10° provided a swath width of 2.65 m. After calibration, constant rate of travel was achieved using an electronic pocket metronome to regulate walking speed for a comfortable stride length. Temperatures in the 10 hours following spraying reached a maximum of 29°C and conditions remained dry. Control treatments included one weeded and one unweeded treatment. The weeded plots were handweeded every 2 weeks from sowing. The unweeded plots were left untouched.

Table 4.8 **Pre-emergence herbicide treatments applied on 30 November 1994 to plots sown with *Desmanthus virgatus* cv. 'Marc' in South-East Queensland.**

Chemical	Product name	Application rate (kg ai/ha)
chlorthal dimethyl	Dacthal 750WP	8.25
diflufenican	Brodal	0.10
imazethapyr	Spinnaker	0.07
metolachlor	Dual	1.44
oryzalin	Surflan 500 Flowable	3.40
pendimethalin	Stomp 330E	0.99
pendimethalin (incorporated)	Stomp 330E	0.99
trifluralin (incorporated)	Treflan	0.84
untreated weeded	-	-
untreated unweeded	-	-

Table 4.9 **Post-emergence herbicide treatments applied on 22 December 1994 to plots of seedling (four to six true leaves) *Desmanthus virgatus* cv. 'Marc' in South-East Queensland.**

Chemical	Product name	Application rate (kg ai/ha)
asulam	Asulox	1.20
bentazone	Basagran	0.96
bromoxynil	Buctril 200	0.40
bromoxynil + diflufenican	Jaguar	0.25
chlorthal dimethyl	Dacthal 750WP	8.25
flumetsulam	Broadstrike	0.02
haloxyfop	Verdict	0.16
imazethapyr	Spinnaker	0.01
propyzamide	Kerb WP	1.00
untreated weeded	-	-
untreated unweeded	-	-

4.3.2.3 Post-Emergence Herbicide Application

Nine post-emergence herbicides (Table 4.9) were applied 6 weeks (22 December 1995) after sowing when desmanthus was at the four to six true leaf stage. Application rates were chosen on the same basis as in the pre-emergence trial. Temperatures reached 35°C and conditions remained dry during the 10 hours following spraying.

4.3.2.4 Management After Herbicide Application

Due to its rapid growth Johnson grass (*Sorghum halepense*), a vigorously growing grass establishing mostly from rhizomes, dominated both trials 5 weeks after sowing. Johnson grass was controlled by wick-wiping with glyphosate (0.36% ai in water) to leaves taller than other species in the plots. The pre- and post-emergence trials were wick-wiped on 10 January and 19 December respectively with no obvious effect on desmanthus plants. Because of rapid weed growth the trial was terminated before desmanthus seed could be collected.

4.3.2.5 Data Collection

Population counts of desmanthus and all weeds present were conducted 8 and 21 days after application in the pre-emergence trial, and 5 days after spraying in the post-emergence herbicide trial. Three randomly placed 0.1 m^2 quadrats were used per plot and averaged. Desmanthus and the major weed species (Table 4.10) were visually scored for height, population density and colour. Scores ranged from 1 to 10, '1' representing complete removal of green matter or, in the case of the weed species, a population of less than 5 per plot whereas a '10' represented most vigorous growth or complete dominance of the plot. All species were scored 40 and 56 days after application in the pre-emergence trial, and 18 and 34 days after application in the post-emergence trial. An additional scoring of desmanthus was conducted in the pre-emergence trial 21 days after application.

Rainfall and irrigation were recorded at the site. Temperature and humidity data was collected in nearby Gympie (55 km east of the trial site) which is a slightly wetter environment. Conditions during the trial period (11 November 1994 to 6 January 1995) were hot and dry with temperatures between a minimum of 12.8°C (8 December) and a maximum of 38.7°C (29 December) with a mean of 24.2°C. The mean daily minimum and maximum temperatures were 18.1°C and 30.3°C respectively. Irregular rainfall totalling 61 mm was supplemented with 160 mm of irrigation water.

Table 4.10 **Weed species present in the herbicide screening plots, Kilkivan, South-East Queensland (11 November 1994 to 5 January 1995).**

Latin name	Common name	Family name	Scored?[1]
Crotalaria juncea	sunhemp	Fabaceae	No
Cyperus rotundus	nutgrass	Cyperaceae	No
Euphorbia prostrata	euphorbia	Euphorbiaceae	No
Hibiscus trionum	bladder ketmia	Malvaceae	Yes
Indigofera hirsuta	hairy indigo	Fabaceae	No
Ipomoea plebeia	bellvine	Convolvulaceae	Yes
Lamium amplexicaule	dead nettle	Lamiaceae	No
Phyllanthus tenellus	phyllanthus	Euphorbiaceae	No
Raphanus raphanistrum	wild radish	Brassicaceae	No
Rhyncosia minima	rhyncosia	Fabaceae	Yes
Sida rhombifolia	sida	Malvaceae	Yes
Sorghum halepense	Johnson grass	Poaceae	Yes
Verbena rigida	veined verbena	Verbenaceae	No
Xanthium pungens	Noogoora burr	Asteraceae	Yes

[1] Those species present at sufficient densities were scored for susceptibility to herbicides

4.3.2.6 Statistical Analysis

Data was analysed using SAS statistical software. Treatment mean values of score and plant number with a significant F value were compared with the Fischer's protected least significant difference procedure (P=0.05). If treatment means for population or vigour scores equalled zero (i.e. no members of a particular species were present), they were omitted for the least significant difference procedure.

4.3.3 RESULTS AND DISCUSSION

4.3.3.1 Crop Growth

Desmanthus establishment and growth was vigorous. The first inflorescences and fully expanded pods were observed 42 and 59 days after sowing, respectively. Establishment of weed species was rapid in untreated plots and, although plant numbers of desmanthus were not affected (Table 4.11), caused decreased vigour of desmanthus plants from the six-true leaf stage onwards (Table 4.14). Significant differences (P=0.05) in the desmanthus score between weeded and unweeded plots 34 days after application were due to weed competition (P=0.05). Weeded plots consistently scored higher than all other treatments (P=0.05). Relatively low vigour scores of weed species were recorded in unweeded plots 34 days after application of post-emergence treatments. These plots were over-run, particularly by the twining bellvine, and the low vigour scores of other weeds probably represent weed competition effects. Again differences between blocks were probably due to a moisture gradient caused by some unevenness in irrigation application.

4.3.3.2 Pre-Emergence Herbicides

Effect on desmanthus

Treatment effects on seedlings of both desmanthus and the weed species studied were consistent (Tables 4.11, 4.12 and 4.13). However, significant (P=0.05) differences in estimated desmanthus and weed populations and vigour scores between treatments and control plots did not occur until 21 and 40 days after application respectively. Hot, dry conditions in the period after sowing (and after applying pre-emergence herbicides) probably lowered seedling growth rates and therefore delayed expression of herbicide effects. During this period moisture gradients due to irrigation were probably responsible for significant block differences (data not presented).

The pre-emergence treatments resulted in a range of plant population from 15.3 (imazethapyr) to 5.3 plants/0.1m^2 (soil incorporated pendimethalin) 8 days after application. The results were very variable, however, and an insignificant F value meant

that pair-wise comparisons between the controls and other treatments were not conducted. The variability is probably due to low plant populations resulting from delayed emergence of desmanthus seedlings (first observed emerging 4 days after application).

After 21 days there were significantly lower (P=0.05) desmanthus populations in plots treated with metolachlor (3.2 plants/0.1m^2), oryzalin (5.2), pendimethalin (6.7) and soil incorporated pendimethalin (7.0) than in the weeded control (12.7) (Table 4.11).

Despite this, the pre-emergence treatments had no measurable effect on desmanthus vigour after 21 days (Table 4.11). This indicates that desmanthus had recovered from any treatment effects by 21 days.

Weed competition effects were apparent after 40 days resulting in lowered desmanthus vigour scores in some treatments. After 56 days the mean score of the weeded control (9.3) was significantly greater than the unweeded control (5.8) (P=0.05) due to weed competition effects on desmanthus seedlings. Consistently the lowest scoring treatments were diflufenican, chlorthal dimethyl and metolachlor. Scores for all remaining treatments (imazethapyr, oryzalin, pendimethalin, soil-incorporated pendimethalin and trifluralin) were not significantly different to the weeded control (P=0.05). After 56 days trifluralin (soil incorporated) plots scored significantly higher than all other treatments except for soil incorporated pendimethalin (P=0.05). In the pot trial, vigour score of desmanthus seedlings 53 days after application was lower (6.0) than control treatments (9.4). More effective weed control (notably of bellvine) in the trifluralin treated plots than in other treatments may explain this (Tables 4.12 and 4.13).

Table 4.11 **Effects of pre-emergence herbicides on germinating *Desmanthus virgatus* cv. 'Marc' seedlings.**

Chemical	Population[1] - 21 days after application (plants/0.1m^2)	Score[1,2] - 40 days after application	Score[1,2] - 56 days after application
chlorthal dimethyl	8.5	5.7	6.7
diflufenican	7.5	5.5	6.5
imazethapyr	12.7	8.5	8.7
metolachlor	3.2	7.0	8.0
oryzalin	5.2	7.2	8.5
pendimethalin	6.7	7.7	8.2
pendimethalin (incorporated)	7.0	8.2	9.5
trifluralin (incorporated)	10.2	8.2	10.0
untreated unweeded	8.7	7.0	5.7
untreated weeded	12.7	8.5	9.2
$LSD_{0.05}$	5.4	1.3	1.2

Table 4.12 **Effect of pre-emergence herbicides on vigour scores (40 days after application) of weed species in plots of germinating *Desmanthus virgatus* cv. 'Marc' seedlings.**

Chemical	Score[1,2]				
	Johnson grass	Noogoora burr	bellvine	sida	bladder ketmia
chlorthal dimethyl	5.5	1.0	5.2	3.5	5.7
diflufenican	7.5	2.0	5.5	3.2	5.5
imazethapyr	6.5	1.0	4.5	1.7	3.5
metolachlor	7.2	1.0	5.2	3.2	6.5
oryzalin	7.5	1.0	5.2	3.5	4.2
pendimethalin	8.7	4.0	6.5	2.2	4.5
pendimethalin (incorporated)	1.0	3.2	3.0	2.7	4.7
trifluralin (incorporated)	1.0	2.7	2.2	1.7	6.0
untreated unweeded	9.2	5.0	6.0	4.0	6.2
$LSD_{0.05}$	1.7	2.9	1.5	1.5	1.9

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

Table 4.13 **Effect of pre-emergence herbicides on vigour scores (56 days after application) of weed species in plots of germinating *Desmanthus virgatus* cv. 'Marc' seedlings.**

Chemical	Score[1,2]			
	Noogoora burr	bellvine	sida	bladder ketmia
chlorthal dimethyl	1.0	6.0	3.0	4.7
diflufenican	1.5	6.2	4.0	5.0
imazethapyr	1.0	4.2	1.7	3.7
metolachlor	1.7	5.2	2.2	5.2
oryzalin	1.0	4.7	3.2	4.7
pendimethalin	3.7	5.2	1.0	3.0
pendimethalin (incorporated)	2.2	3.2	3.2	7.0
trifluralin (incorporated)	3.0	2.2	3.5	6.7
untreated unweeded	3.7	4.0	3.5	4.2
$LSD_{0.05}$	2.2	1.2	1.4	1.6

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

Effect on weeds

Control of weed species varied widely between treatments but was very consistent between times of assessment (Tables 4.12 and 4.13). Best control was achieved by the two soil incorporated herbicides, trifluralin and pendimethalin, which both control a range of grass and broadleaved weed species (O'Connor, 1994). Both of these herbicides caused a significant reduction in Johnson grass and bellvine infestations (P=0.05). After 56 days bladder ketmia scores in the soil incorporated herbicide plots (pendimethalin, trifluralin) were significantly higher than the unweeded plots, probably due to reduced competition pressure on bladder ketmia through better control of Johnson grass in these plots. Pendimethalin applied to the soil surface was less effective at controlling Johnson grass and bellvine than when soil-incorporated (P=0.05) (Tables 4.12 and 4.13).

The remaining herbicides (chlorthal dimethyl, diflufenican, imazethapyr, metolachlor and oryzalin) were only damaging to Noogoora burr (40 days after application) except imazethapyr which affected sida until 56 days after application (Table 4.13).

For best pre-emergence control of grass and broadleaved weeds soil incorporation of either pendimethalin or trifluralin is recommended depending on the predominant weed species present. If non-cultivated sowings are used, imazethapyr, oryzalin and pendimethalin show the greatest potential considering their relative safety to germinating desmanthus and registration to control a wide range of monocotyledonous and dicotyledonous target species. However, as desmanthus is sown in early summer and is relatively slow to establish, further weed control later in the season will probably be necessary.

4.3.3.3 Post-Emergence Herbicides

General effects

The effects of post-emergence herbicides on both desmanthus and the weed species (bellvine, Noogoora burr, bladder ketmia and sida) studied were greater, and occurred more rapidly, than with the pre-emergence herbicides (Tables 4.14, 4.15 and 4.16). No post-emergence treatment completely killed desmanthus although necrosis and defoliation was observed in a number of treatments.

Herbicides for broadleaved weeds

Bentazone and imazethapyr were temporarily damaging to desmanthus (Table 4.14). Both chemicals are registered for the control of seedling broadleaved weeds in legume crops (O'Connor, 1994; Badewitz-Dodd, 1993) although imazethapyr controls a more limited range of broadleaved species when applied post-emergence (Schering Agrochemicals, 1993). Bentazone caused some short term necrosis of desmanthus leaf tips 1 week after application, and I have also observed this with similar rates of bentazone in commercial desmanthus seed crops. Of all the treatments, bentazone gave the best control of the weed species studied and resulted in significantly lower densities of bellvine, bladder ketmia and sida than imazethapyr (P=0.05) (Tables 4.15 and 4.16).

Table 4.14 **Effects of post-emergence herbicides on *Desmanthus virgatus* cv. 'Marc' seedlings following application at the six true leaf stage.**

Chemical	Population[1] 5 days after application (plants/0.1m^2)	Score[1,2] - 5 days after application	Score[1,2] - 34 days after application
asulam	5.4	7.5	5.7
bentazone	4.7	5.5	7.0
bromoxynil	6.3	6.7	6.5
bromoxynil + diflufenican	6.2	5.0	3.7
chlorthal dimethyl	5.0	6.7	5.5
flumetsulam	5.2	5.0	5.2
haloxyfop	7.3	8.7	7.5
imazethapyr	6.2	5.5	7.0
propyzamide	5.4	8.5	6.7
untreated unweeded	6.7	8.5	6.5
untreated weeded	5.5	7.5	9.5
$LSD_{0.05}$	2.0	1.3	1.3

Table 4.15 **Effects of post-emergence herbicides on scores (18 days after application) of weed species in plots of *Desmanthus virgatus* cv. 'Marc' seedlings after application at the six true leaf stage.**

Chemical	Score[1,2]			
	Noogoora burr	bellvine	sida	bladder ketmia
asulam	3.2	5.0	5.7	4.7
bentazone	1.7	1.0	1.0	1.5
bromoxynil	1.2	2.0	1.7	1.5
bromoxynil + diflufenican	1.2	2.2	1.0	1.0
chlorthal dimethyl	2.7	3.2	6.0	4.2
flumetsulam	1.7	2.7	2.2	2.0
haloxyfop	5.2	7.0	6.2	7.2
imazethapyr	1.0	2.7	2.7	4.7
propyzamide	6.2	5.2	4.5	5.7
untreated unweeded	5.2	6.2	5.5	7.2
$LSD_{0.05}$	2.0	1.3	1.3	1.4

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

Table 4.16 **Effect of post-emergence herbicides on vigour scores (34 days after application) of weed species in plots of germinating *Desmanthus virgatus* cv. 'Marc' seedlings.**

Chemical	Score[1,2]			
	Noogoora burr	bellvine	sida	bladder ketmia
asulam	1.3	3.8	2.8	3.8
bentazone	1.3	1.0	1.5	1.0
bromoxynil	1.3	2.3	1.5	1.8
bromoxynil + diflufenican	1.0	1.8	1.0	1.0
chlorthal dimethyl	2.3	3.0	4.3	5.0
flumetsulam	1.3	2.8	1.0	1.8
haloxyfop	3.0	6.3	4.3	6.3
imazethapyr	1.0	2.8	3.8	4.8
propyzamide	3.8	5.5	2.8	3.8
untreated unweeded	2.5	5.0	2.8	5.3
$LSD_{0.05}$	1.2	1.1	1.0	1.4

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present, 10 = most vigorous growth

Bentazone and imazethapyr were the least damaging post-emergence herbicides to desmanthus 34 days after spraying. Bromoxynil and asulam also had little effect on desmanthus vigour. Weed control by bromoxynil was similar to bentazone. Whereas bromoxynil is registered to control a wide range of broadleaved seedlings in legume crops, asulam has a smaller target spectrum (O'Connor, 1994) and this was reflected by poor control of most weed species. Asulam did however cause significant damage to bladder ketmia (P=0.05).

The most damaging treatments to desmanthus were chlorthal dimethyl, flumetsulam and bromoxynil + diflufenican. All caused significant levels of damage to desmanthus 5 days after application (P=0.05) and were also much more damaging 34 days after application than bentazone and imazethapyr (P=0.05). The bromoxynil/diflufenican mixture was particularly damaging to desmanthus seedlings, having significantly lower scores than all

bromoxynil + diflufenican also caused significant damage to the weed species monitored (P=0.05). Reduction of application rates, provided they decrease damage to desmanthus and remain damaging to weeds, may make these chemicals more useful in desmanthus seed crops. Chlorthal dimethyl poorly controlled the weeds scored probably reflecting its limited activity on broadleaved weeds relative to flumetsulam and bromoxynil + diflufenican (O'Connor, 1994, 1996).

The post-emergence herbicides capable of controlling broadleaved weeds which were safest for desmanthus seedlings are asulam, bentazone, bromoxynil and imazethapyr. Asulam has a limited target spectrum which limits its usefulness. However, the remaining chemicals do control most species found in Queensland desmanthus seed crops. Because of similar target spectra bromoxynil has the potential to be an inexpensive (50%) alternative to bentazone.

Herbicides For Grass Weeds

Herbicides assessed that are designed to control grasses in dicotyledonous crops included haloxyfop and propyzamide, although the latter is also used to selectively control a number of broadleaved species in legume crops (O'Connor, 1994). Early desmanthus scores (5 and 18 days post-application) of haloxyfop were not significantly different to the weeded control (P=0.05). This agrees with the previous pot trial. Weed competition stress probably caused desmanthus scores to drop significantly below the weeded control after 34 days (P=0.05). As expected control of broadleaved weeds was poor.

Although not quantified, haloxyfop was observed to control Johnson grass seedlings better than propyzamide although this was insufficient to prevent wick-wiping. Partial selective control of Johnson grass in leguminous crops by haloxyfop has also been reported (Parsons and Cuthbertson, 1992). Better early control of Johnson grass by

haloxyfop may partially explain the higher desmanthus plant vigour scores observed in haloxyfop treatments.

As haloxyfop is suitable for the control of seedling and many mature grasses (O'Connor, 1994), and is apparently not damaging to desmanthus, it should be suitable for grass weed control in desmanthus seed crops.

4.4 Herbicide Screening of *Desmanthus virgatus* cv. 'Marc' in South-East Queensland. 2. Herbicide Combinations on Seedlings

4.4.1 INTRODUCTION

Previous trial work reported in this chapter established that most grass weeds in desmanthus seed crops can be safely controlled using haloxyfop (Section 4.2.3.3). However, some broadleaved weeds which are prevalent in commercial desmanthus crops, particularly *Sida* spp. and leguminous species (Murat pers. comm., 1995), are not controlled well by any of the herbicides identified as being non-damaging to desmanthus. It is possible, however, that combinations of pre- and post-emergence herbicides may control a wider selection of weeds or may additively be damaging to weeds which are partly tolerant to one herbicide.

The objective of this trial was to identify herbicide combinations which are safe for use on desmanthus seedlings and which provide effective control of common broadleaved crop weeds in South-East Queensland. This trial provided the opportunity to confirm previous field trial results and evaluate three recently developed, broader spectrum, herbicides (imazaquin, imazapic and pyridate) which, because of their safe use in other legume crops, show potential for use in desmanthus seed crops.

In the previous trial (Section 4.3), eight selective herbicides which control broadleaved weeds were identified as being relatively non-damaging to desmanthus seedlings. These included four pre-emergence (imazethapyr, oryzalin, pendimethalin and trifluralin) and four post-emergence (asulam, bentazone, bromoxynil and imazethapyr) herbicides.

Trifluralin and pendimethalin (both soil incorporated) were the most effective pre-emergence treatments for controlling the weeds studied. Trifluralin is a root absorbed dinitroaniline herbicide used to control emerging annual grasses and a few dicotyledons in many crops, including legumes (Parsons and Cuthbertson, 1992). Its value in desmanthus seed production is its apparent safeness when used in Queensland conditions and, because it remains active in the soil for some months (Parsons and Cuthbertson,

1992), long term control of emerging grass weeds. Because of this, trifluralin was included in this trial.

Similarly oryzalin and pendimethalin mainly control germinating grasses. However, these chemicals are similar in structure and are both used to selectively control weeds in legume crops. Because these chemicals are so similar only one was included in this trial. Pendimethalin was selected because another soil incorporated herbicide was desired to compare with the trifluralin treatment and because it is considerably less expensive than oryzalin (Appendix 4.6) even when oryzalin is applied at rates one third those used in this study.

Imazethapyr was the only pre-emergence herbicide in this study which is non-damaging to desmanthus and selectively controls a wide range of broadleaved weeds encountered in crops in Australia (Schering Agrochemicals, 1993). It also controls many grass weeds, does not require soil incorporation and remains active in the soil for up to 34 months (high application rates). Imazethapyr also provides selective early post-emergence control of a number of broadleaved weeds (Lignowski *et al.*, 1990) which makes this chemical potentially very useful. Imazethapyr was included in this trial as both pre- and post-emergence treatments to confirm previous findings.

Bentazone and bromoxynil are both post-emergence herbicides which provide selective knockdown control of many broadleaved weeds in a wide range of crops including lucerne (Parsons and Cuthbertson, 1992). Results from the previous herbicide screening (Section 4.3) suggest that these chemicals will provide the basis of post-emergence broadleaved weed control in desmanthus seed crops. These chemicals do not control many leguminous weeds nor *Sida rhombifolia* (O'Connor, 1994; Schering Agrochemicals, 1993) which are problem weeds in desmanthus seed crops in Queensland (Murat, pers. comm., 1995). Many of the crop weeds present on the Atherton Tablelands (e.g. *Cyperus rotundus*, *Euphorbia* spp., *Ipomoea* spp., and *Xanthium* spp.) are not controlled by post-emergence applications of asulam (May and Baker, 1971). Thus asulam is not expected to be useful in commercial desmanthus seed crops in Queensland. Asulam was not included in this trial.

Three additional chemicals were identified from literature with potential for use in desmanthus seed crops. Imazaquin is a pre- and post-emergence herbicide which selectively controls seedling grasses and broadleaved weeds (Parsons and Cuthbertson, 1992) and is tolerated by a number of legume crops including *Glycine*, *Trifolium* and *Vicia* spp. (Cyanamid, 1985). However it has caused decreases in *Glycine max* grain yield when applied at high (420 g ai/ha) rates (Krausz *et al.*, 1994). The weed control spectrum of imazaquin includes problem genera (*Amaranthus, Cyperus, Hibiscus, Sida* and *Xanthium*) encountered in Queensland desmanthus crops (Cyanamid, 1985). Imazaquin was included in this trial as a pre-emergence treatment.

The two other herbicides (imazapic and pyridate) were both included as post-emergence treatments. Imazapic comes from the same chemical family (imidazolinone) as imazethapyr and imazaquin and has been developed for early post-emergence weed control in peanuts. Like the other imidazolinones imazapic has knockdown and residual activity and selectively controls a range of broadleaved and grass (both C3 and C4) weeds. As in the case of imazaquin, the weed spectrum includes genera of weeds present in Queensland desmanthus crops (Cyanamid, 1992).

Pyridate is a post-emergence selective contact herbicide (Seidel and Russell, 1990). It was developed to control broadleaved weeds and some annual grasses in chickpea (*Cicer arietinum*) crops but has also shown promise in *Arachis hypogaea*, *Medicago sativa*, and *Trifolium* spp. (Bayer Australia, 1987). Pyridate controls a number of weeds common in South-East Queensland crops particularly cruciferous weeds. This target spectrum will be useful if pyridate is non-damaging to desmanthus.

This trial attempted to compare pre-emergence and post-emergence herbicides separately as well as combinations of pre- and post-emergence herbicides. To achieve this, different pre-emergence treatments were followed by the same post-emergence treatment (bentazone). Similarly, the various post-emergence treatments were preceded by the same pre-emergence treatment (trifluralin).

4.4.2 MATERIALS AND METHODS

4.4.2.1 Pre-Treatment Preparation

The trial was located at the same site as for the previous field screening (Section 4.3.2.1). Soil tests showed that the site was not deficient in any major elements expected to interfere with desmanthus growth. In the season immediately prior to the trial, the site had been used for a herbicide screening trial of pre-emergence herbicides on desmanthus seedlings (Section 4.3). In that screening pre-emergence and post-emergence treatments were applied 11 November and 22 December 1995 respectively and the trial completed by 6 January 1995. There was no further application of herbicides until the current trial. The trial area was mown to approximately 15 cm on 16 May 1995 and trash removed by hand-raking.

The trial area (25m X 33m) was rotary cultivated to 20 cm depth and plots pegged out on 28 November 1995. Each plot measured 2.5 m X 5.0 m and was surrounded by 0.5 m on each side and 1.0 m at each end to allow for spray overlap. Four replicates of eleven treatments were used and treatments were blocked by replicate down an eastern facing incline (approximately 5°C from horizontal).

Desmanthus seed (germination of normal seedlings after 10 days was 81% one day prior to planting) was prepared as for the previous field trial (Section 4.3.2.1). 'Marc' seed was sown immediately after the application of the pre-plant treatments using the techniques described in Section 4.3.2.1. Rainfall prior to, and during, the trial period was supplemented by regular irrigation as required (Appendix 3.3). On 13 March 1996 one application of dimethoate (30 g ai/100 l applied to run off) was conducted to control a minor psyllid attack.

4.4.2.2 Herbicide Application

Herbicides were applied at rates recommended for selective use in other legume crops (Table 4.17). Where more than one recommended rate was available, the higher one was chosen to provide better weed control. The control treatments consisted of handweeded (every two weeks by hand pulling and hoeing beginning 16 November 1995) and unweeded plots.

Pre-emergence herbicides

The pre-plant herbicides (Table 4.18) were applied on 29 November 1995, using the same method as for the previous field screenings (Section 4.3.2.2). The herbicides were applied between 7 and 9 am in still but cloudy conditions. Immediately after spraying, the plots of pre-plant herbicides were rotary cultivated to approximately 10 cm depth. Temperatures in the 6 hours following spraying reached a maximum of 32°C and conditions remained dry. A light irrigation was applied 14 to 18 hours after herbicide application.

Imazethapyr was applied at 7 am on 31 November in clear dry conditions. Again the techniques in Section 4.3.2.2 were used and a light irrigation applied during the night following herbicide application.

Post-emergence herbicides

The first application of post-emergence herbicides (Table 4.18) occurred at 10 am on 15 January, 48 days after desmanthus emergence (onset of flowering). Conditions during spraying were clear and dry and the temperature reached 30°C in the 6 hours after spraying.

The second application occurred at 9 am on 21 February (85 days after sowing), when desmanthus was approximately 40 cm high and flowering. Some immature pods were present. Conditions at application were clear and dry. The temperature reached 33°C in the 6 hours after spraying.

Table 4.17 **Formulation and rate of herbicides applied in the herbicide combination trial to plots containing *Desmanthus virgatus* cv. 'Marc' seedlings in South-East Queensland.**

Chemical	Product name	Application rate (kg ai/ha)
bentazone	Basagran	0.96
bromoxynil	Buctril 200	0.40
imazaquin	Scepter	0.20
imazethapyr	Spinnaker	0.10
imazapic	Cadre	0.07
pendimethalin	Stomp 330E	0.99
pyridate	Tough	0.90
trifluralin	Treflan	0.84
untreated weeded	-	-
untreated unweeded	-	-

Table 4.18 **Combinations of herbicides applied to *Desmanthus virgatus* cv. 'Marc' seedlings at Kilkivan, South-East Queensland.**

Treatment number	Pre-plant herbicide 29 November	Pre-emergence herbicide 31 November	Post-emergence herbicide 15 January	Post-emergence herbicide 21 February
1	trifluralin	none	bentazone	none
2	trifluralin	none	bentazone	bentazone
3	trifluralin	none	bromoxynil	bentazone
4	trifluralin	none	imazapic	bentazone
5	trifluralin	none	pyridate	bentazone
6	trifluralin	none	imazethapyr	bentazone
7	pendimethalin	none	bentazone	bentazone
8	imazaquin	none	bentazone	bentazone
9	none	imazethapyr	bentazone	bentazone
10	none	none	none	none
11	none	none	none	none

4.4.2.3 Data Collection

Desmanthus

Data collection for desmanthus aimed to evaluate the effect of the herbicides on crop vigour and flowering pattern. A population count of emerging desmanthus seedlings (one 0.25m^2 quadrat randomly assigned per plot) was conducted on 3 January, 35 and 33 days after the application of the pre-plant and pre-emergence herbicides respectively.

Visual scores of plant vigour (see Section 4.3.2.5 for criteria) were conducted on desmanthus plants 1 week after the application of the post-emergence treatments. Additional scores were conducted on 27 March and 30 April during peak and late flowering respectively. Growth stage was recorded at all scorings. Growth stages included seedling (main stem only), pre-mature (appearance of first branch or six true leaves but plants not fully expanded), mature (full expansion of plants, evidence of reproductive buds but no flowering), flowering or carrying seed. If plants showed a variation in growth stage, the most common growth stage was recorded.

One randomly selected plant per plot was tagged and expanded inflorescences counted weekly over the duration of the trial. Immature pods were counted as inflorescences. After counting flowers and pods were removed to avoid double counting.

Weeds

Data on weeds was collected to determine which weeds were present and the extent and duration of herbicide control of these weeds. The most common broadleaved weeds present in plots were selected for monitoring (Table 4.19). Population scores were conducted 1 week prior to, and 1 week after, the two applications of the post-emergence herbicides (Section 4.3.2.5). This allowed an estimation of survival to be made. Two additional population scores were conducted (27 March and 30 April). At each population scoring, growth stages of the monitored weeds was recorded. Vigour scores of the monitored weeds were conducted 1 week after application of the post-emergence herbicides (22 January and 28 February). Vigour scores and recording of growth stage were conducted as for desmanthus.

Table 4.19 **Weed species present in the herbicide combination screening plots, Kilkivan, South-East Queensland (7 December 1995).**

Latin name	Common name	Family name	Scored in trial?
Anagallis arvensis	scarlet pimpernel	Primulaceae	No
Cyclospermum leptophyllum	slender celery	Apiaceae	No
Crotalaria juncea	sunhemp	Fabaceae	No
Cyperus rotundus	nutgrass	Cyperaceae	No
Euphorbia prostrata	euphorbia	Euphorbiaceae	Yes
Hibiscus trionum	bladder ketmia	Malvaceae	Yes
Indigofera hirsuta	hairy indigo	Fabaceae	No
Ipomoea plebeia	bellvine	Convolvulaceae	Yes
Lamium amplexicaule	dead nettle	Lamiaceae	No
Lepidium bonariense	Argentine peppercress	Brassicaceae	No
Macroptilium atropurpureum	siratro	Fabaceae	No
Phyllanthus tenellus	phyllanthus	Euphorbiaceae	Yes
Raphanus raphanistrum	wild radish	Brassicaceae	No
Rhynchosia minima	rhyncosia	Fabaceae	Yes
Sida rhombifolia	sida	Malvaceae	Yes
Sorghum halepense	Johnson grass	Poaceae	No
Verbena rigida	veined verbena	Verbenaceae	No
Xanthium pungens	Noogoora burr	Asteraceae	Yes

General seasonal information

Rainfall and irrigation were recorded at the site. Temperature and humidity data was collected in nearby Gympie (55 km east of the trial site) which is a slightly wetter environment (Appendix 3.3). Rainfall during the trial was inconsistent. Total rainfall was high during November (152 mm) and January (221 mm), moderate during December (89mm) and low during February (26 mm), March (29 mm) and April (46 mm). Irrigation water was applied during December, February, March and April and totalled 320 mm. Of this 120 mm was applied during February (Appendix 3.3). The mean monthly maximum temperature ranged from 29.0°C (April) to 30.9°C (February) whereas mean monthly minimum temperature ranged from 14.8°C (April) to 19.9°C (January) (Appendix 3.3).

4.4.2.4 Statistical Analysis

Data was analysed as described in Section 4.3.2.6.

4.4.3 RESULTS AND DISCUSSION

4.4.3.1 Plant Growth

The desmanthus seedlings emerged 4 days after sowing and grew vigorously thereafter. At the application of the first post-emergence treatment (48 days) most desmanthus plants had begun to branch and some plants were flowering. No pods were found. By the second post-emergence application (85 days) all desmanthus plants were flowering and contained mostly green pods. Mature pods were found on some plants. Dehisced pods were first observed 123 days after germination. At the end of the trial (153 days) few plants contained flowers and most pods were brown (abscised). Most pods had dehisced. In many cases desmanthus plants were showing poor vigour presumably because development for the season was complete.

Weed growth of the monitored species was vigorous in untreated plots. At the time of applying the pre-plant (t=0 days) and pre-emergence treatments (t=2 days) no weeds were present in unweeded plots. One week before the application of the first post-emergence herbicides all weeds present in the unweeded control plots (bladder ketmia, Noogoora burr, bellvine, sida, rhyncosia and phyllanthus) were at the 'pre-mature' stage (i.e. had begun to branch or were past the six true-leaf stage and had not fully expanded). One week before the application of the second post-emergence treatment these species were all at the 'mature' stage (fully expanded but not flowering). The exceptions were a few bladder ketmia and sida plants which had begun to flower. By 119 days after sowing all monitored species except Noogoora burr were flowering. At the end of the trial (153 days) Noogoora burr had been killed by a rust and bladder ketmia had died off following seeding.

4.4.3.2 Effects of Weeds on Desmanthus

Mean vigour scores of desmanthus plants in the weeded control plots were consistently high relative to other treatments during the season (Table 4.20). By 153 days after

sowing mean desmanthus vigour score declined to 7.5 in untreated plots. This decline is probably due to desmanthus plants finishing growth for the season.

Weed competition effects on desmanthus plants in the unweeded control plots were not evident until 92 days after sowing when mean vigour score declined to 6.75 (Table 4.20). At this stage the mean percentage ground cover of the monitored weed species were: bladder ketmia (48%); Noogoora burr (38%); bellvine (73%); sida (15%); rhyncosia, Phyllanthus and euphorbia (0%)[1] (Tables 4.21 to 4.27). Of note is the increase in plot area of bellvine, bladder ketmia and Noogoora burr which coincided with the decline in desmanthus vigour in unweeded control plots (sida population score remained constant from the previous scoring). This also coincided with the complete decline in numbers of rhyncosia, phyllanthus and euphorbia. It appears therefore that these erect (sida, bladder ketmia and Noogoora burr) and twining (bellvine) weeds have competed successfully with the more prostrate species of rhyncosia, phyllanthus and euphorbia. Similarly competition for nutrients has probably contributed to the poor vigour observed in desmanthus plants in the unweeded control plots. The erect weed species continued to dominate the unweeded control pots until the end of the trial (data not presented) (Plate 4.2). Similarly desmanthus scores in these plots remained low and a mean vigour score of 5.0 was recorded at the end of the trial. This was significantly lower than that of desmanthus in the weeded control (7.5) indicating that weed competition effects were still prevalent.

4.4.3.3 Herbicide Effects on Desmanthus Population and Vigour

Herbicides applied before desmanthus emergence

The desmanthus plant population was estimated 36 days after sowing (3 January) to identify pre-emergence herbicides which were damaging to desmanthus (Table 4.20).

[1] total percentage ground cover exceeds 100% because different weed species (particularly the twining bellvine) often occupied the same ground area i.e. were combined in the canopy.

Table 4.20 **Effects of herbicide combinations on population and vigour score of *Desmanthus virgatus* cv. 'Marc' seedlings.**

Treatment number[4]	Population 3 January[1] (pl/m^2)	Vigour score 22 January[1,3]	Vigour score 28 February[1,3]	Vigour score 27 March [1,3]
1	39	8.5	8.8	7.3
2	46	8.8	7.8	7.0
3	38	8.8	7.5	7.8
4	45	8.0	6.8	7.8
5	47	6.3	8.0	8.3
6	47	9.0	7.0	7.5
7	32	8.5	8.3	7.0
8	34	9.3	9.8	9.0
9	40	9.3	8.8	8.3
10	51	8.5	8.0	8.8
11	45	9.3	6.8	6.0
$LSD_{0.05}$	19	1.3	1.0	1.5

Table 4.21 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of bladder ketmia (*Hibiscus trionum*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	23	8	5	0	5.5	none
2	23	15	13	10	7.5	2.0
3	48	23	15	15	6.0	5.5
4	40	55	63	75	9.3	5.5
5	35	58	60	70	10.0	5.3
6	25	43	43	48	9.3	5.0
7	38	0	0	0	none	none
8	0	0	0	0	none	none
9	0	0	0	0	none	none
11	25	33	43	48	9.8	9.5
LSD	18	25	25	25	1.5	0.8

[1] Mean values for 4 plots

[2] Percentage area occupied in plot

[3] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

[4] see Table 4.17

Table 4.22 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of Noogoora burr (*Xanthium pungens*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	18	23	38	40	5.5	10.0
2	20	23	25	33	6.7	5.3
3	25	38	28	30	5.3	5.5
4	28	25	10	10	7.3	2.0
5	23	25	25	38	10.0	6.5
6	33	35	23	20	6.5	5.0
7	33	28	23	25	4.3	10.0
8	0	0	0	0	none	none
9	18	25	23	30	4.8	10.0
11	13	28	33	38	9.8	9.5
$LSD_{0.05}$	21	19	21	21	1.6	0.5

Table 4.23 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of bellvine (*Ipomoea plebeia*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	23	40	23	43	2.7	8.3
2	25	43	30	25	3.8	7.0
3	15	40	33	38	3.8	5.7
4	20	38	18	0	7.5	none
5	20	43	45	48	10.0	7.3
6	20	28	23	18	7.7	5.7
7	25	43	8	15	2.3	8.0
8	0	0	0	0	none	none
9	10	20	10	30	3.0	9.0
11	20	48	48	73	10.0	7.3
$LSD_{0.05}$	17	27	27	33	1.8	2.9

[1] Mean values for 4 plots

[2] Percentage area occupied in plot

[3] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

[4] See Table 4.17

Table 4.24 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of sida (*Sida rotundifolia*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	3	0	3	5	none	10.0 a
2	10	5	5	5	10.0 a[5]	8.0 ab
3	10	3	5	0	7.0 bc	none
4	10	5	3	0	6.5 c	none
5	8	10	18	10	9.5 a	5.0 b
6	10	13	2	8	8.0 b	6.7 ab
7	12	0	3	0	none	none
8	0	0	0	0	none	none
9	10	0	0	0	none	none
11	20	8	15	15	9.3 a	10.0 a
$LSD_{0.05}$	11	10	10	13	-	-

Table 4.25 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of rhyncosia (*Rhyncosia minima*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	5	3	5	0	9.0	none
2	3	3	3	0	8.0	none
3	0	0	3	0	none	none
4	0	3	3	0	8.0	none
5	0	5	3	0	10.0	none
6	0	0	0	0	none	none
7	3	3	0	0	7.0	none
8	3	3	5	0	8.0	none
9	3	5	13	0	6.5	none
11	3	3	0	0	10.0	none
$LSD_{0.05}$	4	6	7	0.0	NT[6]	NT

1 Mean values for 4 plots

2 Percentage area occupied in plot

3 Scores range from 1-10 1 = no green material present
10 = most vigorous growth

4 See Table 4.17

5 Means with the same letter are not significantly different (P=0.05)

6 No test of significance because of insufficient sample size

Table 4.26 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of phyllanthus (*Phyllanthus tenellus*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan.	V.S.[1,3] 28 Feb.
1	0	0	0	0	none	none
2	3	5	0	0	9.0	none
3	3	3	0	3	10.0	10.0
4	0	0	5	10	none	10.0
5	3	0	0	0	none	none
6	0	0	0	0	none	none
7	3	5	18	18	8.0	10.0
8	3	5	8	3	8.5	10.0
9	3	0	0	0	none	none
11	3	0	0	0	none	none
$LSD_{0.05}$	6	9	17	17	NT[5]	NT

Table 4.27 **Effects of herbicide combinations on population score (Popn) and vigour score (V.S.) of euphorbia (*Euphorbia prostrata*) in *Desmanthus virgatus* plots.**

Treatment number[4]	Popn[1,2] 8 Jan.	Popn[1,2] 22 Jan.	Popn[1,2] 7 Feb.	Popn[1,2] 28 Feb.	V.S.[1,3] 22 Jan	V.S.[1,3] 28 Feb
1	0	0	3	0	none	none
2	0	3	0	0	10.0	none
3	0	0	0	0	none	none
4	0	0	0	0	none	none
5	0	0	0	0	none	none
6	0	3	0	0	10.0	none
7	0	0	0	0	none	none
8	0	3	0	0	10.0	none
9	0	0	0	0	none	none
11	0	0	0	0	none	none
$LSD_{0.05}$	0	4	4	0	NT	NT

1 Mean values for 4 plots

2 Percentage area occupied in plot

3 Scores range from 1-10 1 = no green material present
10 = most vigorous growth

4 See Table 4.17

5 No test of significance because of insufficient sample size

Trifluralin was represented in six treatments (Treatments 1 to 6). In each treatment desmanthus plant population (range 38.0 to 47.2 plants/m^2) was not significantly different to that of the weeded (50.8 plants/m^2) or unweeded (47.2 plants/m^2) plots. The other pre-plant soil-incorporated herbicide, pendimethalin (treatment 7), significantly (P=0.05) reduced desmanthus plant population to 32.0 plants per m^2. The results for these two herbicides agree with the previous field screening of desmanthus seedlings (Section 4.3.3.2) The two imidazolinones, imazethapyr (Treatment 9) and imazaquin (8), did not affect desmanthus seedling emergence and had mean populations of 52.8 and 34.0 plants/m^2 respectively which were similar (P=0.05) to the weeded control (Table 4.20). Emergence of desmanthus seedlings in the imazaquin treatments was slower than that in the other three pre-emergence treatments. Otherwise plants in the imazaquin treatments appeared healthy (Plate 4.2).

All pre-emergence treatments were followed by two post-emergence treatments of bentazone. Vigour of desmanthus was scored 1 week after each bentazone application. In addition to evaluating the effects of bentazone on desmanthus, these vigour scores were used to identify any long term effects of the pre-emergence herbicides on desmanthus seedlings. Vigour scores of desmanthus seedlings after the application of all pre-emergence herbicides were high and were not significantly different to weeded controls (Table 4.20). This indicates that the pre-emergence herbicides were non-damaging or that plants were able to recover from the initial growth check if there was one.

Herbicides applied after desmanthus emergence

Vigour scores assessed 1 week after the two applications (55 and 92 days after sowing) of post-emergence treatments and 119 and 153 days after sowing were used to compare the effects of post-emergence herbicides on desmanthus seedlings. The four post-emergence treatments were applied 48 days after sowing when desmanthus was beginning to flower, most plants were branched and approximately 25 cm tall. These treatments (Treatments 1 to 5) were all preceded by trifluralin application and followed by bentazone application.

Plate 4.2 **Typical plots of *Desmanthus virgatus* cv. 'Marc' on 28 February 1996 receiving no weed control (left) or treated with imazaquin (200 g ai/ha, 29 November 1995) and bentazone (960 g ai/ha, 15 January 1996) (right). Note poor vigour of desmanthus in the unweeded control.**

The knockdown herbicides (those with strong contact, and poor residual, activity), bentazone (Treatment 2), bromoxynil (3) and pyridate (5) are considered first. Bentazone (8.8) and bromoxynil (8.8) had similar vigour scores to the weeded (8.5) and unweeded (9.3) controls 1 week after application (Table 4.20). Some damage to leaf tips was observed in both of these treatments. When applied at the second post-emergence treatment, bentazone showed similar effects on desmanthus plants (Plate 4.3). Slightly, but significantly, lower vigour scores for desmanthus in some bentazone (low residual activity) treatments compared to the weeded control after 153 days are probably due to competition from weeds that were not controlled. The benefits of weed control far outweigh this damage however and bentazone is considered by growers and researchers as one of the most potentially useful post-emergence herbicides for use in desmanthus seed crops (Loch pers. comm., 1995; Murat pers. comm., 1995).

Pyridate was damaging to desmanthus seedlings as evidenced by a significantly lower (P=0.05) vigour score (6.25) than the weeded control 1 week after application (Table 4.20). Symptoms included distortion of, and leaf fall in, the top 5 to 10 cm of stem tips. Desmanthus plants recovered well with vigour scores at 119 and 153 days being similar to those of weeded controls.

The post-emergence herbicides with considerable residual activity (imazethapyr and imazapic) were not damaging to desmanthus seedlings. Vigour scores 1 week after application for imazethapyr and imazapic were 9.0 and 8.0 respectively. Plants appeared healthy 1 week after application although some yellowing was observed in the imazapic treated plants. Vigour scores at 119 and 153 days after sowing were similar to weeded controls indicating that these treatments had no apparent delayed effect on desmanthus seedlings. Both of these chemicals are imidazolinones having both contact and residual activity and are used to selectively control mainly broadleaved weeds in legume crops. These trials show this selectivity to be extended to desmanthus.

Plate 4.3 **A typical plant of *Desmanthus virgatus* cv. 'Marc' treated with trifluralin (840 g ai/ha, 29 November 1995) and bentazone (960 g ai/ha, 15 January and 21 February 1996) on 28 February 1996. Note burning of leaf tips in this treatment which represents commercial practice.**

4.4.3.4 Herbicide Effects on Weeds

Herbicides applied before desmanthus emergence

The population scores conducted 41 and 55 days after sowing were used to determine the ability of pre-emergence herbicides to control the selected weeds.

Trifluralin (applied to six treatments) did not control the weeds monitored. All monitored species were present in virtually all (24) trifluralin treated plots after 41 days at similar levels to the unweeded controls (Tables 4.21 to 4.27). A failure to control the species monitored in this trial is not surprising because trifluralin mainly targets annual grasses and is generally tolerated by many members of the Fabaceae, Asteraceae, Brassicaceae and Solanaceae families (Matthews, 1975). Site management prior to the sowing of this trial was not optimal for weed control. Legumes (desmanthus and lucerne) had been grown at the site in the previous six years. This would have resulted in the accumulation of weed seeds, particularly those not easily selectively controlled in legume crops. Also planting took place shortly after cultivation. This did not provide opportunity for germination and subsequent control (by chemical means or cultivation) of weeds. Therefore the weed populations at the trial site were most likely higher, and had a higher proportion of broad-leaved weeds than would be expected if other weed control techniques were used. Although sensitive crops will be affected up to 12 months after application (O'Connor, 1994) trifluralin will control emerging grasses for only 2 to 3 months after application. This should provide control of many grasses during crop emergence making trifluralin a very useful chemical for use in desmanthus seed crops.

Pendimethalin also selectively controls broadleaved and annual grass weeds (O'Connor, 1994). Pendimethalin behaved similarly to trifluralin in this trial (Tables 4.21 to 4.27). The failure of pendimethalin and trifluralin to control euphorbia, bellvine, sida and Noogoora burr agrees with previous literature (Hawton *et al.*, 1990) indicating general resistance of these weeds to dinitroanilines.

The imidazolenones were more effective at controlling the monitored species. Imazaquin completely controlled all monitored species except for rhyncosia and phyllanthus (Tables 4.21 to 4.27). Control was extended to the end of the season. This meant that, of the monitored species, bentazone was only used to control rhyncosia and phyllanthus in these plots. Complete control by imazethapyr was limited to bladder ketmia and euphorbia (Table 4.21). The latter was not present in most other treatments (including the weeded control) at this time so control by imazethapyr may be coincidental.

Imazaquin was clearly the most effective of the selective pre-emergence herbicides, controlling many of the weeds present (Plate 4.2). Because imazaquin also controls a number of grass species it has considerable potential for use in desmanthus seed crops in South-East Queensland. The other pre-emergence herbicides are all potentially useful, however, because they are non-damaging to desmanthus. Their usefulness will be determined by the types of weeds present (e.g. the imidazolenones control more legume species than trifluralin and pendimethalin) and chemical costs (e.g. trifluralin is at least half the price of the other chemicals when applied at rates used in this trial) and application (e.g. imazethapyr does not require soil incorporation whereas the other three do).

Herbicides applied after desmanthus emergence

Comparison of plant populations 1 week before and 1 week after applying post-emergence herbicides, and vigour scores conducted 1 week after application, were used to assess weed control by post-emergence herbicides. Treatments 1 to 5 are compared because they represent the five post-emergence herbicides, are all preceded by trifluralin treatments and followed by bentazone application. The monitored weeds were actively growing and classified as 'pre-mature' at the time of the first application (five different post-emergence herbicides) (48 days) and 'mature' at the second (bentazone) (85 days).

All five post-emergence herbicides failed to eradicate, although damaged, the monitored weeds. Earlier application may have increased weed control. The one exception was pyridate which completely removed phyllanthus (Table 4.26). Of the knockdown herbicides bentazone and bromoxynil were the most damaging to the plants monitored.

These chemicals resulted in vigour scores (48 days) for bladder ketmia, Noogoora burr, bellvine and sida (bromoxynil) being significantly lower (P=0.05) than in the unweeded control plots. Susceptibility of sida and Noogoora burr to bentazone agrees with previous literature (Hawton *et al.*, 1990). Where present rhyncosia, phyllanthus and euphorbia were not affected by bentazone or bromoxynil. The remaining knockdown herbicide, pyridate, was not damaging to any of the weeds scored with vigour scores (48 days) similar to weeds in the untreated plots (Tables 4.21 to 4.27). The failure of pyridate to control sida and Noogoora burr is surprising because this herbicide is reported to control closely related (same genera) species when applied to mature plants at rates used in this trial (Bayer Australia, 1987). However, pyridate is more effective on younger weeds (Seidel and Russell, 1990) and may therefore have been more effective if applied earlier.

These results reinforce the value of bentazone and bromoxynil for post-emergence weed control in desmanthus seed crops. The limited weed control spectra of these products is a concern, however, and additional post-emergence herbicides are required.

The 'residual' post-emergence herbicides (imazethapyr and imazapic) were damaging to some of the weeds present. Imazethapyr resulted in Noogoora burr and bellvine having significantly (P=0.05) lower vigour scores than plants in the unweeded controls 1 week after application. In addition to these weeds, imazapic was damaging to sida. These chemicals were not damaging to bladder ketmia or, where present, rhyncosia, phyllanthus and euphorbia. Bellvine and sida were completely removed 92 days after sowing in the imazapic treatments. Although this is after the second post-emergence treatment (bentazone), the fact that this did not occur in any other treatment indicates that imazapic caused the decline. Control of Noogoora burr, bellvine and sida by imazapic is not surprising as similar species (same genera) are reported as being susceptible (Cyanamid, 1985). Both of these chemicals have considerable potential for broadleaved weed control in desmanthus seed crops.

Other weeds not scored

A number of unscored broadleaved weeds were first identified 1 week before the second applications of post-emergence herbicides (71 days after sowing). These were siratro (*Macroptilium atropurpureum*), indigofera (*Indigofera hirsuta*), 'Wynn' cassia (*Chamaecrista rotundifolia*) and cottonbush (*Gomphocarpus physocarpus*). By the end of the season populations of indigofera and siratro (both legumes) over-ran some treatments (particularly imazaquin and imazethapyr treatments), bentazone having little controlling effect. Resistance of indigofera agrees with previous screenings in Queensland but siratro has previously been reported as being susceptible to bentazone applied at rates used in this trial (Hawton *et al.*, 1990). Large numbers of siratro did not occur until one month after the final bentazone application. Thus the siratro present probably arose from siratro seed which germinated after the bentazone application.

Treatments which previously had the most effective weed control were the treatments most affected by siratro and indigofera. Also, these weeds were not found in the unweeded controls. This indicates that competition from existing weeds and desmanthus reduced indigofera and siratro populations.

4.4.3.5 Herbicide Effects on Desmanthus Flowering

Introduction

Seed yield data was not collected as quadrat collection of fallen seed has been found to be unreliable (Section 3.4.7) and collection of all seed in the pod was unlikely because of ready pod dehiscence in 'Marc' plants. Instead, flowering patterns were studied to estimate herbicide effects on 'Marc' seed yields because seed yield of desmanthus is influenced more by inflorescence number than any other seed yield factor particularly at peak flowering (Section 3.3.10).

Flowering was first observed on 7 February and occurred in most plots by 21 February. This was after all treatment applications, except the application of bentazone to all treatments on 21 February. Flowering was complete in most plots by 17 April. Early inflorescences occurred on the main stem with inflorescences forming on the secondary

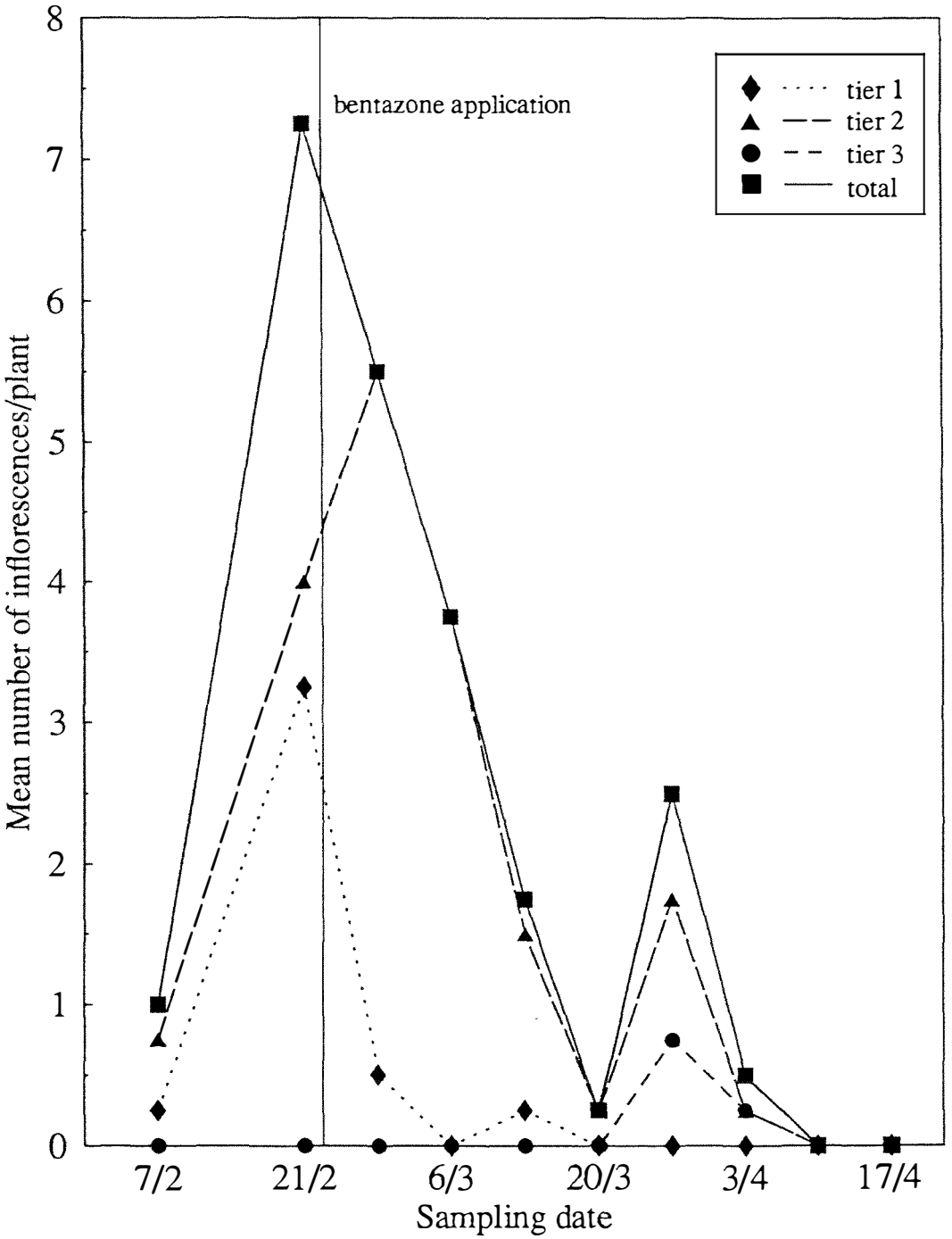
and tertiary branching tiers progressively later. Flowering on the three tiers often occurred concurrently (Figure 4.1). Inflorescences on secondary branches contributed most to total inflorescence production over the season, usually, in combination with main stems, producing a peak of inflorescence numbers in the first third of the flowering period. Inflorescences on tertiary branches typically combined with secondary branches to produce a small secondary peak in the final third of the flowering period (Figure 4.1). Some treatments affected this bimodal flowering pattern and are discussed below.

Flowering varied widely between plants resulting in high LSD values (Figures 4.1 and 4.2). Failure of treatment differences in mean inflorescence number to reach the 5% level of significance is thought to be due to low sampling intensity (one tagged plant per plot using four replicates). Similar sampling intensities used to compare flowering of 'Marc' in other trials in this study did not result in variation of the scale observed in this trial. It is thought that variation in competition effects caused by weeds (of varying habit and time of influence) surrounding the tagged plant was responsible for the variation in flowering. Weeds were not present in the other trials in which inflorescence numbers were counted. Instead competition came from neighbouring desmanthus plants of which, because of uniformity in sowing time and morphological development, it can be assumed competition stress effects were not as variable. Even though statistical significance (P=0.05) was often difficult to obtain, scale differences in mean values often indicate treatment differences. Results have been interpreted with this in mind but treated with caution.

Effects of weed competition on flowering

Flowering patterns in the weeded (Treatment 10) and unweeded (11) treatments were not typical of other treatments. Onset of flowering in these treatments was delayed until 6 March. This caused a delay in peak flowering of plants in the weeded plots (Figure 4.2b). The total number of flowers produced by plants in the weeded plots was substantially lower than some of the other treatments although this result was not

Figure 4.1 **Flowering pattern of *Desmanthus virgatus* cv. 'Marc' plants treated with trifluralin and bentazone (Treatment 1).**



significant (P=0.05) in most cases (Figure 4.2a). This trend agrees with that of vigour scores recorded on 28 February (Table 4.20) and is probably due to physical damage of the plants incurred during hand weeding, most likely caused by damage to desmanthus roots when weed plants were removed.

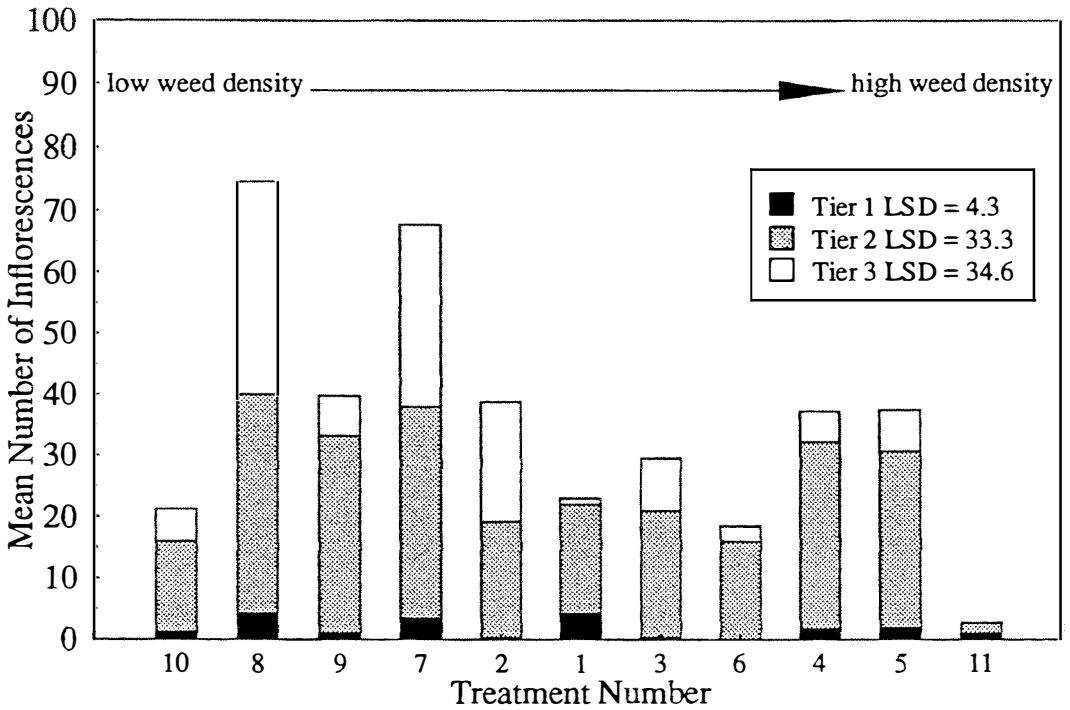
In most other treatments total flower number reflected weed density in the plots. For this reason treatments have been ranked (Figures 4.2a and 4.2b) by total weed density in plots at the onset of flowering (7 February) using the data presented in Tables 4.21 to 4.27. This helps to discern whether inflorescence number is a result of weed competition effects or herbicide effects e.g. desmanthus plants in the very weedy unweeded plots (Treatment 11) produced few flowers (Figure 4.2a) and showed poor vigour (28 February, Table 4.3) presumably because of weed competition effects whereas excellent weed control and plant vigour in the imazaquin (Treatment 8) treatment probably contributed to high total inflorescence number. Proportionately more inflorescences occurred on tertiary branches in weed-free treatments (Figure 4.2a) indicating that extent of branching was also related to weed density. Highest inflorescence numbers were recorded in pre-emergence treatments (Treatments 7, 8 and 9) emphasising the requirement for effective early weed control.

Effects of herbicide treatment on flowering

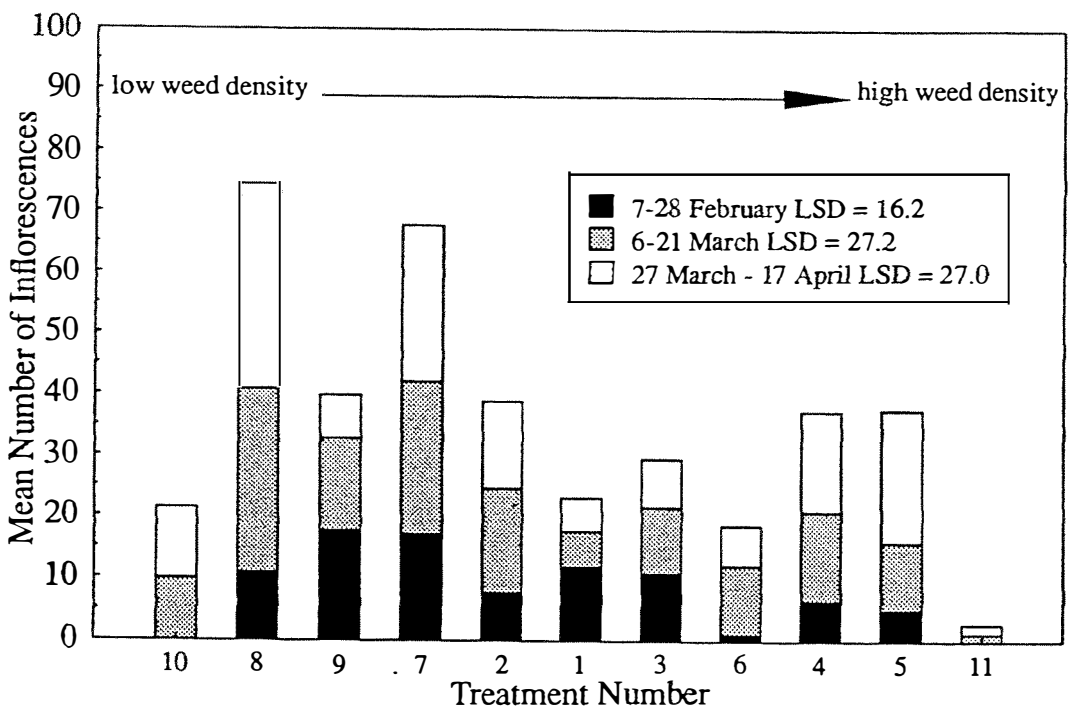
Inflorescence location (branching tier), flowering pattern and total inflorescence number per plant was related to weed density in all herbicide treatments except imazethapyr, applied both pre- (Treatment 9) and post-emergence (Treatment 6) (Figures 4.2a and 4.2b). When imazethapyr was applied pre-emergence total inflorescence number was lower than expected considering that weed control was similar to the pendimethalin treatment at the onset of flowering (Treatment 7) (Tables 4.21 to 4.27). Low total inflorescence number was due to proportionately few inflorescences produced on tertiary branches. Also fewer inflorescences were produced late in the flowering period (27 March to 17 April). Similarly total inflorescence number in post-emergence imazethapyr plots was less than treatments with similar weed populations at the onset of flowering (Figures 4.2a and 4.2b) although the effect was smaller. These results suggest that

Figure 4.2 **Effects of herbicide combinations on flowering pattern of *Desmanthus virgatus* cv. 'Marc' plants.**

A. Distribution of inflorescences on branching tiers



B. Production of inflorescences over time



imazethapyr can depress flowering in 'Marc' desmanthus. However, the decline in inflorescence number (from 27 March onwards) in imazethapyr treatments coincided with the appearance of weeds (*Macroptilium atropurpureum* and *Indigofera hirsuta*) not previously identified and therefore not scored at the site (Section 4.4.3.4). These weeds were not present in the pendimethalin and imazapic treatments which had more inflorescences per plant than the pre- and post-emergence applications of imazethapyr respectively but had similar weed densities (Figures 4.2a and 4.2b). Therefore weed competition probably contributed to the depressed flowering late in the season. Direct herbicide effects can not be completely outruled, however.

Repeat applications of bentazone (Treatment 1), the second of which occurred during early flowering, reduced total inflorescence number per plant compared to a single application before flowering (Treatment 2) (Figures 4.2a and 4.2b) even though weed populations were similar (Table 4.21 to 4.27). This is presumably because of damage to plants as evidenced by significantly (P=0.05) lower vigour score 1 week after the late application (28 February) (Table 4.20). This suggests that repeat applications of bentazone can suppress flower numbers slightly if applied during flowering and that this practice should be avoided. Application of bentazone, or any other post-emergence herbicide is unlikely to be conducted at this time, however, as canopy closure (at optimum populations for seed production) occurs before flowering (8 to 10 weeks after emergence).

4.4.3.6 Herbicide Recommendations

Early season control of grass weeds and most broadleaved weeds can be achieved by the pre-plant or pre-emergence herbicides used in this trial (imazethapyr, imazaquin, trifluralin and pendimethalin). Imazaquin provided best long term control of weeds but is not available in Australia. Otherwise choice of chemical should be based on the weed control spectrum and which is cheapest. Grass weeds can be safely controlled post-emergence by haloxyfop whereas broadleaved weeds are more difficult to control. Therefore pre-emergence herbicides which have stronger activity against broadleaved weeds, such as the imidazolenones, are recommended over herbicides (pendimethalin and

trifluralin) with relatively high activity against grasses. The need to soil-incorporate all of the pre-plant and pre-emergence herbicides except imazethapyr is another consideration.

All post-emergence herbicides used in this trial (bentazone, bromoxynil, imazapic and imazethapyr) except pyridate are considered safe for use on desmanthus older than 48 days. All of these chemicals selectively control different broadleaved weeds. Again choice of chemical should be based on the weeds present. This will depend on site history, the type of pre-emergence herbicide used and the growth stage of the crop. Residual activity, which is greater in the imidazolenones than bentazone and bromoxynil, is another consideration.

Although some of the chemicals identified as being safe for use on desmanthus control a number of leguminous weeds, it is likely that some leguminous weeds are going to be difficult to control in desmanthus crops. There is expected to be an ongoing need to identify selective herbicides, or crop management techniques, which control these leguminous weeds.

In most situations, however, the best overall programme will be to use soil incorporated trifluralin (cheaper than pendimethalin) followed by imazethapyr (pre-emergence) for broadleaved weed control and haloxyfop for any grasses not controlled by trifluralin. Bentazone or bromoxynil (cheaper) may be required early post-emergence to control broadleaved weeds not controlled by imazethapyr.

4.5 Herbicide Screening of *Desmanthus virgatus* cv. 'Marc' in South-East Queensland. 3. Established Plants

4.5.1 INTRODUCTION

Control of weed species in mature desmanthus stands will be necessary if desmanthus seed crops are grown into the second year or thereafter. Results from the radial trial (Section 3.2.2) indicate that 'Marc' is slow to establish in the second year following destructive harvest. Therefore it is likely to suffer from weed competition during summer, a period when many weeds are growing rapidly (Loch pers. comm., 1994).

Control of weeds in mature stands will probably be most important in late spring or early summer, because:

(a) the stand will be open, due to destructive harvesting (5 to 6 months earlier) and poor regrowth, providing space for weeds to establish

(b) desmanthus will tolerate higher rates of certain chemicals because it is in a 'dormant' or slow growing state

(c) many weed species will have germinated but be in early stages of establishment making them more susceptible to most chemicals

(d) perennial weed species that survived from the previous season are likely to be growing vigorously and will therefore be more susceptible to herbicides.

Most grass weeds can be safely controlled using haloxyfop (Section 4.2.3.3). Control of broadleaved weeds, particularly leguminous weeds in desmanthus seed crops is the major problem. It is likely that the post-emergence herbicides effective on broadleaved species (e.g. bentazone, bromoxynil and imazethapyr) which were non-damaging to desmanthus seedlings (Section 4.2.3.4 and 4.3.3.3) will be safe for use in established stands. Higher application rates of these chemicals could probably be safely used on mature desmanthus plants. However, the herbicides identified as being non-damaging to desmanthus seedlings only control a limited range of broadleaved weeds. Of note is the failure to control leguminous weeds and *Sida rhombifolia* (O'Connor, 1994; Schering Agrochemicals, 1993) both of which are problem weeds in desmanthus seed crops in

Queensland (Murat pers. comm., 1995). The objective of this trial was to identify herbicides which control a wide spectrum of broadleaved weeds and which are safe for use on one year old desmanthus plants.

There is no reference in the literature to the use of herbicides on mature desmanthus plants and there is little information available on the use of herbicides on mature tropical forage legumes. It was decided to evaluate herbicides which are used commercially, or had been evaluated in research, in mature temperate legume crops. Priority was given to herbicides used on established lucerne (*Medicago sativa*) and lotus (*Lotus pedunculatus*) because of their similar growth habits to desmanthus. Herbicides used in these crops at mature stages include asulam, atrazine, carbetamide, diquat, ethofumesate, hexazinone, metribuzin, paraquat, simazine and terbacil (Meeklah, 1984; Butler, 1980). All are registered to control a wide range of broadleaved weeds except asulam. Because of its inappropriate target spectrum (Parsons and Cuthbertson, 1992), asulam was not included in this trial. Carbetamide was also omitted because it is not available in Australia (Badewitz-Dodd, 1993).

Atrazine and simazine are both triazines which selectively control grasses and broadleaved weeds in many crops including lucerne (O'Connor, 1994). Atrazine has both knockdown and residual activity whereas simazine has very little activity on existing vegetation and is not recommended to control established weeds (O'Connor, 1994). It is likely that established weeds will be present in mature desmanthus stands. For this reason atrazine was included in the trial as a representative of the triazine group of herbicides. Paraquat and diquat are closely related knockdown herbicides (desiccants) with limited degrees of selectivity. Paraquat has the advantage over diquat in that it controls many grass species in addition to many broadleaved species. Because of this paraquat was included in the trial instead of diquat.

Glyphosate (a non-selective, leaf absorbed, systemic compound) was included in the trial because of its extremely wide weed control spectrum, availability and relatively low cost (Appendix 4.6). Acifluorfen, a selective contact herbicide that controls many grass and broadleaved species, was also included because of tolerance shown to it by fine stem

stylo (*Stylosanthes guianensis* var. *intermedia*), another tropical shrub legume (Loch and Harvey, 1990) and other herbage legume crops (Badewitz-Dodd, 1993; Rhone-Poulenc, 1989).

4.5.2 MATERIALS AND METHODS

4.5.2.1 Pre-Treatment Preparation

The trial was located at the same site as the previous field screening (Section 4.3.2.1). Soil tests conducted showed that the site was not deficient in any major elements expected to interfere with desmanthus growth. The same plots used for the field screening of pre-emergence herbicides were used for this trial (see Section 4.3.2.1 for sowing details). Measurements in the pre-emergence herbicide screening were completed by 6 January 1995. Thereafter weed grasses, notably *Sorghum halepense,* were controlled by applications of haloxyfop (0.21 kg ai/ha) on 9 February, 2 March and 13 April 1995. Broadleaved weeds were controlled by application of bentazone (1.44 kg ai/ha) on 24 January 1995. This reduced broadleaved weed growth of most weed species to acceptable levels and no further chemical controls of broadleaved weeds was conducted prior to the trial. All plots were mown to approximately 15 cm on 16 May 1995 and residue removed from plots by raking.

4.5.2.2 Herbicide Application

Prior to the beginning of the trial, desmanthus and weed populations were uniform across all plots and no differences in plant vigour were observed. The ten treatments were randomly re-assigned in the four blocks to allow for any residual activity of chemicals used in the previous trial on the same site though presence of such residues was considered unlikely. Eight herbicides were applied at rates recommended for other legume crops (Table 4.28). Where more than one rate was recommended, the higher one was chosen. The remaining treatments consisted of handweeded (by hand-pulling and hoeing every 2 weeks beginning 16 November 1995) and unweeded controls. The herbicides were applied on 15 December 1995 using the same method as for the previous

field screenings (Section 4.3.2.2). The herbicides were applied between 8 and 10 am in still but cloudy conditions. Temperatures in the 6 hours following spraying reached a maximum of 28°C and conditions remained dry.

Table 4.28 **Herbicide treatments applied on 15 December 1995 to plots containing one year old plants of *Desmanthus virgatus* cv. 'Marc' in South-East Queensland.**

Chemical	Product name	Application rate (kg ai/ha)
acifluorfen	Blazer	0.45
atrazine	Atradex 900WG	0.99
ethofumesate	Tramat 500SC	2.00
glyphosate	Roundup	1.80
hexazinone	Velpar L	1.00
metribuzin	Lexone DF	0.56
paraquat	Gramoxone	0.40
terbacil	Sinbar	2.40
untreated weeded	-	-
untreated unweeded	-	-

4.5.2.3 Data Collection

Weeds present at the site are listed in Table 4.19. Population counts of desmanthus and monitored weeds present were conducted 8 days prior to spray application. Three randomly placed 0.1 m^2 quadrats were used per plot and averaged. The stage of plant development of all species was also recorded. Stage classifiers were 'seedling' (emergence until development of the first branch), 'pre-mature' (presence of branches but plants not fully expanded), mature (full expansion of plants, evidence of reproductive buds but no flowering), flowering or carrying seed. If plants of a species showed variation in growth stage, the most common growth stage (as determined by visual appraisal) was recorded. This information was used to select eight weed species for scoring and later population counts. Species were generally only selected if they were dominant and widespread across plots.

After herbicide application desmanthus and the selected weed species were visually scored for vigour, population density and growth stage. The scoring system for vigour and population density was the same as that used in the previous field trials (Section 4.3.2.5). All species were scored 7 and 39 days after herbicide application. An additional vigour scoring of desmanthus was conducted 8 days prior to spraying.

Rainfall and irrigation were recorded at the site and are presented in Appendix 3.3. Between 1 January 1996 and 30 April 1996 280 mm of irrigation water was used to supplement low rainfall. Irrigation was restricted to October, November and December because of, otherwise, good rainfall. Temperature and humidity data (Appendix 3.3) was collected in nearby Gympie (55 km east of the trial site) which is a slightly wetter environment.

4.5.2.4 Statistical Analysis

Statistical analysis was conducted as described in 4.3.2.6.

4.5.3 RESULTS AND DISCUSSION

4.5.3.1 Plant Growth

Growth of desmanthus and the weed species was slow during winter and spring and increased growth was not apparent until November. Thereafter, desmanthus grew steadily by producing shoots from buds located on the crown and on branches remaining from the previous season. Although plant growth was not rapid the desmanthus plants appeared healthy. Drier than normal conditions during December are not thought to have affected desmanthus growth because of supplementation with irrigation. One week before the application of treatments most desmanthus plants had begun to flower and a few immature pods were present. Most plants were approximately 20 cm tall at the time of herbicide application. Growth of untreated plants (weeded controls) was slow in the period after 15 December and before the end of the trial (23 January). Desmanthus plants remained in flower during this period. By the end of the trial most plants contained flowers and immature pods (fully expanded but not abscised). No pod dehiscence occurred.

Most weed species present were annuals. Exceptions were *Sida rhombifolia* and *Cyperus rotundus* which both perennate and were represented by seedlings and second-year plants. Weed growth was vigorous in untreated plots. Weed species were at various stages of development 1 week prior to the application of treatments. Of those scored bellvine, Noogoora burr, rhyncosia and euphorbia were typically classified as immature, phyllanthus and verbena as mature and bladder ketmia and sida as flowering.

4.5.3.2 Effects of Weeds on Desmanthus

Mean vigour scores (Table 4.29 and 4.30) of desmanthus in weeded and

Table 4.29 **Effects of herbicides applied 15 December 1995 on vigour score of mature *Desmanthus virgatus* cv. 'Marc' plants.**

Chemical	Pre-spray (7 December 1995)[1,2]	Post-spray 1 (22 December 1995)[1,2]	Post-spray 2 (23 January 1996)[1,2]
acifluorfen	8.2	7.3	8.8
atrazine	9.0	6.3	9.0
ethofumesate	8.5	8.0	8.5
glyphosate	8.0	2.0	6.0
hexazinone	7.8	1.5	6.5
metribuzin	8.3	2.3	7.8
paraquat	8.8	5.5	8.8
terbacil	8.5	2.5	7.8
untreated weeded	9.8	10.0	10.0
untreated unweeded	9.0	9.8	9.3
$LSD_{0.05}$	0.8	1.3	1.2

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

Table 4.30 **Effects of herbicides applied 15 December 1995 on population (plants/m^2) of mature *Desmanthus virgatus* cv. 'Marc' plants.**

Chemical	Pre-spray (7 December 1995)[1]	Post-spray (23 January 1996)[1]
acifluorfen	43	38
atrazine	55	55
ethofumesate	68	45
glyphosate	68	8
hexazinone	55	48
metribuzin	53	48
paraquat	63	63
terbacil	60	55
untreated weeded	73	80
untreated unweeded	65	55
$LSD_{0.05}$	38	26

[1] Mean values for 4 plots

unweeded plots were very similar, differing by less than one unit (on a scale of 1 to 10). This indicates that either:

(a) competition effects due to weed species were minimal. This could be due to not enough weeds being present resulting in no restrictions on nutrient supply, or slow desmanthus growth meaning that desmanthus was not demanding high levels of nutrient, or

(b) some effect (e.g. damage to desmanthus roots during hand weeding) is causing as much damage to desmanthus in weeded plots as competition from weeds in unweeded plots.

High vigour scores of desmanthus indicate that plants were healthy and that therefore the former is the most likely situation. Plants were observed to be slow growing, however, and did not grow as fast as seedlings (in the herbicide combination trial) growing at the same time. This feature of poor second season growth was also observed in the radial trial (Section 3.2.2).

Weed populations increased during the trial (Tables 4.31 and 4.32). The weeds present in the unweeded plots were initially dominated by bellvine and sida which both occupied approximately 10% of the area of the plot. Later in the season, numbers of verbena and Noogoora burr increased. Phyllanthus and bladder ketmia were less common and no rhyncosia or euphorbia were found. Because plots were dominated by weeds by the end of the trial, it can be assumed that competitive restrictions in the supply of nutrient to desmanthus plants existed. However this did not affect desmanthus vigour score. Low demand for nutrients associated with slow desmanthus growth may partially explain this.

4.5.3.3 Herbicide Effects on Desmanthus

Introduction

The chemicals used in this trial are discussed as knockdown herbicides with either virtually no (acifluorfen, ethofumesate, glyphosate and paraquat) or some residual activity (atrazine, metribuzin, hexazinone and terbacil).

Table 4.31 **Populations[1,2] of bladder ketmia (bk), Noogoora burr (nb), bellvine (bell), sida, rhyncosia (ryhn), phyllanthus (phyll), euphorbia (euph) and verbena (verb) in plots of mature *Desmanthus virgatus* cv. 'Marc'. 1. Eight days prior to herbicide application.**

Chemical	bk	nb	bell	sida	rhyn	phyll	euph	verb
acifluorfen	0	0	10	13	0	0	0	3
atrazine	0	8	15	18	0	3	3	3
ethofumesate	3	0	10	10	0	0	3	0
glyphosate	3	10	10	23	0	0	3	0
hexazinone	0	0	13	13	0	3	0	3
metribuzin	0	5	13	10	0	10	0	3
paraquat	0	0	13	18	0	5	3	5
terbacil	0	0	10	10	0	3	0	3
untreated unweeded	0	0	13	10	3	13	0	3
$LSD_{0.05}$	3	8	6	12	2	13	4	6

Table 4.32 **Populations[1,2] of bladder ketmia (bk), Noogoora burr (nb), bellvine (bell), sida, rhyncosia (ryhn), phyllanthus (phyll), euphorbia (euph) and verbena (verb) in plots of mature *Desmanthus virgatus* cv. 'Marc'. 2. Thirty-nine days after herbicide application.**

Chemical	bk	nb	bell	sida	rhyn	phyll	euph	verb
acifluorfen	3	0	38	38	0	0	0	18
atrazine	0	0	0	48	0	0	0	8
ethofumesate	3	5	63	40	0	8	0	10
glyphosate	0	0	5	0	0	0	0	0
hexazinone	0	0	0	3	0	0	0	0
metribuzin	0	0	8	20	0	10	0	8
paraquat	0	0	33	18	0	0	0	3
terbacil	0	0	0	0	0	0	0	5
untreated unweeded	5	13	75	5	0	18	0	18
$LSD_{0.05}$	4	9	19	21	0	14	0	11

[1] Mean values for 4 plots

[2] Percentage area occupied in plot

Knockdown herbicides with little residual activity

All of these herbicides used in the trial were damaging to desmanthus, resulting in vigour scores significantly lower (P=0.05) than the weeded control (Table 4.29). The extent of the damage varied greatly however: acifluorfen and ethofumesate were the least damaging, paraquat moderately damaging and glyphosate the most damaging to desmanthus plants 1 week after application (Table 4.29).

Acifluorfen and ethofumesate caused some loss of leaf 1 week after application (Table 4.29). This is expected because acifluorfen has largely contact action on leaves and does not translocate (Yanase and Andoh, 1989). Selectivity by diphenyl ethers (e.g. acifluorfen) is due to either placement, the presence of a waxy cuticle or internal detoxification mechanisms (Ross and Lembi, 1985). Desmanthus recovered well from acifluorfen and ethofumesate as indicated by vigour scores conducted 39 days after application (Table 4.29). The slight damage caused by, and the rapid recovery from, these chemicals suggests that they will not interfere with seed production. While acifluorfen is registered for selective control of grass and broadleaved weeds in legume crops (*Arachis hypogaea* and *Glycine max*) ethofumesate mainly targets annual grasses, including C4 species (O'Connor, 1994). Control of broadleaved weeds has already been identified as a priority in herbicide screening work (Loch pers. comm., 1994). Thus ethofumesate, an expensive chemical (Appendix 4.6), is expected to have a limited use because haloxyfop is expected to provide effective post-emergence control of most, if not all, grasses present in desmanthus seed crops.

The next least damaging knockdown herbicide was paraquat, a desiccating bipyridyl compound. Paraquat caused necrosis of all leaf tissue and some stem tips in the week after application. Entire branches were killed in some plants. Desmanthus recovered well, however, and plants were growing vigorously by the end of the trial. This recovery is typical of many species (e.g. *Trifolium repens*) exposed to paraquat when in mature form (Butler *et al.*, 1981). The quadrat population counts indicate that few, if any, desmanthus plants were killed. Although desmanthus plants recovered from paraquat damage, checked growth due to paraquat application at similar rates to those used in this trial have reduced seed yields in other forage legume (*Trifolium repens*) seed crops

(Butler *et al.*, 1981). It is suggested that, if used, paraquat should be applied early to allow regrowth before flowering.

Glyphosate was the most damaging chemical to desmanthus included in this trial. This is not surprising as glyphosate is a translocated herbicide registered to control a wide spectrum of weeds (O'Connor, 1994). Some legumes (e.g. *Trifolium repens*) tolerate glyphosate at relatively high rates (1.08 kg ai/ha in pasture) and it is recommended, for example, that a selective herbicide be included in the tank mix to control these more tolerant species (O'Connor, 1994). Genetic modification of *Glycine max* to encourage glyphosate resistance has been successful (Delannay *et al.*, 1995) with no major changes to chemical composition (Padgette *et al.*, 1996) or nutritive value (Hammond *et al.*, 1996). Tolerance of desmanthus to glyphosate at label rates (1.8 kg ai/ha used in this trial) would have been very useful as most, if not all, weeds would have been controlled easily. Instead glyphosate damaged all above ground structures causing desmanthus, and all other species present, to brown off 1 week after application. Some plants survived and produced new growth by the end of the trial. Most desmanthus plants died, however, as evidenced by the extremely low population by the end of the trial (Table 4.30). When applied at rates (1.8 kg ai/ha) used in this trial glyphosate is expected to severely depress desmanthus seed production in the season after application because of extensive damage to plants. However, it is possible that lower rates could be used but with the risk of providing poorer control of perennial weeds.

Knockdown herbicides with strong residual action

These herbicides were generally more damaging to desmanthus than the herbicides with little residual activity. Vigour scores, 1 week after application of herbicide treatments, of hexazinone, metribuzin and terbacil were not significantly different (P=0.05) to glyphosate (Table 4.29). Mean values ranged from 1.5 to 2.5 indicating severe damage to desmanthus plants. The other residual herbicide tested, atrazine, was not as damaging to desmanthus but resulted in a vigour score (6.25 1 week after application) significantly lower (P=0.05) than both weeded and unweeded controls.

By the end of the trial the mean vigour score (9.0) of desmanthus plants sprayed with atrazine was not significantly different (P=0.05) to desmanthus plants in both the weeded and unweeded controls. Atrazine, a root- and leaf-absorbed photosynthesis inhibitor, is used for the selective control of grass (not C4) and broadleaved weeds in cropping situations including some legumes e.g. lucerne (O'Connor, 1994). Atrazine is relatively soluble in soil and can be damaging to susceptible plants up to 6 months after application. Its solubility means that atrazine is not suitable for depth protection in many crop species. Mature desmanthus, however, appears to tolerate atrazine at rates used in this trial. The residual nature of atrazine means that it has the potential to control many grass and broadleaved plants over an extended period of time making it a potentially useful herbicide for use in desmanthus seed production. Simazine, a closely related compound, was extremely damaging to desmanthus seedlings (Section 4.2.3.2). Thus it is suspected that atrazine will also be damaging to emerging desmanthus plants.

Metribuzin and terbacil both caused yellowing of desmanthus leaves and leaf fall 1 week after application. Recovery of desmanthus from metribuzin and terbacil damage was poor, possibly reflecting residual activities of these chemicals in soil. Both are used to selectively control grass and broadleaved weeds in a number of crops including legumes and were not applied at unusually high rates. These results indicate that these chemicals have limited potential for use in desmanthus crops.

Hexazinone caused desmanthus plants to brown off 1 week after application. The extent of damage is not surprising as hexazinone is often used in non-crop situations to non-selectively control perennial grasses and broadleaved weeds. Rates used in this study were those recommended for use in mature lucerne crops (O'Connor, 1994). Desmanthus did not recover from hexazinone damage by the end of the trial (Table 4.29). This is probably due to a combination of the extent of damage and the long residual life that hexazinone has in the soil (Parsons and Cuthbertson, 1992).

4.5.3.4 Herbicide Effects on Weeds

The rationale for the study of herbicide effects on weeds present was the same as for Section 4.4.3.4. Not all weeds were present in plots of each treatment (Tables 4.31 and 4.32). Thus evaluation of herbicide application effectiveness has to be limited to those species which were present in all plots i.e. bellvine and sida. All treatments except ethofumesate (bellvine and sida), acifluorfen (sida) and atrazine (sida) had significantly lower vigour scores for bellvine and sida than the untreated plots 1 week after herbicide application (Table 4.33). Atrazine and acifluorfen were very damaging to bellvine however, indicating that the poor effect on sida was probably due to tolerance rather than poor application. This indicates that all herbicides, with the possible exception of ethofumesate, were successfully applied at rates damaging to weed species. Ethofumesate mainly controls grass species. These were not monitored in this trial. Therefore application of ethofumesate may indeed have been successful with results reflecting tolerance by the weed species present. This is considered likely because all other treatments worked.

Ethofumesate and acifluorfen were the safest of the knockdown herbicides with low residual activity for use on desmanthus (Section 4.5.3.3). However, neither of these chemicals provided short or long term control of sida, a problem weed in commercial desmanthus seed crops (Table 4.33). Thus while these two chemicals have potential use for the control of many grass (ethofumesate) and broadleaved (particularly acifluorfen) weeds they do have limitations in weed target spectrum. Atrazine was the safest knockdown herbicide with residual activity (Section 4.5.3.3) and as such has the greatest potential for use in second year seed crops. Atrazine was very damaging to bellvine providing control throughout the trial period. Sida, however, was not significantly ($P=0.05$) affected (Table 4.33). The use of a non-ionic surfactant is recommended to enhance the knockdown activity of atrazine in some crops (e.g. *Zea mays*, O'Connor, 1994). A surfactant was not included in this trial. Thus knockdown activity on problem weeds such as Sida, but also desmanthus, may be increased by use of a surfactant. This requires further investigation.

Table 4.33 **Effects of herbicides applied 15 December 1995 on vigour score[1,2] of bellvine (*Ipomoea plebeia*) and sida (*Sida rhombifolia*) plants in plots of mature *Desmanthus virgatus* cv. 'Marc'.**

Chemical	bellvine		sida	
	Vigour score (22 December)	Vigour score (23 January)	Vigour score (22 December)	Vigour score (23 January)
acifluorfen	5.0	7.5	9.5	8.8
atrazine	3.3	NP[3]	8.8	9.8
ethofumesate	8.8	7.8	9.3	9.5
glyphosate	4.0	1.8	4.5	NP
hexazinone	1.3	NP	2.0	1.3
metribuzin	3.3	2.5	4.8	8.0
paraquat	2.8	7.3	4.5	8.5
terbacil	1.0	NP	2.0	NP
untreated unweeded	10.0	8.8	10.0	10.0
$LSD_{0.05}$	2.2	2.0	2.1	1.7

[1] Mean values for 4 plots

[2] Scores range from 1-10 1 = no green material present
10 = most vigorous growth

[3] Not present for scoring because of herbicide damage

4.5.3.5 Recommendations

Control of perennial weeds is likely to be difficult in desmanthus seed crops: the chemicals (acifluorfen, atrazine and ethofumesate) which were least damaging to one year old desmanthus plants do not control mature weeds whereas hexazinone, glyphosate, metribuzin and terbacil are very damaging to desmanthus and mature weeds. Although desmanthus regrew well after paraquat application this chemical will only be useful if desmanthus recovers faster than other weed species.

Poor second year regrowth of 'Marc' desmanthus also suggests that seed production should be limited to annual stands. However, if chemical weed control of establishing weeds is required in second year desmanthus stands it should be conducted with the chemicals identified as being useful during desmanthus establishment i.e. imazethapyr, bentazone, bromoxynil (all for broadleaved weeds) and haloxyfop (for grasses).

4.6 Discussion

4.6.1 INTRODUCTION

Prior to this study two chemicals, trifluralin (pre-plant soil incorporated) and bentazone (post-emergence), were used in commercial desmanthus seed crops (Murat pers. comm., 1995) in Atherton Tableland, North Queensland to control a wide range of grass and broadleaved weeds (O'Connor, 1994). Although these chemicals are reported to be non-damaging to three cultivars ('Bayamo', 'Marc' and 'Uman') of desmanthus, they provided poor control of some weeds (notably *Aeschynomene americana* and *Sida* spp.) present in desmanthus seed crops (Murat pers. comm., 1995).

The initial pot-based screenings (Section 4.2) on desmanthus seedlings using recommendations for (mostly) legume crops identified potentially useful chemicals (Section 4.2.3): pre-plant soil incorporated (trifluralin); pre-emergence (chlorpropham, chlorthal dimethyl, diflufenican, pendimethalin and oryzalin); and post-emergence (asulam, benazolin, bentazone, bromoxynil, chlorpropham, chlorthal dimethyl and ioxynil). With the exception of ethofumesate, post-emergence herbicides which mainly control monocotyledons were non-damaging to desmanthus seedlings. The chemicals which were non-damaging and available in Australia were evaluated in field trials in South-East Queensland along with some potentially useful chemicals (those used to control broadleaved weeds in legume crops) which were either recently released or were about to be released in Australia. These included pre-plant incorporated (imazaquin), pre-emergence (imazethapyr) and post-emergence (flumetsulam, imazapic, imazethapyr and pyridate) herbicides applied at rates recommended for similar legumes. The performance of the above chemicals is discussed in Sections 4.6.2.1 and 4.6.2.2.

A number of post-emergence herbicides were also tested on one year old desmanthus plants (Section 4.5). As with desmanthus seedlings, glyphosate, hexazinone, metribuzin and terbacil were very damaging to mature desmanthus plants although plants showed some recovery. Safe herbicides were acifluorfen and ethofumesate whereas atrazine and paraquat were moderately damaging. These chemicals are discussed in Section 4.6.2.3.

4.6.2 HERBICIDE RECOMMENDATIONS FOR WEED CONTROL IN DESMANTHUS SEED CROPS

4.6.2.1 During Seedling Emergence

Effective early chemical or mechanical weed control is important as it reduces the need to apply post-emergence herbicides such as bentazone which can check desmanthus growth (Section 4.2.3.4) and interfere with flowering (Section 4.4.3.5).

All pre-plant incorporated and pre-emergence chemicals identified as being non-damaging to desmanthus seedlings in the pot trial were also relatively non-damaging under field conditions (Section 4.3.3). Of these, trifluralin and pendimethalin show greatest potential for use in desmanthus seed crops as the other chemicals either showed some damage to desmanthus seedlings (chlorthal dimethyl and diflufenican, Section 4.3.3) or controlled similar weeds at greater cost even when used at low rates (oryzalin).

Trifluralin, an inexpensive dinitroaniline, is used to selectively control annual grasses and broadleaved weeds in a number of crops (O'Connor, 1994). However, many members of the Fabaceae, Asteraceae, Brassicaceae and Solanaceae families tolerate trifluralin so that control of broadleaved weeds is limited (Matthews, 1975). Trifluralin has a half-life of 1.5 to 6.5 months (Jolley *et al.*, 1990) so is expected to provide weed control of many species until canopy closure. When trifluralin is used, a post-emergence herbicide which controls a wide range of broadleaved weeds will usually be necessary. Other considerations when using trifluralin include the need to incorporate in soil prior to planting (Silk *et al.*, 1977) and higher application rates on heavy clay soils (O'Connor, 1994).

Pendimethalin is very similar to trifluralin in structure, mode of action and target spectrum (O'Connor, 1994). Thus a post-emergence herbicide which controls a wide range of broadleaved weeds is likely to be required following pendimethalin application. Unlike trifluralin, soil incorporation is not usually required provided adequate rainfall or irrigation is provided after application (O'Connor, 1994). However, in this study weed

control was found to be enhanced by soil incorporation. Volatilisation can dramatically affect persistence and performance of herbicides (Branham, 1994). Pendimethalin is considered as being moderately volatile (Branham, 1994), readily volatilising in the presence of sunlight (Dureja and Walia, 1989). Losses of 6.1% and 13.0% have been observed in turf 2 and 5 days after application respectively at temperatures (up to 37.3°C) similar to those of this study (Cooper *et al.*, 1990). It appears likely that soil incorporation of pendimethalin in the trial at Kilkivan has reduced volatilisation losses and that this has contributed to its greater effectiveness over the non-incorporated treatment.

Two imidazolenone herbicides, imazaquin (pre-plant soil-incorporated) and imazethapyr (pre-emergence), were also evaluated in field conditions. Imazaquin, initially developed for pre-emergence weed control in soybeans (*Glycine max*) (Cyanamid, 1985), was the most effective pre-emergence herbicide used in this study. It provided complete weed control of most monitored species for 10 weeks after sowing and was non-damaging to desmanthus seedlings (Section 4.4.3.3). Imazaquin selectively controls a wide range of broadleaved and grass weeds including legumes, C4 grasses and sedges, all types of plants which are expected to be encountered in desmanthus seed crops. Imazaquin also has some contact activity (Cyanamid, 1985) and may therefore be a useful post-emergence herbicide provided it becomes available in Australia.

Imazethapyr was also non-damaging to desmanthus and provided good control of most monitored (broadleaved) weed species. Imazethapyr is registered for use in legume crops where it is applied either pre- or early post-emergence (with a wetting agent) to control many broadleaved and some grass weeds. One advantage of imazethapyr over imazaquin is that it does not require soil incorporation (Schering Agrochemicals, 1993). Good control of broadleaved weeds suggests that imazethapyr should be applied (pre-emergence) after either trifluralin or pendimethalin. This should control most grass and broadleaved weeds reducing the need for post-emergence herbicides.

4.6.2.2 Between Seedling Emergence and First Harvest

Post-emergence grass control, if required after pre-emergence treatments, is best conducted with haloxyfop which is used to selectively control grass weeds in broadleaved crops. Similarly propyzamide targets grasses although it is used to control some broadleaved weeds (O'Connor, 1994). Propyzamide is very expensive, however, (Appendix 4.6) and this is expected to limit its use.

Control of broadleaved weeds is considered more urgent than control of grasses (Loch pers. comm., 1994). The most promising post-emergence herbicides which control broadleaved weeds are bentazone, bromoxynil, imazethapyr and imazapic.

Evaluation in this study and commercial crops have shown desmanthus to be tolerant to bentazone. Although some necrosis of leaf tips occurs, desmanthus seedlings recover rapidly. Bentazone has contact action and is typically used to control broadleaved weeds in monocotyledonous crops although is tolerated by some dicotyledonous plants (typically with very waxy cuticles) including a few legumes (O'Connor, 1994). Tolerance of desmanthus to bentazone is useful because bentazone has the ability to control many broadleaved weeds albeit mostly at seedling stages. However, persistent problems with *Sida* spp. have been encountered in commercial desmanthus seed crops treated with bentazone despite *Sida* spp. seedlings (3 week old) being reported to be susceptible at similar rates (Hawton *et al.*, 1990). It is possible that in commercial stands bentazone is being applied to sida at a later growth stage and, because of this, is more tolerant to this chemical. Sida was controlled by imazethapyr in this study (Table 4.24) indicating that this weed should be eradicated before bentazone application provided the recommended pre-emergence herbicides are applied. Some other problem weeds (e.g. *Aeschynomene* spp.) are also tolerant to bentazone (Murat pers. comm., 1995; Hawton *et al.*, 1990). Bentazone has no residual activity so weeds are controlled for a short period and new weed seedlings might establish while desmanthus is temporarily damaged by bentazone.

Bromoxynil is very similar in action and weed control spectrum to bentazone, and they performed similarly within these trials. Because of its similarities to bentazone it also shares its disadvantages. The key advantage of bromoxynil over bentazone is its cost being half the price at rates used in these trials (Appendix 4.6).

The two imidazolenones imazapic and imazethapyr were non-damaging to desmanthus seedlings when applied early post-emergence and controlled some of the weeds monitored including sida (imazapic) (Section 4.3.3.2). Both have contact and residual activity but contact activity is limited to young weeds (Schering Agrochemicals, 1993; Cyanamid, 1992). Thus post-emergence applications are limited to the early period of crop development. This is not expected to be a problem in desmanthus seed production because most weed problems are envisaged to occur early in the season. The residual activity is of benefit because weed control should occur over a prolonged period, at least until canopy closure. Both chemicals control a wide range of broadleaved weeds including many problem weeds (or weeds of the genera) encountered in Queensland desmanthus seed crops. These chemicals are strongly recommended provided they are applied when weeds are at an early growth stage. Imazethapyr is relatively inexpensive when applied at rates used in this trial (Appendix 4.6). Imazapic was not for sale in Queensland in 1997, however.

Other post-emergence chemicals showing less promise included asulam, bromoxynil + diflufenican, chlorthal dimethyl, flumetsulam and pyridate.

Although asulam was not damaging to desmanthus many of the weeds (e.g. *Cyperus rotundus*, *Ipomoea* spp., *Xanthium* spp. and *Raphanus raphanistrum*) found in South-East and North Queensland cropping situations are resistant to post-emergence applications of this chemical (May and Baker, 1971). Interestingly this study found asulam moderately damaging to *Ipomoea plebeia*, *Hibiscus trionum*, *Sida rhombifolia* and *Xanthium pungens* (Table 4.16). These were all damaged by either imazethapyr or bentazone in this study. Therefore asulam is expected to have a limited role in desmanthus seed production.

Bromoxynil + diflufenican, chlorthal dimethyl and flumetsulam treatments were damaging to desmanthus plants in field trials even 34 days after application. These chemicals all have residual activity (O'Connor, 1996; Parsons and Cuthbertson, 1992) so desmanthus seedlings would have been exposed to, and affected by them, for a greater period. Chlorthal dimethyl provided poor control of monitored weeds and it is possible that poor vigour of desmanthus plants 34 days after application was due, at least in part, to competition effects. Because chlorthal dimethyl was not damaging to some problem weeds (sida) (Section 4.3.3.3) and is very expensive (Appendix 4.6), this chemical is not expected to be useful in desmanthus seed production. Flumetsulam and bromoxynil + diflufenican provided better control of weeds including sida (Section 4.3.3.3). Thus damage to desmanthus seedlings at 34 days was probably due to physiological intolerance to these chemicals rather than weed competition. Although the weed control spectra and cost (Appendix 4.6) of these chemicals make them potentially useful for desmanthus seed production the long term damage they have on desmanthus plants may interfere with seed production. Further trial work is required in this area only if other chemicals do not control weeds in commercial stands.

Pyridate is a non-residual contact herbicide (Seidell and Russell, 1990) which controls a wide range of broadleaved weeds including *Sida* spp. and legumes (Bayer Australia, 1987). However, pyridate was found to be moderately damaging (significantly (P=0.05) more so than bentazone or bromoxynil) to desmanthus in this study and because of this pyridate is not recommended for use in desmanthus seed crops.

4.6.2.3 After First Harvest

The broad-spectrum contact herbicides which were least damaging to desmanthus (acifluorfen, atrazine, ethofumesate and paraquat) did not provide long term control of the perennial weeds present particularly problem weeds in desmanthus seed crops i.e. sida (Table 4.33). Although acifluorfen can control problem legume weeds found in desmanthus seed crops (*Aeschynomene americana*) (Hawton *et al.*, 1990) it is recommended that application should only be on young, actively growing weeds (Rhone-Poulenc, 1989). When perennial weeds were controlled (e.g. sida by paraquat) this was

only temporary. Thus these chemicals show no advantages in weed control over the post-emergence herbicides evaluated, and found to be safe, on desmanthus seedlings. Therefore it is suggested that bentazone, bromoxynil, imazapic and imazethapyr be used in mature stands to control immature weeds, possibly at higher rates than when applied to desmanthus seedlings. Also pyridate may be useful in mature or dormant desmanthus stands because of its appropriate weed control spectrum.

Poor regrowth of desmanthus after cutting in a fashion similar to combine harvesting (Section 3.2.2; Adjei and Pitman, 1993) suggests that the use of second year seed crops may be limited. Poor control of perennial weeds likely to be a problem in desmanthus seed crops (e.g. sida) also limits the potential for second year stands of desmanthus.

4.6.3 LEGAL RESTRICTIONS TO HERBICIDE USE IN QUEENSLAND

Adoption of chemical recommendations are subject to legal restrictions of their use. Registration of herbicides and regulatory control of their sale and use in Australia was traditionally (after 1935) controlled by state governments (Matthews, 1993; Hooper, 1992) and was subject to abuse. 'Off label' use (i.e. not using the product as described on the product label or related literature) of chemicals was common (Matthews, 1991).

Increasing awareness and concern over chemical issues resulted in the formation of the federally controlled Agricultural and Veterinary Chemicals Act (1988) and the establishment of the Australian Agricultural and Veterinary Chemicals Council (AAVCC) (Hooper, 1992). This later became a National Registration Scheme (Hooper, 1992) which was formalised in the formation of the National Registration Authority and the passing of the Agricultural and Veterinary Chemicals Act (1992) (Psaltis, 1994). The legislation increased the level of control on the use of agricultural chemicals and eliminates non-label use of chemicals (e.g. situation / crop other than the one specified on the label, higher rates, application frequency or non-specified application technique). Exceptions apply to people using hand-pumped applicators with tank capacity of less than 10 l but only for certain chemicals (Psaltis, 1994). Application of this type is inappropriate for seed crops.

Clearly, under new legislation, there is no opportunity for legal off-label use of herbicides. As no herbicides are registered for use on desmanthus seed crops, current legislation means that technically the herbicides identified as being useful for desmanthus seed production cannot be used. However, bentazone and trifluralin have been, and still are, used in commercial desmanthus seed crops (Murat pers. comm., 1995). Although not legal, this activity is not actively policed in Queensland and is likely to continue at least in the short term. Technically, the results of research reported in my thesis cannot be formulated into recommendations for seed growers unless the chemicals become registered for use in future. However, reporting the findings of my research to such growers is not illegal.

4.6.4 INTEGRATED APPROACHES TO WEED CONTROL

Selective chemical control of weeds should only be conducted if other approaches to weed control are unsuccessful. Also there is increasing public pressure to reduce the amount of chemicals applied to crops in order to reduce environmental damage and residues in end products (Combellack, 1992).

This study of selective herbicides was intentionally conducted in a weedy environment in order to ensure weed competition effects on desmanthus. The site at Kilkivan provided this: five years of lucerne production, during which weed control was minimal, followed by desmanthus allowed the build up of weed seeds, particularly of broadleaved species. Poor control of Johnson grass during this period resulted in the accumulation of rhizomes which subsequently produced vigorous tillers. Although perennial weeds were controlled by glyphosate prior to sowing trials, there was no weed control after cultivation. This allowed seeds which were previously at ungerminable depths to germinate and compete with the crop.

Of particular importance was the monoculture of lucerne prior to the study. Usually a succession of different crops are grown at one site. Each different crop provides a different competitive environment therefore denying one weed species from gaining dominance (Elliot *et al.*, 1977). Crop rotation also allows for rotation of herbicides.

Prior to growing desmanthus, a crop should be grown which allows use of herbicides that control weed species likely to be troublesome in desmanthus crops. A monocotyledonous crop is likely to be most useful because herbicides which control a wide range of broadleaved weeds (e.g. MCPA) can be used thus reducing the numbers of problem weeds in the desmanthus crop. This approach should target weed species (e.g. *Aeschynomene americana*) which are difficult to control in desmanthus crops by selective herbicides. Consideration should be made of the period for which seeds of problem weeds remain viable in soil and the crop rotation adjusted accordingly.

Existing weeds, particularly perennial weeds, need to be removed and are often controlled mechanically during cultivation immediately prior to sowing. Although weeds are buried (e.g. mouldboard plough) and / or damaged (e.g. rotary cultivator), cultivation can redistribute some weed seeds and rhizomes within the soil profile so that weed seeds previously at an ungerminable depth are able to germinate (Fryer and Makepeace, 1977). This problem can be reduced in various ways. The simplest involves two or more cultivations of decreasing depth, separated by a period which allows weed seeds to germinate. Thus successive cultivations reduce the number of germinable seeds in the soil. Timing must be correct. This technique is also used to control rhizomatous species such as Johnson grass by exhausting rhizomes (Parsons and Cuthbertson, 1992). An alternative is the use of a broad-spectrum, non-residual herbicide to control the establishing weeds. Glyphosate is particularly useful because it is relatively inexpensive (Appendix 4.6), has low residual activity and is tolerated by few weeds (including perennials) at high application rates.

Rapid establishment and vegetative growth of the crop so that a dense canopy is formed before weeds establish is also important. The crop must therefore be sown in optimum conditions (notably temperature and moisture but also soil nutrients) for maximal growth. For desmanthus optimum conditions of growth during establishment occur when temperatures surrounding the seed are 26 to 33°C (Njarui *et al.*, 1992) and moisture is non-limiting. Sowing during spring or early summer should provide this. For desmanthus this would require cultivation in early spring to allow weed seed germination and subsequent chemical / mechanical control prior to the final cultivation. Delaying of

sowing date (of pastures) until weeds have germinated and been subsequently controlled has reduced the need for chemical control (Partridge and Miller, 1991). This method is expected to be useful in desmanthus seed production because sowing can be delayed at least until December before seasonal constraints on seed yield occur. Seed has to be scarified before sowing to ensure even germination (Hopkinson, 1993). Adequate soil nutrients, particularly N, should be present provided that an appropriate cropping rotation, or site fertiliser history, has been used. Seed inoculation with *Rhizobium* (CB3126) is also recommended to encourage growth (Date, 1991) but is not expected to have a large influence until well after canopy closure. High plant populations also contribute to a 'competitive advantage' of the crop. Seed yield (Section 3.3.11) and flowering spread (Section 3.3.3) of 'Marc' were not adversely affected at high population densities. The seed price of desmanthus is also relatively low. Thus high sowing rates (to ensure a plant population of up to 160 plants/m^2) can be used to suppress weeds.

Sometimes populations of problem weed species (i.e. those which cannot be selectively controlled within the crop) cannot be limited sufficiently by the above methods to prevent competition with the seed crop. This is especially a problem when weeds are taxonomically similar to the crop species e.g. *Aeschynomene americana* in desmanthus seed crops. A method used in *Trifolium repens* seed crops is to control volunteer weeds, typically legumes, by band spraying dicamba between crop rows (Delacey, 1986). Care must be taken to avoid herbicide contact with the crop. A similar approach could be used in desmanthus using a non-residual contact chemical such as glufosinate. Desmanthus is best grown at populations which encourage rapid canopy closure (Section 3.4.8). Thus, if required, use of 'band spraying' will be limited to establishing desmanthus crops.

Although different integrated approaches have been used successfully in the production of other crops (e.g. allelopathy in cereals, Putnam, 1988) and pastures (e.g. biological controls by grazing animals or damaging insects, Combellack, 1992) these approaches are unlikely to be useful in desmanthus seed production certainly in the short term. I suggest the most effective techniques are crop rotation and those which encourage rapid

establishment and early canopy closure i.e. cultivation practices and sowing date / rate. These should, in combination with the use of the selective chemicals identified, control weeds in desmanthus seed crops.

4.6.5 EXTRAPOLATION OF RESULTS

4.6.5.1 Cultivar Differences

Cultivar differences in tolerance to chlorsulfuron (0.03 kg ai/ha) have been observed in seedling *Hordeum vulgare* (Lemerle *et al.*, 1993) and to diuron (1.5 to 2.5 kg ai/ha) and hexazinone (0.5 kg ai/ha) in *Medicago sativa* (Marble, 1989). Susceptibility of certain cultivars of *Zea mays* to dicamba, a herbicide which is normally safe, has also been noted (O'Connor, 1996). However, examples of cultivar differences in herbicide tolerance are not common, but the possibility in desmanthus cannot be ruled out.

Herbicides applied in this study to 'Marc' seedlings are expected to behave similarly when they are applied to 'Bayamo' and 'Uman' seedlings. This is because the cultivars are sown at similar times, with similar techniques and show similar development patterns during establishment when most weed control is required. Similarly, cultivar differences are not expected in dormant plants because all cultivars become dormant during the same period (unpublished data). Despite this, extrapolation of herbicide recommendations to 'Bayamo' and 'Uman' should be treated with caution. Testing of a small area before applying a herbicide to the whole crop is recommended.

4.6.5.2 Site Location

The current study was conducted in the Gympie seed growing area. The geography and climate differ to that of Mareeba, the area in which commercial seed production is being conducted (Table 4.34). Of note is low winter rainfall (~18% of total annual rainfall) and low frost risk in the Mareeba environment compared to the Gympie environment (~45% and high frost risk). The rarity of frost in the Mareeba region suggests that the growing season may be extended. This is not expected to affect herbicide recommendations, however, because most weed control should occur during establishment when conditions are similar. Also site differences in rainfall are not expected to affect herbicide action provided herbicide application is conducted in appropriate conditions. Irrigation in seed crops will prevent moisture deficiency problems.

Grass weed species are not expected to be a problem in desmanthus seed crops because most, if not all, should be easily controlled by pre-emergence (e.g. trifluralin) and post-emergence (e.g. haloxyfop) herbicides. However, some grasses (*Vulpia bromoides* and *Festuca rubra*) are not controlled at economical rates by haloxyfop (O'Connor, 1996) leaving the possibility that there are resistant grasses in desmanthus seed crops. If grasses occur which are resistant to both trifluralin and haloxyfop other herbicides used to control grasses in broadleaved crops (particularly legumes) should be considered.

Table 4.34 Geographical and climatic features of the Gympie and Mareeba seed growing districts, Queensland.

Feature	Gympie	Mareeba
latitude (°S)	26	17
elevation (m)	100	400
$LTMT_{coldest\ month}$ (°C)[1]	14	18
$LTMT_{hottest\ month}$ (°C)[2]	25	26
LTAR (mm)[3]	1100	900
LTDSC (mm)[4]	500	160
frost risk	high	low

1 Long term mean temperature during coldest month
2 Long term mean temperature during hottest month
3 Long term mean annual rainfall
4 Long term dry season (April to September) component of annual rainfall (adapted from Hopkinson, 1988)

Of the broadleaved weed species present at the trial site (Table 4.19) only *Cyperus rotundus, Raphanus raphanistrum* and *Sida rhombifolia* are major crop weeds on the Atherton Tableland (Table 4.35). *Anagallis arvensis, Indigofera hirsuta, Ipomoea plebeia* and *Xanthium pungens* are less common crop weeds on the Atherton Tableland (Wilson *et al.*, 1995). Other broadleaved weed species found in crops in North Queensland are listed in Table 4.35. Of the species recognised as major weeds in North Queensland, three are *Sida* species and one of these, *S. rhombifolia*, is a major problem in desmanthus crops (Murat pers. comm., 1995). Imazaquin and imazapic provide pre- and early post-emergence control respectively of *Sida spinosa* (Cyanamid, 1992, 1985) but these chemicals are not available in Queensland. In this study imazethapyr applied pre-emergence controlled sida. Bentazone (0.96 kg ai/ha) also controls young (3 week old) *Sida* plants (Hawton *et al.*, 1990). Thus *Sida* seedlings are expected to be easily controlled. Control of more mature *Sida* plants may be more difficult but should not be required if previous weed management is effective.

Some legumes (e.g. *Neonotonia wightii* and *Crolataria goreensis*) are also recognised as major weeds in North Queensland (Table 4.35) and at least one legume (*Aeschynomene americana*) is also currently a problem in desmanthus crops (Murat pers. comm., 1995). *Neonotonia wightii* is susceptible to bentazone (0.96 kg ai/ha) (Hawton *et al.*, 1990). However *Aeschynomene americana* and *Crolataria goreensis* seedlings are tolerant to bentazone (Hawton *et al.*, 1990). This suggests that some leguminous weeds are unlikely to be selectively controlled post-emergence by the chemicals identified as being safe for use on desmanthus seedlings. These species should be targeted during crop rotation.

Herbicides and other weed control techniques identified in this trial are expected to control seedling grass and broadleaved weeds in desmanthus seed crops in the Gympie and Mareeba seed growing districts.

Table 4.35 **Types and weed status of weeds found in northern Queensland crops.**

Latin name	Common name	Weed status[3]	Life cycle
Acanthospermum hispidum	star burr[2]	major	annual
Anagallis arvensis	scarlet pimpernel[2]	minor	annual
Argemone ochroleuca	Mexican poppy[2]	major	annual
Bidens pilosa	cobbler's pegs[2]	major	annual
Boerhavia dominii	tarvine	minor	annual
Citrullus lanatus	paddy melon	minor	annual
Corchorus olitorius	jute	moderate	annual
Coronopus didymus	bittercress[2]	minor	annual/biennial
Crassocephalum crepidioides	thickhead[2]	moderate	annual
Crotalaria goreensis	gambia pea	major	annual/perennial
Cyperus rotundus	nut grass[2]	major	perennial
Datura ferox	fierce thornapple	moderate	annual
Emex australis	spiny emex[2]	minor	annual/perennial
Euphorbia heterophylla	milkweed	moderate	annual
Flaveria australasica	speedy weed	minor	annual
Galinsoga parviflora	yellow weed	moderate	annual
Hyptis suaveolens	hyptis	major	annual
Indigofera hirsuta	hairy indigo[2]	moderate	annual
Ipomoea hederifolia	bellvine (red)	moderate	annual
Ipomoea plebeia	bellvine[2]	minor	annual
Ipomoea purpurea	morning glory[2]	moderate	annual
Neonotonia wightii	Tinaroo glycine	major	perennial
Nicandra physalodes	apple of Peru	major	annual
Parthenium hysterophorus	parthenium weed	moderate	annual
Physalis minima	wild gooseberry[2]	moderate	annual
Portulaca oleracea	pigweed	major	annual
Raphanus raphanistrum	wild radish	major	annual
Rumex crispus	curled dock[1]	moderate	perennial
Sesbania cannabina	sesbania pea[2]	minor	annual
Sida acuta	spiny-headed sida	major	perennial
Sida cordifolia	flannel weed	major	perennial
Sida rhombifolia	Paddy's lucerne[2]	major	perennial
Sonchus oleraceus	sowthistle[2]	minor	annual
Stachys arvensis	staggerweed	minor	annual
Stellaria media	chickweed	moderate	annual
Trianthema portulacastrum	giant pigweed	moderate	annual
Tribulus terrestris	caltrop	moderate	annual/biennial
Verbena bonariensis	purpletop[2]	minor	perennial
Verbena officinalis	common verbena[2]	minor	perennial
Xanthium pungens	Noogoora burr[2]	moderate	annual

[1] found in winter pasture on Atherton Tableland

[2] also a crop weed in the Burnett region (Gympie region)

[3] based on prevalence and impact on production

(source: Wilson *et al.*, 1995)

4.7 Conclusion

Selective chemicals commonly used in commercial practice (notably trifluralin and bentazone) do not control all problem weeds (particularly other legumes and *Sida* spp.) likely to occur in desmanthus seed crops grown in Queensland and can be damaging (bentazone) to desmanthus seedlings.

An integrated approach to weed control will reduce the need for selective chemical control of weeds during desmanthus crop development. The best method to achieve this is expected to be by crop rotation which targets weeds (notably *Aeschynomene americana*, a problem weed in commercial desmanthus seed crops) not expected to be controlled by selective chemicals. Repeat cultivations or use of a broad spectrum herbicide prior to delayed sowing of desmanthus at rates which ensure a high plant density are also recommended.

Selective herbicides have been identified which are expected to control all other weeds present in desmanthus seed crops in Queensland:

Herbicides which mainly control grass weeds are generally safe for use on desmanthus plants at all growth stages. Imazethapyr, imazaquin, trifluralin and pendimethalin are pre-emergence chemicals which can be safely used to control emerging grasses during crop establishment. Haloxyfop is recommended for post-emergence control of most grasses.

Desmanthus seedlings poorly tolerate many of the selective herbicides used to control broadleaved weeds in other legume crops. Pre-emergence chemicals which are relatively non-damaging to desmanthus and which control many broadleaved weeds found in North and South-East Queensland cropping situations include imazaquin, imazethapyr, trifluralin and pendimethalin, the latter two requiring soil incorporation. Post-emergence chemicals recommended for control of broadleaved weeds in desmanthus seed crops in the first growing season include bentazone, bromoxynil and imazethapyr. Inappropriate weed control spectra (e.g. asulam) and unavailability in Australia (e.g. clethodim and imazapic), of some other

selective post-emergence chemicals restricts their use despite evidence that these chemicals are non-damaging to desmanthus seedlings.

Pre-emergence application of imazaquin provided the best weed control in this study and was non-damaging to desmanthus. Unfortunately this chemical is not available in Australia. Evaluation of other imidazolenone herbicides which become available in Australia in the future is recommended.

Most desmanthus will be grown as annual crops because of poor regrowth in the second season eliminating the need to control mature weeds in desmanthus seed crops. Most (mainly broad-spectrum) chemicals which controlled mature weeds were damaging to one year old desmanthus and those which were least damaging (acifluorfen, atrazine, ethofumesate and paraquat) to desmanthus did not control mature weeds.

Seed production is not expected to be affected by the use of the chemicals identified as being safe for use on establishing desmanthus if used as in this trial. The exception is bentazone which may decrease flowering in desmanthus when applied during flowering.

Herbicide recommendations for the control of weeds in establishing 'Marc' seed crops are expected to apply to the other cultivars (cvs. 'Bayamo' and 'Uman') released in Queensland. Extrapolation of results from the South-East to North Queensland environments is not expected to affect herbicide recommendations.

Restrictions on the use of 'off-label' use of chemicals in Queensland mean that, unless registered in future, most chemicals recommended cannot be legally used on desmanthus seed crops. However, in Australia these restrictions are often ignored and are therefore not expected to influence adoption of the chemicals recommended for use in desmanthus seed crops.

CHAPTER FIVE

THE EFFECTS OF PRE-HARVEST TREATMENT AND HARVESTING TECHNIQUE ON PRESENTATION AND RECOVERED YIELDS OF EARLY AND LATE FLOWERING DESMANTHUS CULTIVARS

5.1 Introduction

5.1.1 HARVEST INEFFICIENCIES IN DESMANTHUS SEED PRODUCTION

Harvest recovery of presented seed in tropical herbage seed crops is typically poor (Humphreys and Riveros, 1986). In many tropical herbage species poor synchronisation of flowering and / or uneven ripening of seed on individual inflorescences results in a low proportion of total seed produced being present at one time. Rapid shedding of ripe seed often increases this problem. In forage legumes the high proportion of vegetative matter relative to seed may also reduce the efficiency of seed separation and hence seed recovery (Humphries and Riveros, 1986).

In Chapter 3 it was demonstrated that 'Marc' has the ability to produce high (up to 1400+ kg/ha) potential seed yields over a range of population densities. However, because of its indeterminancy, seed maturation occurred over a prolonged period limiting the potential effectiveness of a single pass harvest. Susceptibility to pod dehiscence in 'Marc' exacerbates this problem. Although losses during harvest have not been previously measured, high numbers of seed are present in and on the soil after combine harvesting (Murat pers. comm., 1995). Also, 30% + gains in seed yield have been achieved by vacuum harvesting fallen seed after combine harvesting (Hopkinson pers. comm., 1995).

The longer flowering period of 'Marc' compared to 'Bayamo' and 'Uman' means that less 'Marc' seed is likely to be recovered using conventional harvesting techniques (combine harvesting). The flowering period of 'Bayamo' and 'Uman' is greater than two months (unpublished data), however, indicating that there is some potential to increase recovery through improved pre-harvest treatments and / or harvesting technique in these

cultivars. Cultivar differences in ease of pod dehiscence have not been documented suggesting it might be possible to improve harvest recovery in late-flowering cultivars by improving seed retention in the pod.

There is a need therefore to investigate methods which will increase the proportion of seed recovered during harvest. This can be achieved for single pass, destructive harvest systems by:

(a) reducing the flowering, and therefore the presentation, period

(b) reducing losses due to pod dehiscence.

Alternatively, or in combination with the above, harvesting techniques (e.g. multiple pass systems or those which collect fallen seed) which better recover the seed present can be used. A number of pre-harvest treatments and harvesting techniques have been trialed on herbage seed crops, many of which have similar obstacles to efficient seed recovery as occur in 'Marc' desmanthus. These are discussed below with emphasis on seed recovery, rather than seed presentation.

5.1.2 PRE-HARVEST TREATMENTS USED TO INCREASE HARVEST EFFICIENCY

Pre-harvest treatments include any manipulation to the seed crop between establishment and harvest. Such treatments have the potential to affect pre-harvest seed yields by influencing:

(a) potential seed yield (PSY), and

(b) the efficiency of conversion of PSY to presentation yield.

5.1.2.1 Use of Plant Growth Regulators (PGR)

Plant growth regulators have been used to improve characteristics of cereal, fruit and vegetable crops and ornamental plants (O'Connor, 1994). Use of PGR to enhance recovered seed yield in herbage species is more widespread in grasses than legumes.

Grasses

Plant growth regulators have been predominantly used in grass seed crops to prevent lodging associated with the high fertiliser N applications used to promote tillering and therefore increase seed yield (Albeke *et al.*, 1983). Early trialwork on commercially released products found that chlormequat (CCC) (Bochniarz *et al.*, 1983 as cited by Hampton, 1988b) and paclobutrazol (PCB) (Hampton, *et al.*, 1983; Hampton and Hebblethwaite, 1983; Albeke *et al.*, 1983; Hampton and Hebblethwaite, 1985a) (both gibberellic acid biosynthesis inhibitors (Hedden, 1990 as cited by Budhianto *et al.*, 1994a)) reduced or delayed lodging in a variety of temperate herbage grass species, principally by reducing internode elongation. Results have not always been consistent however with increased seed yields due to CCC application not always being associated with lodging control (Hampton, 1986).

Decreased lodging in paclobutrazol (PCB) treated *Lolium perenne* has been associated with increased seed numbers per spikelet (Hampton and Hebblethwaite, 1985b), and increased numbers of fertile tillers which increased seed yields (Young *et al.*, 1995; Hampton, 1986; Hampton and Hebblethwaite, 1985a; Hebblethwaite *et al.*, 1985). The fungicidal properties of PCB has been shown to reduce the rate of leaf senescence in *Lolium perenne* (Hampton and Hebblethwaite, 1985a). It has been suggested (Hampton and Hebblethwaite, 1985a) that gains in assimilate due to lodging prevention in PCB-treated *Lolium perenne* seed crops contribute to decreased seed abortion (Hampton and Hebblethwaite, 1985a). More recent work (Martins and Gamble, 1993a) investigating floret dynamics in *Lolium perenne* seed crops found that seed abortion occurs rapidly (within 2 days) after anthesis and that PCB application reduces abortion rates although significant PGR X rate X developmental stage interactions occurred.

Although PCB and CCC are apparently useful in many species, responses of herbage grasses to CCC (Humphreys and Riveros, 1986) and PCB (Ehlke, 1992; Albeke *et al.*, 1983) have been variable with decreases in seed yield being reported in some species exposed to these chemicals.

A number of other PGRs have been evaluated on forage grasses but have been less effective than PCB at decreasing lodging (e.g. XE1019, Martins and Gamble, 1993a, 1993b; and ethephon, Martins and Gamble, 1993b), have not increased seed yields (e.g. flurprimidol, Hebblethwaite *et al.*, 1985) or have been too expensive for commercial use in herbage crops (e.g. ancimydol, Wright and Hebblethwaite, 1979).

Legumes

Many forage legumes have indeterminate (apical dominant) growth habits resulting in prolonged flowering periods and are often 'bulky' to harvest (Humphreys and Riveros, 1986). It is plausible therefore that growth regulating substances, particularly gibberellic acid biosynthesis inhibitors which reduce apical dominance, could increase seed yields and ease of harvest as they do in many grass species.

Early investigations into the effects of PGR on temperate forage legume seed yields and seed yield components have found that a variety of substances increased inflorescence number per unit area (daminozide on *Trifolium pratense*, Puri and Laidlaw, 1983) or retention of inflorescences (NAA in *Medicago sativa*, Yadava *et al.*, 1984 as cited by Hampton, 1988b) and therefore increased seed yields. Early investigations into PGR use on indeterminate tropical herbage legumes proved less successful with poor transfer of promising results to field conditions (TIBA on *Macroptilium atropurpureum* and *Neonotonia wightii*, Edey and Byth, 1970) and with seasonal effects interfering with results (ethrel and CCC on *Centrosema pubescens*, Stobbs, 1973).

Recent research examining the effects of PCB, triapenthenol (Budhianto *et al.*, 1994a, 1994b; Boelt and Nordesgaard, 1993; Rijckaert, 1991), ethephon (Boelt and Nordestgaard, 1993), daminozide (Budhianto *et al.*, 1994a, 1994b; Boelt and Nordestgaard, 1993), tebuconazol (Boelt and Nordestgaard, 1993), cerone (Marshall and Hides, 1986) and CCC (Budhianto *et al.*, 1994a, 1994b; Marshall and Hides, 1986) on seed yield in *Trifolium repens* found that PCB is generally superior to other chemicals (Budhianto *et al.*, 1994a, 1994b; Boelt and Nordestgaard, 1993; Rijckaert, 1991). Although PCB has substantially increased (up to 271% under Belgian climatic

conditions, Rijckaert, 1991) *T. repens* seed yields, results have often been inconsistent with strong seasonal effects (Boelt and Nordestgaard, 1993).

In trialwork, PCB has been applied to *T. repens* during early reproductive development (when first green flower buds are present (Budhianto *et al.*, 1994a, 1994b; Rijckaert, 1991) or shortly after defoliation (Marshall and Hides, 1991a, 1991b)) and at rates between 0.25 and 1.0 kg ai/ha (Budhianto *et al.*, 1994a, 1994b; Marshall and Hides, 1991a, 1991b; Rijckaert, 1991). In *T. repens* inflorescences arise from reproductive nodes located on the stolon. Certainly PCB application has been shown to reduce stolon length but can also have varying effects on reproductive sites per stolon (Marshall and Hides, 1989). Although PCB effects on the number and ratio of axillary buds and reproductive nodes per stolon are inconsistent, axillary buds, growing points and total nodes per m^2 are increased as a result of PCB effects on stolon length (Budhianto *et al.*, 1991a; Marshall and Hides, 1991a, 1991b, 1989). This provides a greater number of sites (nodes) per m^2 for inflorescence development and, because PCB does not interfere with the intermittent pattern of flowering along the stolon, results in increased inflorescences per m^2 (Marshall and Hides 1991a, 1991b, 1989). This results in increased numbers of harvestable inflorescences and improved potential seed yield (Budhianto *et al.*, 1994b; Marshall and Hides, 1991b).

Increased seed weight, numbers of seed per inflorescence and (in one season of two) increased seed set per floret have also improved potential seed yield in PCB treated *T. repens* plants (Marshall and Hides, 1991b). However, consistent relationships between seed yield responses to PCB application and seed yield components other than inflorescence number have not always occurred in this species (Budhianto *et al.*, 1994b; Rijckaert, 1991).

The other consistent effect of PCB application is a reduction in canopy height through decreasing internode (Marshall and Hides, 1989) and petiole length (Budhianto *et al.*, 1994a) with little effect on peduncle height (Budhianto *et al.*, 1994a; Marshall and Hides, 1991a; Rijckaert, 1991). This elevates the inflorescences above the canopy and may make it more attractive to pollinators. Increased seed set has been observed (Boelt and

Nordestgaard, 1993) in some PCB treated plants but not in others (Marshall and Hides, 1989) and there is some debate as to whether increased pollination is responsible for higher levels of seed set.

Paclobutrazol has been reported to increase germination performance of *T. repens* seed (Marshall and Hides, 1991b) but there is little supporting literature for this result (Rijckaert, 1991).

Considerably less work has been conducted on PCB effects on herbage legumes with similar habits to ('Marc') desmanthus i.e. prolonged flowering period and ready seed loss through pod dehiscence. Studies with *Lotus corniculatus* and *L. uliginosus* have found that PCB applied when reproductive nodes are visible produces a greater increase in seed yield in both species than when applied at reproductive node initiation (Hampton *et al.*, 1989). Application rates of 0.5 or 1.0 kg ai/ha provide similar yield responses in this species. Paclobutrazol application increases inflorescence number per m^2 (presumably through increased branching) and decreases flowering spread. Yield increases are due to increased pods per m^2 and seeds per pod. Another benefit is reduced crop height and the prevention of lodging, a problem often encountered in *Lotus* spp. seed crops (Hare, 1985). A later investigation (Tabora and Hill, 1992) into the effects of PCB using similar rates but some different application times (50 to 60 days before flowering, floral bud primordia appearance and the onset of flowering) on *L. uliginosus* cv. 'Grasslands Maku' resulted in increased numbers of reproductive main shoots and primary lateral shoots which later became reproductive. These contributed to increased inflorescence density and seed yield. This effect was greatest at the latter two application times. As in previous trials reduction in internode length resulted in a contracted flowering period (early application), decreased plant height and total dry matter.

Similar seed yield and seed yield component responses have been reported (Askarian *et al.*, 1994) in first year *Medicago sativa* plants treated with PCB during vegetative growth. Application at first flower bud appearance in the first, and during vegetative growth in the second, year decreased seed yield, however. Again, however, treatment differences in branching and inflorescence number per unit area contributed most to

treatment differences in seed yield. Lower pod abortion (per umbel) after anthesis in PCB treated plants also improved seed yield.

Similarity in growth habit between *Lotus* spp., *Medicago sativa* and *D. virgatus* suggests that application of PCB to the latter species may improve harvested seed yields particularly by increasing branch and inflorescence numbers per unit area and possibly by contracting of the flowering period. In addition, it is possible that plant bulk at harvest may be reduced resulting in increased threshing efficiency.

5.1.2.2 Use of Water Soluble Adhesives

Dehiscence of 'Marc' pods decreases the amount of seed presented for harvest by single or multiple harvest techniques and is a particular problem for combine harvesting, the standard technique for recovering desmanthus seed. Decreasing pod dehiscence and increasing seed retention in the pod after pod opening would increase seed presentation at harvest resulting in higher yields. Water soluble glues (polyvinylacetate (PVA)), sprayed onto seed crops during late seed development, have been found to successfully reduce losses associated with pod dehiscence in carrots and onions (Williams, 1978). Testing of glues on herbage seed crops has been limited to a few grasses and results have been variable. Spraying PVA onto seedheads shortly before seed maturity increased seed retention in *Phalaris tuberosa* (McWilliam and Schroeder, 1974) and *Chloris gayana* (Loch and Harvey, 1983). However, no improvement in seed retention occurred when a water-soluble acrylic glaze was applied to *Setaria sphacelata* var. *sericea* (Loch and Harvey, 1983), a result attributed to limited penetration into the seedhead.

It is feasible that the application of penetrative, quick-setting adhesives such as PVA could increase harvest recovery in desmanthus seed crops by increasing seed presented for single or multiple pass harvesting.

5.1.2.3 Pre-harvest Chemical Desiccant Application

In many forage legumes, the high proportion of vegetative matter relative to seed (i.e. low harvest index) reduces harvest efficiency (Hopkinson and Clifford, 1993). Defoliation of the crop can reduce vegetative bulk at harvest (Hampton, 1988b). One method of achieving this is by spraying the crop with a desiccating chemical shortly before harvest.

Chemicals with strong and rapid foliar contact action are most appropriate because they minimise possible herbicide effects on the seed and facilitate harvest shortly after application. Non-selective action is advantageous because it provides the opportunity to also control weeds while desiccating the crop. Diquat is the most commonly used chemical for desiccation in herbage seed crops although paraquat, glufosinate and glyphosate have also been evaluated. These latter chemicals all have disadvantages compared to diquat: glufosinate is slower acting than diquat (Moyer *et al.*, 1996); paraquat is less effective at desiccating many broadleaved species (O'Connor, 1994); glyphosate is slower acting and is translocated more readily in the plant (O'Connor, 1994) providing more risk of seed damage.

Diquat is registered for pre-harvest weed and crop desiccation in cereals and in legumes including *Pisum*, *Vicia* and *Trifolium* spp. (O'Connor, 1994). Diquat will defoliate most actively growing broadleaved species within 7 days of application although some grasses are tolerant at recommended rates. Translocation is rare (although it may apparently occur at very low light intensities) and seed quality of legumes is generally not affected by diquat application although decreased germination rate in some herbage grasses has been reported (Roberts and Griffiths, 1973).

Investigation into the use of diquat as a desiccant for improving harvestability in forage legume crops other than *Trifolium* spp. is limited to *Medicago sativa* (Moyer *et al.*, 1996; Sedivy, 1987). Like desmanthus, this species has obstacles to high harvesting efficiency, including small seed combined with a high vegetative bulk and a protracted flowering period. Benefits of desiccation are to decrease bulk at harvest and to facilitate

premature abscission of late developing seed making this seed harvestable. Timing of desiccation in *M. sativa* is important. If desiccation occurs too early (when less than 20% of pods present are brown) seed yield, quality and weight can all be decreased. Alternatively, delayed desiccation can promote pod dehiscence and therefore loss of seed yield. Desiccation when 60 to 75% of seed pods are brown permits maximum seed yield (Moyer *et al.*, 1996). Rate of diquat application is clearly a consideration as it affects the cost of production. Seasonal effects on optimum rates of diquat needed to desiccate *M. sativa* have been reported. These relate to the productivity of a crop in a particular season. For example, although rates of less than 0.7 kg ai/ha have effectively desiccated *M. sativa* plants (Moyer *et al.*, 1996; Sedivy, 1987), plants exhibiting high growth rates (and therefore high vegetative mass present at time of desiccation) have required up to 2.0 kg ai/ha for effective desiccation (Sedivy, 1987).

It appears likely that the use of a desiccant such as diquat will facilitate easier combine harvesting of desmanthus seed crops by reducing vegetative bulk. Just as importantly, however, desiccation might increase harvestable yields by prematurely 'browning off' late developing pods thus making them available for harvest.

5.1.3 TIMING OF HARVEST

The optimum time to harvest herbage seed crops is often difficult to determine and harvested seed yields may be substantially reduced by poor harvest timing (Hampton, 1988b).

Optimum harvest date of herbage grasses is species specific (Hampton, 1988b) and must be made with regard to seed moisture content (Andrade *et al.*, 1994), ease of pod dehiscence and related economies such as costs of drying seed for safe storage (Simon, 1987).

In herbage legume seed crops peak presentation time is dictated by flowering spread, changes in rate of pod development and the degree of pod dehiscence. Thus in single pass, destructive harvest systems (e.g. combine harvester) a 'harvest window' which

coincides with maximum presentation of mature seed must be identified to maximise seed recovery. In strongly determinate species, this is reasonably easy to determine because the bulk of seed in the crop is maturing at the same time. In indeterminate species, or in those determinate species with extended flowering periods, identification of the harvest window is more difficult and is often confounded by changes in seed quality (seed weight and germination performance) as well as yield. For example, the optimum time to harvest *Lotus uliginosus* cv. 'Grasslands Maku' has been identified (Hare and Lucas, 1984) as 2 to 4 days after seed maturity when seed moisture content is 35%, pods are light brown and the first visible signs of pod dehiscence have occurred.

There is a need to identify the optimum time of harvest in desmanthus seed crops, particularly in the early flowering cultivar 'Marc'. Cues which consistently identify the 'harvest window' and which can be easily used in combine harvesting systems need to be identified.

5.1.4 FORAGE LEGUME HARVESTING TECHNIQUES

Seed harvesting techniques are influenced by the demographic situation in which the crops are located, the crop type and the availability of harvesting technologies to seed growers. The cost of labour ultimately dictates the type of harvest system used and, at this level, harvest systems can be divided into 'hand' and 'mechanical' types. In temperate countries the cost of labour is typically high and seed crops are harvested by mechanical means (Hopkinson and Clifford, 1993). In most sub-tropical and tropical countries (except Australia and Brazil), labour costs are low (often seed being produced by the immediate family) and most seed is harvested by hand (Hopkinson and Clifford, 1993; Kowithayakorn and Phaikaew, 1993).

5.1.4.1 Harvesting by Hand

Land areas of individual seed crops in tropical countries are typically small relative to their temperate counterparts. This, combined with cheap labour, means that seed can be harvested by labour intensive methods. As these methods do not apply to Australian

herbage seed production, they will not be reviewed further. The reader is referred to Kowithayakorn and Phaikaew (1993) for further information on this topic.

5.1.4.2 Mechanical Harvesting

Hopkinson and Clifford (1993) provide a comprehensive review of the history of mechanical harvesting systems used in Australian herbage seed production and the reader is referred to this for historical information. Of note is that the 'wild type' characteristics (indeterminance, ready pod dehiscence and seed dormancy mechanisms) required for the end use of herbage seed has meant that emphasis has been on developing harvesting technology rather than breeding for ease of harvest. Innovations have mainly involved adaptation of technologies used in other agricultural areas, particularly the combine harvester.

Single pass harvest systems

Single pass, destructive or 'header' harvesting for many herbage grass and legume crops is conducted using a combine harvester where cutting, threshing and much of the seed cleaning occurs in the field. Processes used in combine harvesting of seed crops are represented in Figure 5.1. Losses of seed during harvest by a 'combine' or 'header' can be considerable, particularly during cutting although large losses can also occur during threshing and sieving if the harvester is poorly set up for a particular crop (Hopkinson and Clifford, 1993).

Because combine harvesters were originally designed to harvest cereals, they are less effective for harvesting many smaller seeded herbage species which often contain large masses of moist green material at harvest. A variety of options are available prior to threshing to improve combining efficiency. Crops can be cut prior to harvest and allowed to dry. This reduces moist vegetation mass and allows some seed maturation in the swath. A similar effect can also be achieved by pre-harvest crop desiccation (Section 5.1.2.3).

Threshing is conducted by rubbing seed between a slotted concave and a rotating drum, which is often modified to suit certain species. Threshing efficiency is affected by drum speed and the clearance between the drum and the concave. If threshing is too soft, seed recovery will be poor; too hard and seed will be damaged (Millar, 1988 as cited by Hopkinson and Clifford, 1993).

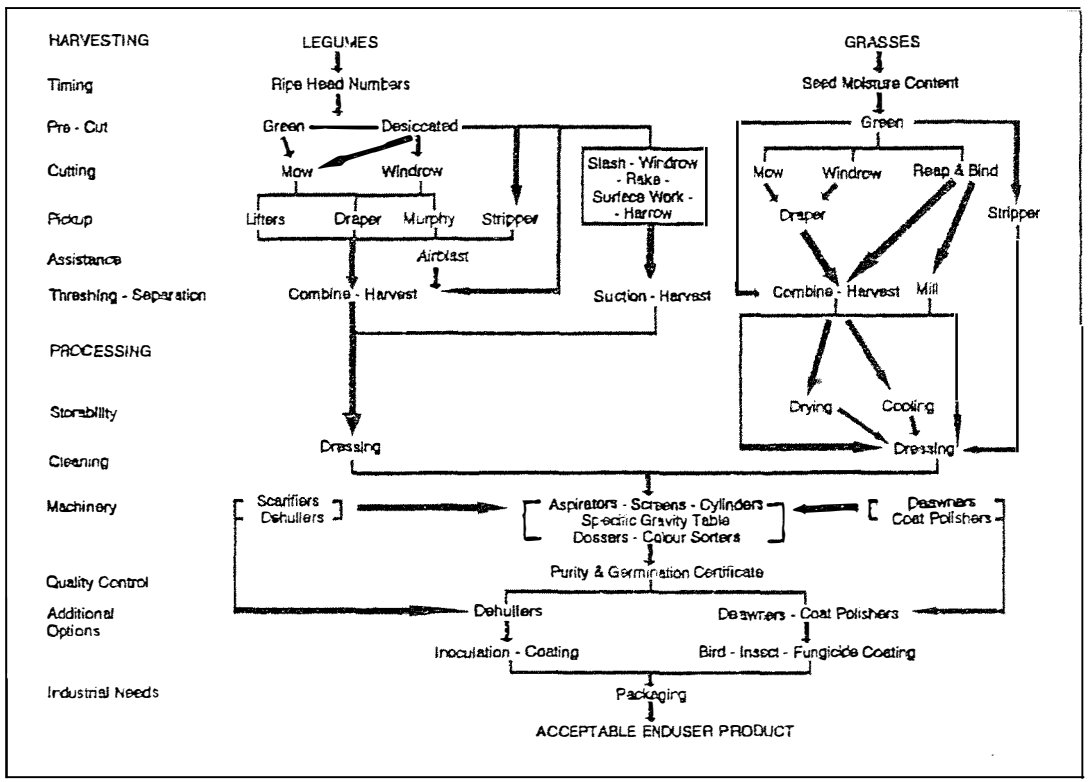
Changes to combine harvesters have generally been beneficial to herbage seed growers. Increased capacity to process material (when combined with small pickup fronts) and hydrostatic drive to the ground wheels allowing slower forward travel speed have increased the ability to efficiently process bulky crops. Axial flow drums have also increased threshing capabilities. Despite these improvements, combine harvesting is often far from satisfactory, requiring synchronised development, a level site and freedom from weeds. Combine harvested crops are often heat or pathogen damaged after swathing and retrieved yield inevitably contains various amounts of immature and poor quality crop seed as well as other crop seeds (Hopkinson and Clifford, 1993).

Multiple pass harvest systems

Harvesting techniques which are multiple and non-destructive have mainly been used on tropical grasses and include brush and beater systems. The former involves the stripping of seed of (mostly) chaffy grasses by an upward stroke of a rotating brush. This is a slow process because the harvester typically has a narrow (2.5 m) harvesting width (Jensen *et al.*, 1993). However, improvements are continually being made to brush harvesters to increase seed yields, reduce damage to seed (Dewald *et al.*, 1993; Wilden *et al.*, 1993) and make them more adaptable to use with standard farm equipment (Dewald *et al.*, 1993).

Beater systems are used to retrieve seed from grasses which loosely retain seed in the seedhead (e.g. *Cenchrus ciliaris*). Seed and attached material is gently beaten by a downward stroke and is directed onto a collecting platform from which it is elevated to a bin. Seed collected by both of these systems tends to be of high quality and good yields can be achieved by virtue of multiple passes (Hopkinson and Clifford, 1993).

Figure 5.1 **Pre-harvest, harvest and cleaning procedures used in tropical forage seed crops.**



(Source: Hopkinson and Clifford, 1993)

Recovery of fallen seed

An alternative to collecting seed at a particular and often very precise time in crop development is allow all pods to dehisce and to collect fallen seed from the ground at the end of the season. Vacuum, or pneumatic, recovery of fallen seed has been used successfully in herbage species, particularly tropical legumes (*Stylosanthes* spp., *Macroptilium atropurpureum* and *Cassia rotundifolia*) (Hopkinson and Vicary, 1974). Disadvantages include the requirement of a hard, level soil surface, treating crops as annuals (mostly) and difficulty of seed cleaning. Benefits, however include high seed yields of high quality because seeds have been allowed to fully mature (Hopkinson and Clifford, 1993).

5.1.5 OBJECTIVES AND TRIAL DESIGN

The objectives of this trial were to:

(a) evaluate the effectiveness of three different pre-harvest techniques (plant growth regulator, water soluble adhesive and chemical desiccation) for increasing presentation seed yields after combine harvesting

(b) compare the harvesting efficiency of differing harvest strategies

(c) document the development of seed yield in 'Marc' by tagging and determining individual inflorescence fate and performance

(d) monitor the development of seed yield in a late flowering desmanthus cultivar ('Bayamo') to determine whether management of the seed crop should be similar to 'Marc'.

Cultivar 'Marc' was included because it has the greatest obstacles to seed production (most extended flowering period and pods dehisce readily) and because it originated from higher latitudes than the other cultivars (Section 2.1.4.2). This suggested that 'Marc' was better suited to conditions at the trial site. 'Bayamo' and 'Uman' are more similar to each other in flowering response (short-day flowering) and plant canopy structure (canopy height) than to 'Marc'. Because of this, it was decided to include only one of these later season flowering desmanthus cultivars in order to increase replication and reduce treatment numbers providing more time for detailed monitoring of treatments. The choice of the late season cultivar was based on likely site suitability. Because the trial site (Brian Pastures Research Station, Gayndah) typically receives a few frosts each winter, the earlier flowering 'Bayamo' was chosen over 'Uman' to reduce the possible risk of seed damage due to frost.

Pre-harvest treatments included;

(a) Plant Growth Regulator (PGR) application

One PGR (paclobutrazol) was included because this chemical has been shown to increase harvestable seed yields in other herbage legumes (Section 5.1.2.1). Paclobutrazol has also been shown to be effective at manipulating development in other forage legumes with similar growth habits and obstacles to seed production to those found in

desmanthus. Greater documentation on the use of paclobutrazol on forage legume seed crops compared to other PGR meant that most likely effective application rates and timing was easier to predict.

(b) Glue spraying

Although trialwork with water soluble glue application has been largely limited to grass and vegetable seed crops (Section 5.1.2.2) it was considered that the use of an adhesive substance to decrease pod dehiscence and seed shed had potential to increase harvestable seed yield in desmanthus, particularly in 'Marc'. The glue chosen (Agropol 63029) was a PVA type because of the success of similar glues in other herbage species (Section 5.1.2.2). Similar dilution and application techniques were used to those previously used with this glue by Williams (1978). Although 'Marc' has an extended flowering period, most of the seed presented for harvest arises from peak flowering (Section 3.3.3). This suggested an optimum glue application time coincident with the maturation of seed arising from peak flowering would be likely to most effectively increase retention of seed produced just prior to peak presentation.

(c) Desiccant spraying

Seed pods in desmanthus are located within, rather than above, the vegetative canopy. Thus, harvest by combine harvester requires that considerable amounts of vegetative matter are processed which can lead to recovery inefficiencies (Section 5.1.2.3). Chemical desiccation of the crop was evaluated to determine whether recovery could be improved if the vegetative bulk was decreased. Diquat (Reglone) was used as it is widely used as a desiccant and there is an abundance of literature from which suitable application rates and times can be determined (Section 5.1.2.3).

Seed in all pre-harvest treatments was combine harvested as is standard practice in desmanthus seed crops (Murat pers. comm., 1995). Comparison was also made between harvest techniques (combine harvester and a stripper harvester) which had no pre-harvest treatment. Fallen seed was collected to determine the potential for vacuum harvesting of an entire seasons crop.

5.2 Materials and Methods

5.2.1 DESIGN

A randomised block design of eleven treatments and four replicates was used (Figure 5.2). Pre-harvest and harvest treatments were applied in a manner which allowed comparison between pre-harvest (followed by combine harvesting) and harvest treatment combinations (no prior pre-harvest treatment) while minimising overall treatment number (Table 5.1). Each plot measured 3 m X 25 m and blocks were sown north-south across a western facing slope (Figure 5.2).

5.2.2 CROP MANAGEMENT

The trial was located at Brian Pastures Research Station (25°39' south; 151°, 45' east), near Gayndah, South-East Queensland. The soil type was a moderately to strongly self-mulching brown clay with a surface pH of 6.0 to 7.0 and increasing alkalinity with increasing depth reaching 8.5 to 9.0 1 m below the surface. Prior to 1991 the site had been open woodland (*Eucalyptus* spp.) containing native grass species (*Andropogon* spp. and *Bothriochloa* spp.). Since then the site has contained a mixture of crop legume species and pasture. Soil test results (Appendix 5.1) showed the site had adequate nutrients for desmanthus production. Total P content was noticeably high which should promote both legume growth and nodulation.

Site preparation involved herbicide spraying (glyphosate @ 2.16 l ai/ha) of existing weeds and a 3 week fallow prior to rotary cultivation to a depth of 20 cm. Rotary cultivations repeated twice at weekly intervals effectively removed emerging weeds and provided a friable, aerated seedbed. Trifluralin (Treflan) was applied at 1.2 kg ai/ha and incorporated by rotary cultivation to a depth of 10 cm immediately prior to sowing.

Figure 5.2 **Harvest trial layout at Brian Pastures Research Station, near Gayndah, South-East Queensland, 1995/1996.**

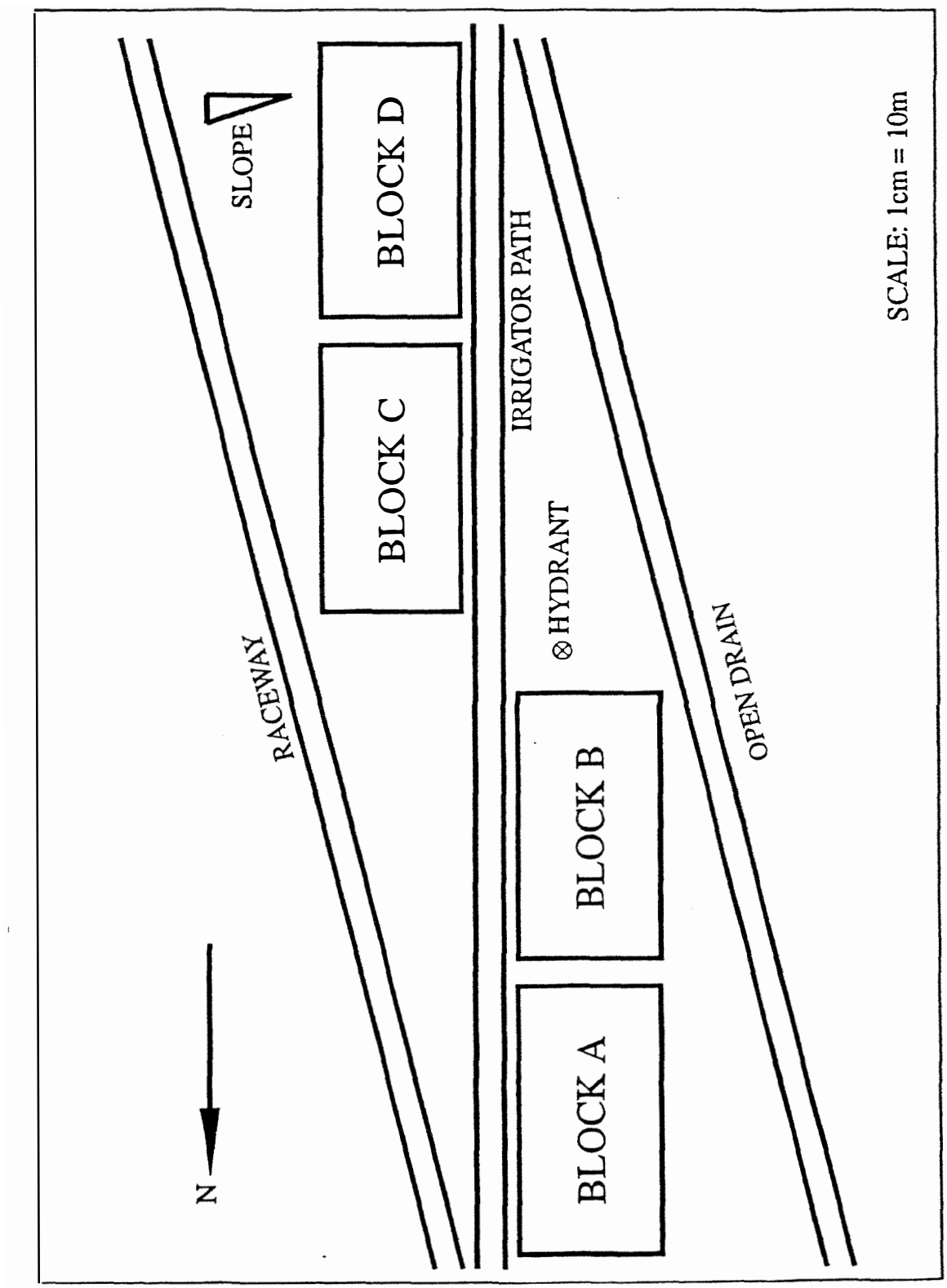


Table 5.1 **Application details of pre-harvest and harvest treatments on *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' grown at Gayndah, South-East Queensland, 1995/1996.**

Treatment number	Treatment type	Pre-harvest treatments		Harvest treatments	
		Date applied	Stage of crop development	Harvest date	Stage of crop development
'Marc'					
0	none/none	-	-	-	-
1	none/combine	-	-	29 April	> all 'Marc':
2	PGR[1]/combine	11 April	peak flowering	29 April	> mature crop,
3	desiccant[2]/combine	18 April	active flowering	29 April	> flowering
4	none/keyhole	-	-	29 April	> virtually
5	glue/[3]combine	18 April	active flowering	29 April	> finished
'Bayamo'					
6	none/none	-	-	-	-
7	PGR[1]/combine	20 May	peak flowering	1 August	> all 'Bayamo':
8	none/keyhole	-	-	1 August	> 10 days after
9	desiccant[2]/combine	n/a[4]	n/a[4]	1 August	> severe
10	none/combine	-	-	1 August	> frosting

[1] Paclobutrazol (Cultar) @ 1.0 kg ai/ha
[2] Diquat (Reglone) @ 0.8 kg ai/ha + Agral600 @ 200 ml/100 l water
[3] PVA (Agropol 63029) @ 133 l product/ha + water at 1:10
[4] Not applied due to frost damage

'Marc' and 'Bayamo' seed was scarified (Appendix 3.2) and inoculated (Appendix 3.2) within 24 hours of sowing. Germination tests (Appendix 3.2) of scarified 'Marc' and 'Bayamo' seed showed normal germination of 83% and 88% respectively. Seed was sown (18 December 1995) within 24 hours of inoculation using a 4 row (rows 45 cm apart) cone seeder and sowing 7 rows per plot down the slope. Planting depth was 0.5 to 1.0 cm and sowing rate sufficient to provide a population of approximately 80 plants/m^2 (assuming normal germination rates were realised under field conditions). Conditions at the time of sowing were hot (35°C) and humid and 9 mm of storm rainfall fell immediately after sowing. Storm rainfall in the 2 weeks after sowing resulted in poor emergence because seed was either washed away or covered too deeply. More seed was

scarified and inoculated and seed resown by hand into the existing rows on 18 January 1996. This seed established effectively and plants grew vigorously (Plate 5.1).

Weed control with trifluralin was effective in the first 4 weeks after which time bentazone (Basagran) was applied at a rate of 0.96 kg ai /ha. There was no need for further chemical weed control and any emerging weeds were removed by hand. Rainfall was supplemented by night time irrigation at rates sufficient to prevent wilting (Appendix 5.2). Two applications (26 March and 9 April) of dimethoate (0.03 kg ai/100 l water and soaking leaves until runoff) were required to control psyllid (*Acizzia* sp.). Psyllid presence was identified early and control was rapid and effective.

Heavy frosting in mid-July (Appendix 5.2) resulted in a cessation of flowering and necrosis of leaves and stem tips. This trial was monitored for a further month after frosting to measure its effects (e.g. potential for regrowth) and only casually monitored thereafter.

5.2.3 APPLICATION OF PRE-HARVEST AND HARVEST TREATMENTS

Details of the pre-harvest and harvest treatments are listed in Table 5.1. Paclobutrazol and diquat were applied to investigate the possibility of chemically increasing harvestable presentation yield whereas the glue was applied to reduce losses associated with pod dehiscence by influencing the time mature seed was held in the pod. All three treatments were applied to 'Marc'. Losses through ready pod dehiscence are not a problem in 'Bayamo' however and no glue treatment was used on this cultivar.

Seed development in 'Marc' was virtually complete before frosts began but frosting did occur during late season flowering (~60 days after peak flowering) of 'Bayamo' causing immediate cessation of flowering and pod development and abscission of leaves. Abscission of leaves by frosting meant that application of diquat was pointless and it was omitted from the trial for this cultivar.

Conditions at the time of paclobutrazol application to 'Marc' were fine and the recently irrigated soil was moist. Clear, warm (25°C) conditions were experienced when diquat, the glue and the paclobutrazol (to 'Bayamo') was applied.

Harvesting of 'Marc' treatments by combine or keyhole thresher (29 April) was completed in warm (20°C), overcast conditions after rain had delayed harvest from the optimum harvest date by five days. The combine harvester was a small plot model (1.75 m cutter bar) (Plate 5.2) and was set to specifications (no fan; concave set to minimum clearance; drum speed = 900 to 1000 rpm) used in the harvesting of *Stylosanthes* sp., a plant which presents its small seed similarly to desmanthus. A 20 m strip down the centre of each 'combine' plot was harvested to a height of 10 cm above the ground. No pods were observed below approximately 40 cm above ground level in either 'Bayamo' or 'Marc' plots. The combine harvesting was effective with no visible seed in threshed trash.

The harvested material was transported to Gympie and emptied into ventilated trays and left under rotating ceiling fans to dry slowly. The field sample was leafy and required cleaning: firstly through a 1 cm hand sieve to remove large trash, which was kept aside. The sieved fraction containing the seed was then passed slowly through a winnower to reduce the bulk by removing very light material before being passed through a small experimental screen cleaner (Bodington - 3 mm and 1.15 mm top and bottom screens respectively with air one third on). The trash which had been kept aside was passed through a 'peg-drum' which vigorously beat pods and collected all matter < 5 mm in diameter. This was then passed through the winnower and the screen cleaner as above. Seed collected from the screen cleaner was in two fractions: generally well developed and therefore 'heavy' seed which was collected through the screens and undeveloped and light seed which was collected by blowing off the screens by the fan. Four fractions of seed were therefore collected per harvested plot. These were all weighed for yield separately and sub-sampled for quality analysis for standard germination (Appendix 3.2), hardseededness (Appendix 3.2) and thousand seed weight (Appendix 3.2). This process was conducted for both 'Marc' and 'Bayamo' seed in late August 1996.

Plate 5.1 **Plots of *Desmanthus virgatus* cvs. 'Marc' (left) and 'Bayamo' (right) during active reproductive and vegetative growth respectively (10 March 1996).**

The keyhole thresher consisted of a modified brush harvester of the front-end-loader mounted type but having firm, rubber 'teeth' mounted on the revolving cylinder instead of a 'brush' (Plate 5.2). The cylinder rotated to lift plant material from the base and therefore strip the plant of pods, leaf etc. Stripped material was then collected in a tray. The thresher was powered by a 2 hp Briggs and Stratton motor connected to the cylinder by belts which effectively acted as the clutch. The 'front' of the keyhole harvester measured 1.8 m. During harvest the keyhole thresher was lowered to approximately 20 cm above the ground and set to the minimum drum speed. Forward speed of the tractor was approximately 1 km per hour. Plants were stripped of all but their branches resulting in a considerable bulk of harvested material (Plate 5.3). Few pods were observed on the ground after harvest of the 1.8 X 20 m strip. Material collected at harvest was air dried, cleaned, weighed and analysed for quality as for the combine harvested material.

5.2.4 MEASUREMENTS

Trial measurements were concentrated in three areas: flowering pattern; the development of seed yield potential and its conversion to presentation yield, and the evaluation of various pre-harvest and harvest techniques.

5.2.4.1 Flowering Pattern

Two typical plants (at approximately 7.5 and 15 m down each plot and not in the outside rows) per plot were tagged and a location peg placed nearby. Flower counts were conducted twice a week by removing fully expanded inflorescences and young pods (pods which had not previously been removed) from the onset of flowering (4 March 1996) to one month after final harvesting (25 July 1996). Inflorescence location was categorised by tier (Section 3.2.3.2). The tagged plants in those plots which were harvested by combine and keyhole thresher were cut at ground height immediately before the plot was machine harvested, divided into stem, pod and leaf material, dried (60°C for 48 hours forced draft) and weighed. Those tagged plants not in harvested plots were left

Plate 5.2 Harvesting of *Desmanthus virgatus* cv. 'Marc' plots by combine harvester (top) and keyhole harvester (bottom), 29 April 1996.

in place and flowering monitored until the end of the trial to document flowering over the entire season.

5.2.4.2 Seed Yield Components

Two plants were selected as in Section 5.2.4.1, and a location peg placed nearby, in the PGR (Treatments 2 and 7) and control (Treatments 0 and 6) treatments in both cultivars. These were chosen because they were considered most likely to show differences in SYC over the season.

On each marked plant one reproductive site located on a secondary branch was tagged directly below the peduncle with plastic tape. Reproductive sites were tagged when pre-expanded florets were beginning to swell prior to anthesis. Each reproductive site was monitored every 3 or 4 days and the following details recorded:

(a) number of florets per reproductive site at tagging

(b) the time in days for the reproductive site to:

- set seed (any evidence of pod development)
- form an immature (fully expanded) pod (Plate 3.2)
- form a mature (fully expanded pod in which >50% is brown and therefore pod has abscised) pod (Plate 3.2)
- pod dehiscence (as indicated by the first slitting of the pod)

(c) the number of immature or mature pods per cluster

(d) the number of seeds per immature and mature pods.

Monitoring began on 14 March 1996 and a further eleven rounds of tagging were conducted on a regular (usually fortnightly) basis until the end of the trial (final tagging was on 4 July 1996). At each interval different coloured tape was used.

In order to obtain information on changes on seed weight and quality over the season, fallen seed was also recovered in all plots. This material was included in seed yield

Plate 5.3 **Residue of *Desmanthus virgatus* cv. 'Marc' after keyhole harvest (left) and combine harvest (right), 29 April 1996.**

component information. Free draining trays (30 X 40 cm) constructed from low density plastic seedling trays with weed mat glued into the base were placed between the rows into each plot, one each at 7.5 m and 15.0 m down each plot. These were attached to the ground by wire pegs and served to catch falling seed while preventing loss from trays by strong rain or wind. The trays were added to plots as early season pods approached maturity (14 March 1996) and were used until seed fall was complete. Fallen seed was collected from trays weekly, counted and stored in cool dry conditions for later seed quality evaluation. When it was expected that not enough seed for seed quality analysis had fallen into the trays, additional seed was collected by placing a bucket under randomly selected plants and gently shaking the plant causing mature seed to fall. This was particularly important in the 'Bayamo' plots as natural pod dehiscence was at a low level.

Standard germination (Appendix 3.2), seed weight (Appendix 3.2) and hardseededness (Appendix 3.2) information of stored seed was collected in mid-September 1996. Seed was pooled for testing and analysed for the period before the following dates and after the previous date tested: 'Marc' 18 April, 13 May, 30 May, 13 June, 11 July, 8 August; 'Bayamo' 17 July, 1 August, 15 August, 4 September. As a check for deterioration of seed quality, bi-monthly standard germinations (Appendix 3.2) were also conducted on seed collected from control plots which had been stored under ambient conditions.

5.2.4.3 General Trial Information

Plant populations were measured by counting the number of plants in 2 X 1 m of row 7.5 and 15.0 m down each plot (8 February 1996).

Climatic and irrigation information was obtained from the site by staff of the Brian Pastures Research Station. Mean monthly rainfall, irrigation, minimum and maximum temperatures and number of frosts are presented with associated long term averages in Appendix 5.2.

Rainfall was very variable during the 1995/1996 season with mean rainfall deviating significantly from long term means in most months. Rainfall was unseasonably high prior to 1 February 1996 and during May 1996. January was particularly wet receiving more than twice the average rainfall. During these months irrigation was limited to 50 mm. However mean rainfall during February, March and April were less than 30% of the long term mean. Irrigation (275 mm) was applied to supplement the low rainfall. Mean rainfall in June and July was low (less than 30 mm) but similar to the long term average. Irrigation was limited to 75 mm because reproductive development had virtually ceased by this time. Wilting was not observed at any stage of plant development.

Mean minimum and maximum temperatures during the 1995/1996 season ranged from 5.8°C (July) to 20.9°C (January) and 21.6°C (July) to 32.1°C (November) respectively. Values did not generally deviate from long term means. The exception was mean minimum temperature (11.5°C) during April which was lower than the long term mean (15.2°C). Air frosts were recorded on 16, 17 and 23 July 1996.

5.2.5 STATISTICAL ANALYSIS

Identification of trends was conducted as for the radial trial (Section 3.2.4). Means of variables with significant F values were generated and compared using analysis of variance or general linear model procedures and separation procedures conducted with the Fischer's protected least significant difference test (P=0.05). Where incomplete data was used least squares means were generated and compared using 'PDIFF' procedure.

5.3 Results

5.3.1 INTRODUCTION

High temperatures (30°C+) and water application (260 mm rainfall in January) to the crop after sowing (18 January) resulted in vigorous establishment and vegetative growth in both cultivars (Plate 5.1). Mean plant populations per plot ranged from 4 to 21 plants/m row. Variation in plant population down rows was caused by storm rains moving seed from the first planting and depositing it in a 'clumped' fashion. When pooled by treatment and replicate, mean plant population ranged from 12.0/m^2 to 27.8/m^2 and 16.5/m^2 to 26.4/m^2 in 'Marc' and 'Bayamo' plots respectively. Treatment and replicate differences in plant population were not significant (P=0.05) (data not presented). Overall mean population was 21.2 plants/m^2 which is lower than the population density found to be necessary to optimise potential seed yield (Section 3.4.8). Canopy closure generally occurred before the beginning of March 1996.

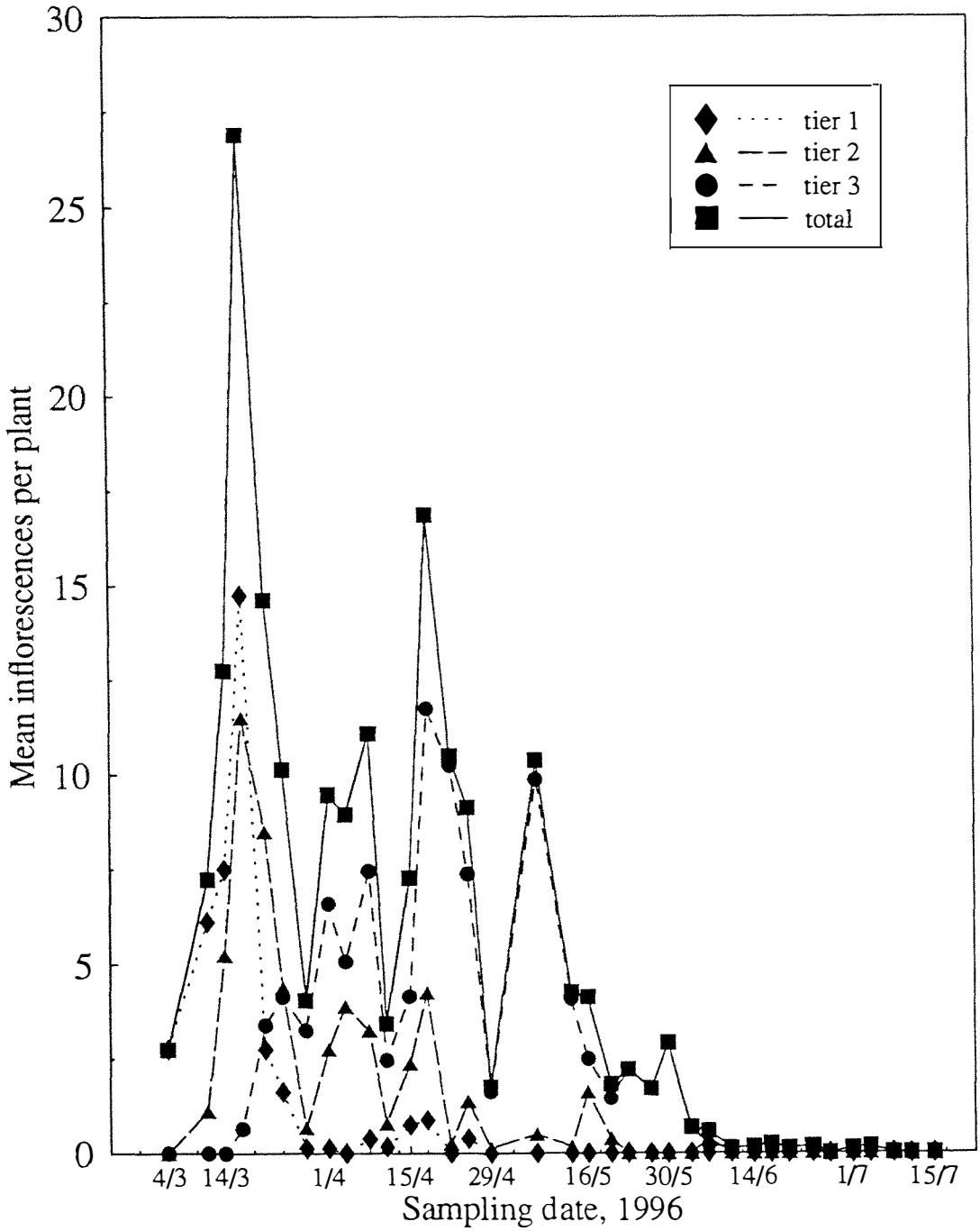
First 'Marc' and 'Bayamo' inflorescences were observed on 27 February and 11 March respectively. Reproductive development continued in both cultivars until July frosts caused abrupt cessation of growth. At this time 'Marc' had virtually finished reproductive development whereas 'Bayamo' was still actively flowering. Both cultivars regrew poorly following frost damage and few further inflorescences were produced (unpublished data) before the termination of the trial in October 1996.

5.3.2 FLOWERING PATTERN

5.3.2.1 Flowering of Untreated Plants

Untreated plants (those which received no pre-emergence or harvest treatment) provided flowering patterns of the entire season. Treatments 0 and 6 represent untreated plants for 'Marc' and 'Bayamo' respectively (Table 5.1).

Figure 5.3 **Seasonal flowering pattern of untreated (Treatment 0) plants of *Desmanthus virgatus* cv. 'Marc'.**



Cultivar 'Marc'

The flowering distribution of 'Marc' (Treatment 0) is presented in Figure 5.3. Flowering occurred in a series of peaks over the season reflecting development of branching tiers. The main stem (tier 1) contributed inflorescences (~ 55% of total) to the first peak (4 to 24 March) but produced few inflorescences thereafter. Inflorescences on the second branching tier contributed most to total inflorescences between 11 March and 22 April after which time the third branching tier was the greatest contributor to total inflorescences (50 to 100% of total). Similar distributions of inflorescences occurred in the other treatments (Appendices 5.3 to 5.7). These results support findings in the density trial (Section 3.3.11.2). Few inflorescences were produced after May.

Cultivar 'Bayamo'

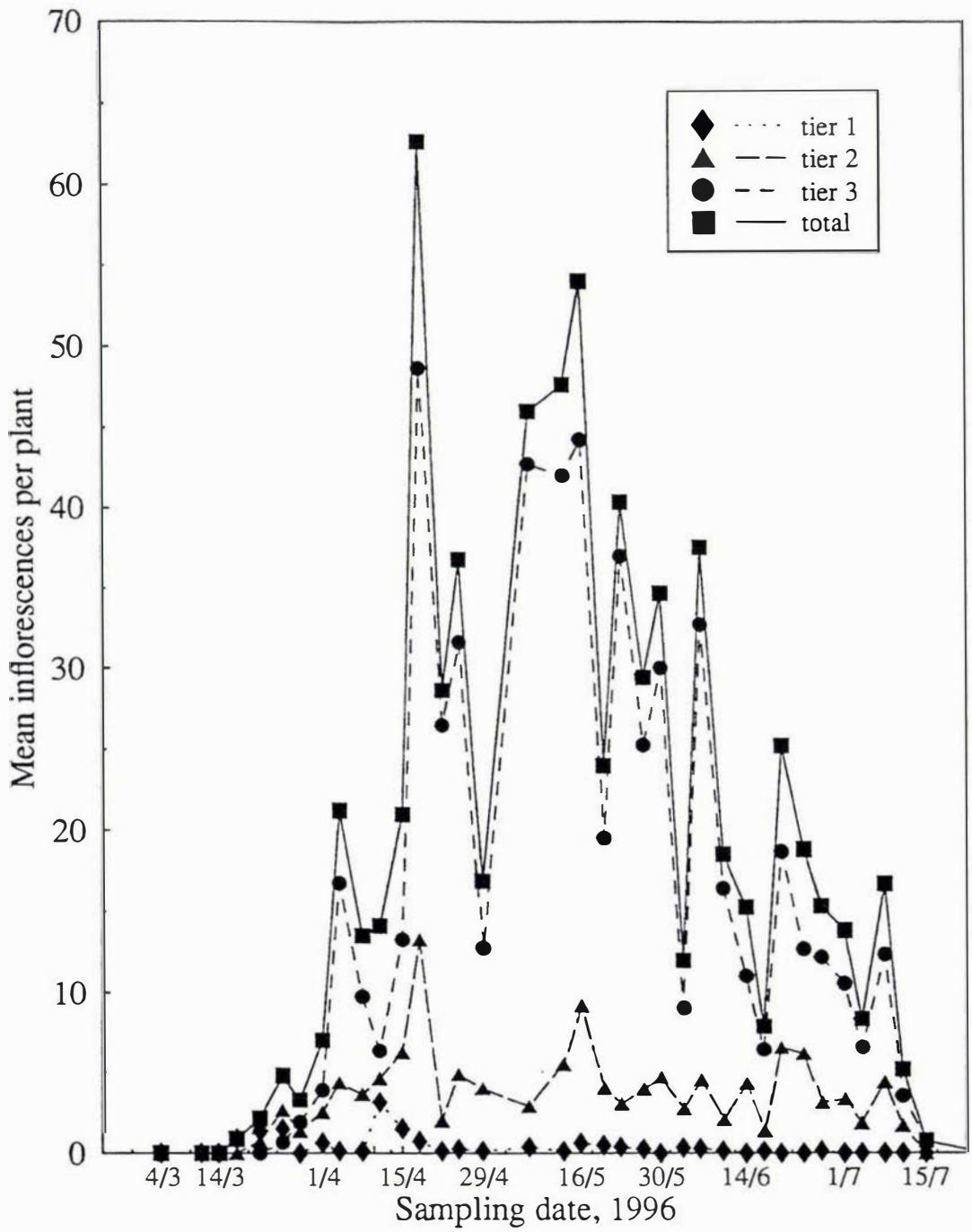
The 'Bayamo' flowering pattern (Treatment 6) is presented in Figure 5.4. By the time flowering had started tertiary branches were well developed. As a result relatively few inflorescences were produced on the main stem and secondary branches. Most inflorescences (>80%) were produced on tertiary branches because these represented a greater proportion of total branches. Most inflorescences were produced between 13 April and 8 June. There was a marked but temporary decrease in total inflorescence number between 21 April and 5 May in all 'Bayamo' treatments (Appendices 5.8 to 5.11). The reason for this is uncertain because any psyllid was controlled well before peak flowering and moisture (103 mm rainfall) and temperatures (maximum ~ 26°C, minimum ~ 12°C) were favourable for growth during this period.

5.3.2.2 Effect of Pre-Harvest Treatments on Flowering

Plant growth regulator treatments

Paclobutrazol (PCB) was applied to 'Marc' plots during the first flowering peak (18 March). A strong (24 flowers per plant) flowering peak occurred 24 days after application (Appendix 5.4). Although this peak also occurred in non-PGR treated plots of 'Marc', it was not as strong (< 15 inflorescences per plant) (Figure 5.3, Appendices

Figure 5.4 Seasonal flowering distribution of untreated (Treatment 6) plants of *Desmanthus virgatus* cv. 'Bayamo'.



5.3 to 5.7). In order to confirm these findings a detailed glasshouse study evaluating the effect of various PCB application rates and dates on 'Marc' plants was conducted. This is presented in Chapter 6. Application of PCB to 'Bayamo' plots also occurred on 11 April during early flowering. The duration of the second flowering peak (beginning 25 days after application) appears to be longer in the PCB treatment than in the control treatment (Appendices 5.8 to 5.11). Again evidence of this is inconclusive and more detailed study was required.

Adhesive and desiccant treatments

These were applied 11 days prior to harvest of 'Marc' plots when pods arising from the first flowering peak were mature (18 April). Desiccation caused rapid defoliation and cessation of flowering three days after application. However, adhesive application had no apparent effect on subsequent plant growth or flowering.

5.3.2.3 Effect of Harvest Treatments on Flowering

Both cultivars regrew poorly following combine harvest until the termination of the trial (October 1996) and few new inflorescences were produced. This agrees with other literature regarding defoliation of desmanthus late in the growing season (Adjei and Pitman, 1993). Cool and dry conditions after harvest probably contributed to poor regrowth (Plate 5.4). Cultivar 'Bayamo' was most severely affected presumedly because 'Marc' plots were harvested earlier and plants had the opportunity to regrow under more favourable conditions (higher temperatures and water supply).

The keyhole stripper also severely defoliated the desmanthus plants leaving mostly bare stems (Plate 5.3). Although the residual photosynthetic area was greater than for the combine harvested plants regrowth was poor. Flowering of cv. 'Marc' recommenced in the 77 days prior to frosting but inflorescence numbers did not exceed 3 per plant (unpublished data).

Plate 5.4 **Regeneration of *Desmanthus virgatus* cv. 'Marc' after harvest on 29 April 1996: (Top) Fallen seed immediately prior to harvest. (Bottom) Regeneration of 'Marc' plants from harvested plants (large plants in rows) and from seed (small plants between rows) 28 days after harvest. Note cracking in the clay soil which might contribute to losses of seed in vacuum harvest systems.**

5.3.3 HARVESTED SEED YIELDS

Total harvested seed yields of individual plots ranged from 15.3 g/m^2 to 24.4 g/m^2 and 7.3 g/m^2 to 20.4 g/m^2 for 'Marc' and 'Bayamo' respectively. These represented the sum of cleaned (air and screen separation) seed obtained directly from mechanical harvest and cleaned seed obtained from rethreshing (peg drum) unopened pods. No closed pods remained after peg drum threshing and even the lightest fractions of seed were collected during air / screen cleaning. The comparative yield results therefore identify pre-harvest treatment effects and efficiencies of harvesting processes rather than any differences caused by variation and cleaning in peg drum threshing procedures.

Significant block effects were observed for total seed yields (Table 5.2). These were significantly higher in blocks 'A' and 'B' than in 'C' and 'D' (data not presented). The latter two blocks were located higher on the incline than blocks 'A' and 'B' and had shallower soils (Mullaly pers. comm., 1998). Factors associated with the shallower soils (poorer water retention and lower fertility) probably contributed to the low seed yields in blocks 'C' and 'D'.

Table 5.2 **Analysis of variance (ANOVA) table of total harvest yield of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

Source	Degrees of freedom	Sum of squares (ss)	Mean square	F value	Pr > F
Model	10	1552	155	7.76	0.0001
Error	21	420	20		
Corrected total	31	1973			
	R-square	Co-efficient of variance	Root mean square	Mean	
	0.79	24.83	4.47	18.02	
	Degrees of freedom	**ANOVA ss**	**Mean Square**	**F value**	**Pr>F**
Treatment	7	873	124	6.23	0.0005
Replicate	3	680	226	11.32	0.0001

Plate 5.5 Condition of *Desmanthus virgatus* cvs. 'Marc' (top) and 'Bayamo' (bottom) plots immediately before combine harvest on 29 April 1996 and 1 August 1996 respectively. Note the presence of pods at various stages of development (green to dehisced) in 'Marc' plants and frost damage to 'Bayamo' plants.

5.3.3.1 Cultivar 'Marc'

Cultivar 'Marc' plots were harvested when seed present from the main flowering peak was mature but had not fallen (Plate 5.5). Despite this, considerable amounts of seed lay on the ground at harvest (Plate 5.4). Mean total seed yields ranged from 153 kg/ha to 243 kg/ha equivalent (Table 5.3) but treatment differences did not reach significance (P=0.05). These yields are considered to be low compared to those obtained in commercial desmanthus seed crops (300 to 400 kg/ha) (Anon, 1993b) and probably reflect low plant density. More than 90% of total seed was classified as 'heavy seed' in all treatments. This indicates that seed produced at peak flowering had sufficient time to develop prior to harvest. Quality differences between heavy and light seed are discussed in Section 5.3.8.

The combine harvester effectively threshed all pods in the control (Treatment 0), glue (Treatment 5) and desiccant (Treatment 3) treatments. The drum speed and concave clearance selected (Section 5.2.3) was therefore suitable for pod / seed separation. However, post-harvest threshing (peg drum) was required to separate seed from pods in harvest residue in the PCB pre-harvest (Treatment 2) and the keyhole harvest treatments (Treatment 4). The reason for the high proportion (22%) of seed retrieved by peg drum threshing (i.e. poor threshing during combine harvesting) in the PCB treatment is discussed in Section 5.4.3.1. Unlike the combine harvester, the keyhole harvester does not have a threshing component. Any threshing that did occur would have been during removal of pods from the plant. It is not surprising therefore that post-harvest peg-drum threshing following keyhole harvesting was required to remove a significant quantity of seed in intact pods (43% of total seed recovered).

5.3.3.2 Cultivar 'Bayamo'

The frost damage (Plate 5.5) in 'Bayamo' plots resulted in low total seed yields, ranging from 73 kg/ha to 204 kg/ha (Table 5.3). Highest seed yields were achieved when 'Bayamo' was harvested by combine whereas keyhole harvesting resulted in the lowest seed yield.

Table 5.3 **Harvested seed yields (g/m^2) of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' under differing pre-harvest and harvest treatments.**

Treatment Number	Treatment Type	Seed receiving no post-harvest threshing			Seed receiving post-harvest threshing[1]			Total		
		Heavy[2]	Light[3]	Total	Heavy[2]	Light[3]	Total	Heavy[2]	Light[3]	Total
'Marc'										
0	none/none	-	-	-	-	-	-	-	-	-
1	none/combine	21.05	0.38	21.43	0[4]	0	0	21.05	0.38	21.43
2	PGR/combine	19.43	0.15	19.58	4.60	0.25	4.85	23.95	0.43	24.38
3	desiccant/combine	18.60	0.33	18.93	0	0	0	18.60	0.33	18.93
4	none/keyhole	12.45	0.33	12.78	8.93	0.78	9.71	21.38	1.13	22.51
5	glue/combine	14.83	0.43	15.26	0	0	0	14.83	0.43	15.26
'Bayamo'										
6	none/none	-	-	-	-	-	-	-	-	-
7	PGR/combine	9.88	1.52	11.40	1.30	1.25	2.55	11.18	2.78	13.96
8	none/keyhole	3.93	0.60	4.53	1.88	0.95	2.83	5.80	1.52	7.32
9	desiccant/combine	-	-	-	-	-	-	-	-	-
10	none/combine	15.85	1.65	17.50	1.73	1.18	2.91	17.60	2.83	20.43
$LSD_{0.05}$		6.33	0.38	6.78	1.74	0.33	1.77	6.56	0.58	6.58

[1] Threshed by peg drum

[2] Heavy fraction of seed as separated by air separation

[3] Light fraction of seed as separated by air separation

[4] Not threshed because no non-dehisced pods were present in combine residue

Post-harvest threshing was required to remove seed (at least 14% of total seed yield) from pods in all 'Bayamo' combine harvested treatments and is a result of differences in crop maturity at combine harvesting. There was also a greater proportion (> 10%) of light seed in 'Bayamo' than 'Marc' samples presumedly reflecting frost induced premature abscission of seed arising from peak flowering. Thus less efficient combining is probably due to the presence of greater numbers of immature pods which were cross-sectionally thinner than more developed pods and were apparently not rubbed as effectively in the concave. As with 'Marc', post-harvest threshing after keyhole harvesting was necessary and contributed a large proportion (~40%) of total harvested seed. Although post-harvest threshing increased seed yields, at least 25% of the seed obtained from this process was classified as 'light'.

5.3.4 SEED YIELD COMPONENTS

Seed yield components (SYC) (see Section 5.2.4.2 for details) of plants in control and PGR plots were measured on tagged inflorescences appearing between 14 March and 4 July or until harvest ('Marc' PGR plots on 29 April). This covered the flowering period of both cultivars.

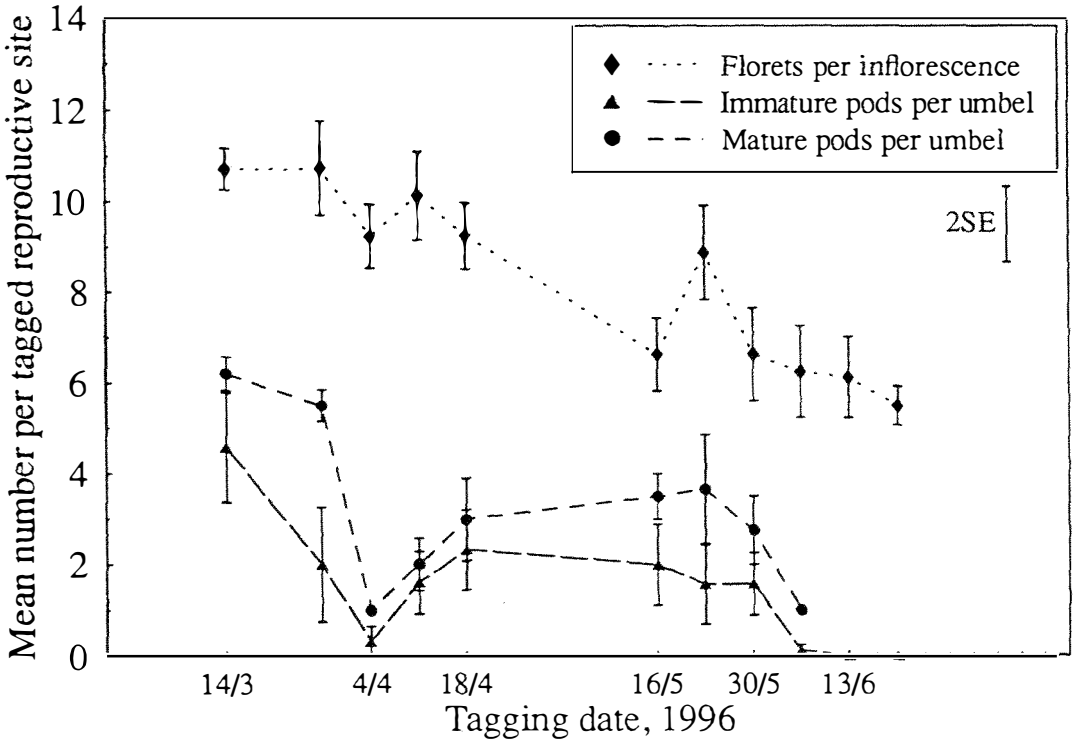
5.3.4.1 Changes in SYC of Untreated Plants Over the Season

Cultivar 'Marc'

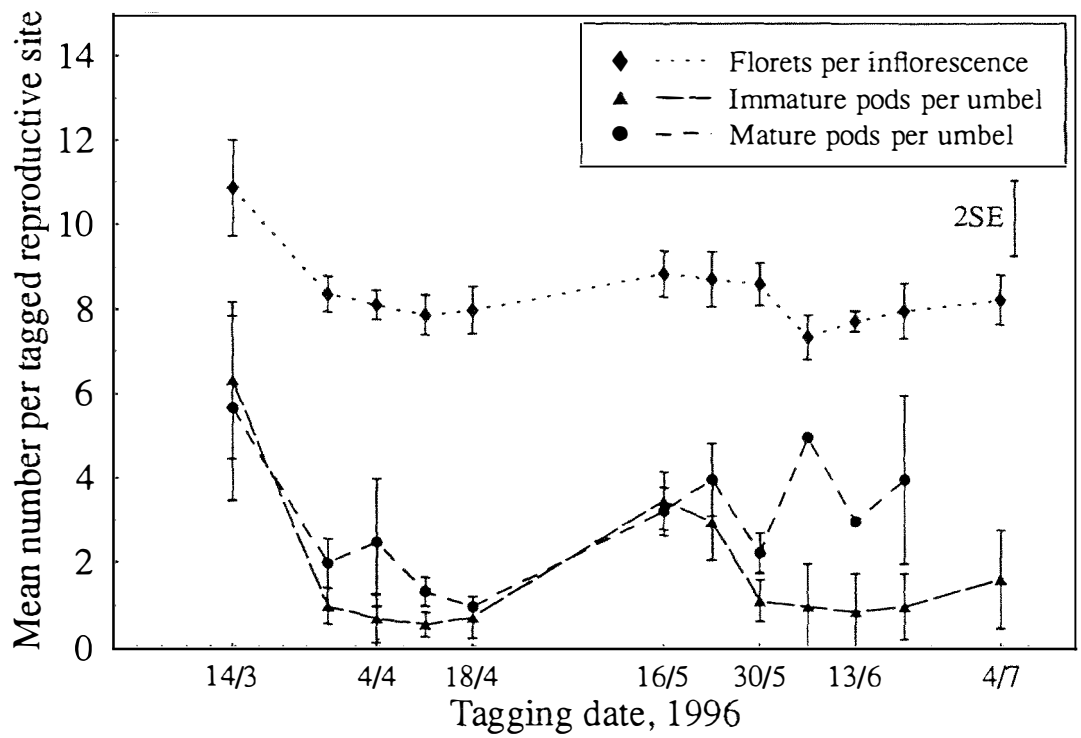
The number of florets per inflorescence decreased from nearly 11 to less than 6 over the season (Figure 5.5a). Mean immature pods (fully expanded but not abscised) per umbel arising from these inflorescences also declined over the season although results were more variable. Less than 45% of florets formed pods at any stage of flowering. By the end of the flowering period no florets formed pods. Most immature pods formed mature pods, however. Occasionally mean mature pod number per umbel was higher than immature pod number per umbel. This was because loss of umbels containing few pods,

Figure 5.5 **Seasonal distribution of selected seed yield components of untreated plants of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

A. Cultivar 'Marc'



B. Cultivar 'Bayamo'



between the immature and mature pod stages, resulted in decreased sample sizes at the later stage and bias of the mean towards mature umbels containing greater numbers of pods. Overall, abortion rates are similar to those of the radial spacing trial in which destructive harvests were used to estimate floret and pod abortion (Section 3.3.7).

The mean times taken for tagged inflorescences to reach pollination, immature pod and mature pod stages and to dehisce are presented in Figure 5.6a. The mean period from peduncle expansion to anthesis (full expansion of the inflorescence) was consistently about 5 days. The mean period from anthesis to the immature pod stage increased from approximately 5 to 18 days over the season whereas the period from immature to mature pod stages increased from approximately 22 to 30 days over the same period. Pod dehiscence was only recorded in umbels arising from inflorescences tagged before 18 April. Pod dehiscence occurred about 10 days after the mature pod stage with little change over time. Of note is a rapid decline in the period between immature and mature pod stages in reproductive sites tagged after 30 May. This is because of frosting during mid-July which prematurely abscised pods causing them to brown and be classed as mature pods.

Changes in seed number per pod over the season were not detected (Appendix 5.12).

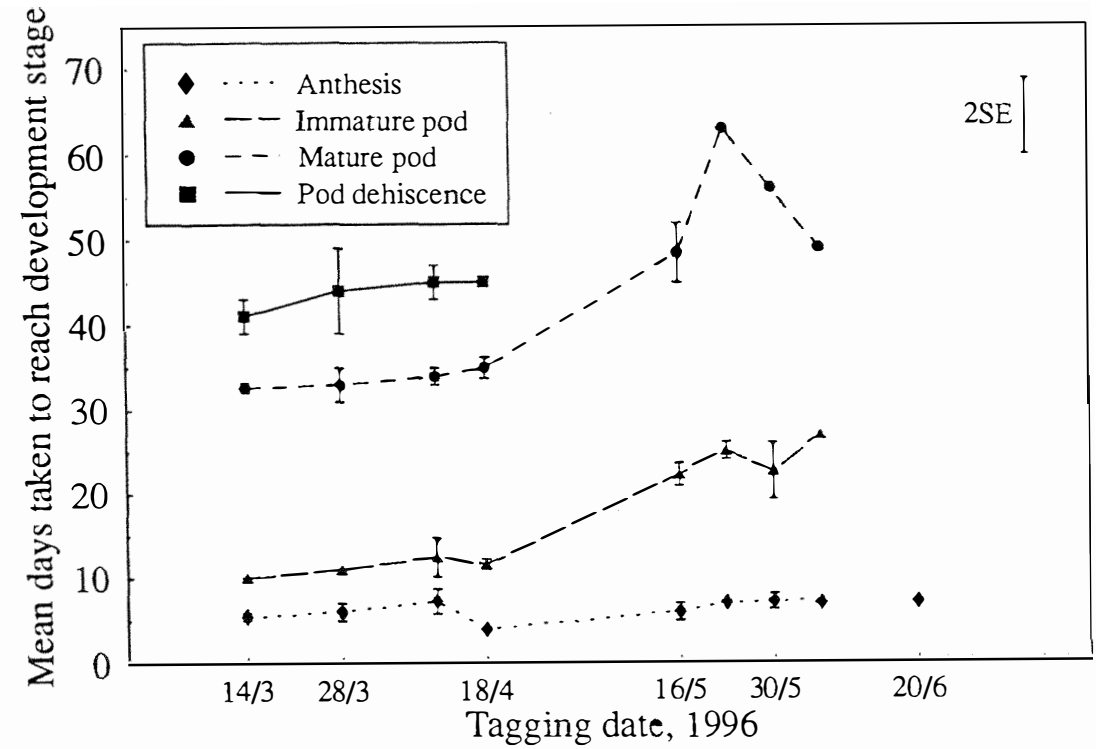
Cultivar 'Bayamo'

Mean numbers of florets per inflorescence, and immature and mature pods per umbel of 'Bayamo' (Figure 5.5b) were very similar to 'Marc' (Figure 5.5a). The only difference is that mean florets per inflorescence of 'Bayamo' plants did not decline below 7 whereas those of 'Marc' declined below 6. As in 'Marc', mean number of seeds per pod did not change significantly over the season (Appendix 5.12).

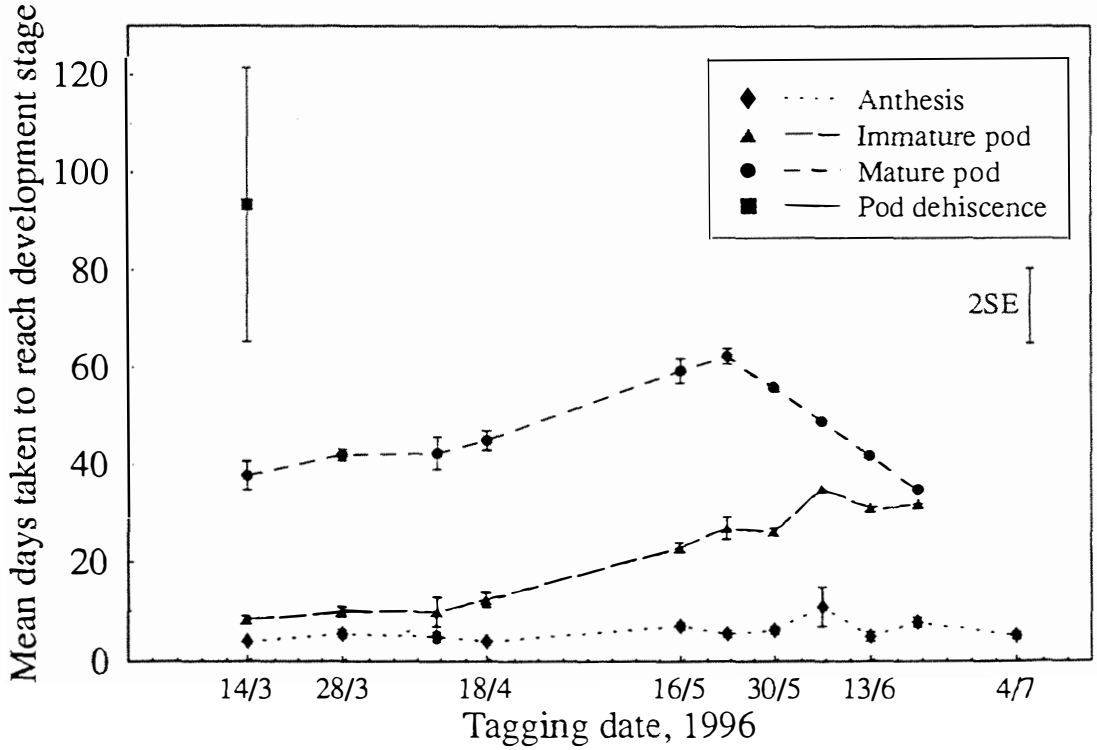
'Bayamo' pods took longer to develop after anthesis than 'Marc' pods (Figure 5.6b) although they also showed similar patterns of declining development rate over time. Of note is that very few 'Bayamo' pods dehisced, even before frosting, and that when they did, it took on average approximately 50 days after pods had reached the mature stage.

Figure 5.6 **Seasonal distribution of times of inflorescence and pod development of untreated plants of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

A. Cultivar 'Marc'



B. Cultivar 'Bayamo'



This indicates that pod-dehiscence losses of mature seed presented for harvest may be minimal in 'Bayamo' seed crops grown under similar conditions.

5.3.4.2 Changes in SYC of Paclobutrazol Treated Plants Over the Season

The effects of PCB on the development of SYC were compared with untreated plants between PCB application dates and harvest of PCB treated plots (Figures 5.8a and 5.8b).

In both cultivars, both paclobutrazol and untreated plants had similar effects on the numbers of florets per inflorescence or pods per umbel (Figure 5.7a and 5.7b). The rate of pod development from tagged inflorescences (Figure 5.8a and 5.8b) and number of seeds per pod (Appendix 5.12) was also not affected.

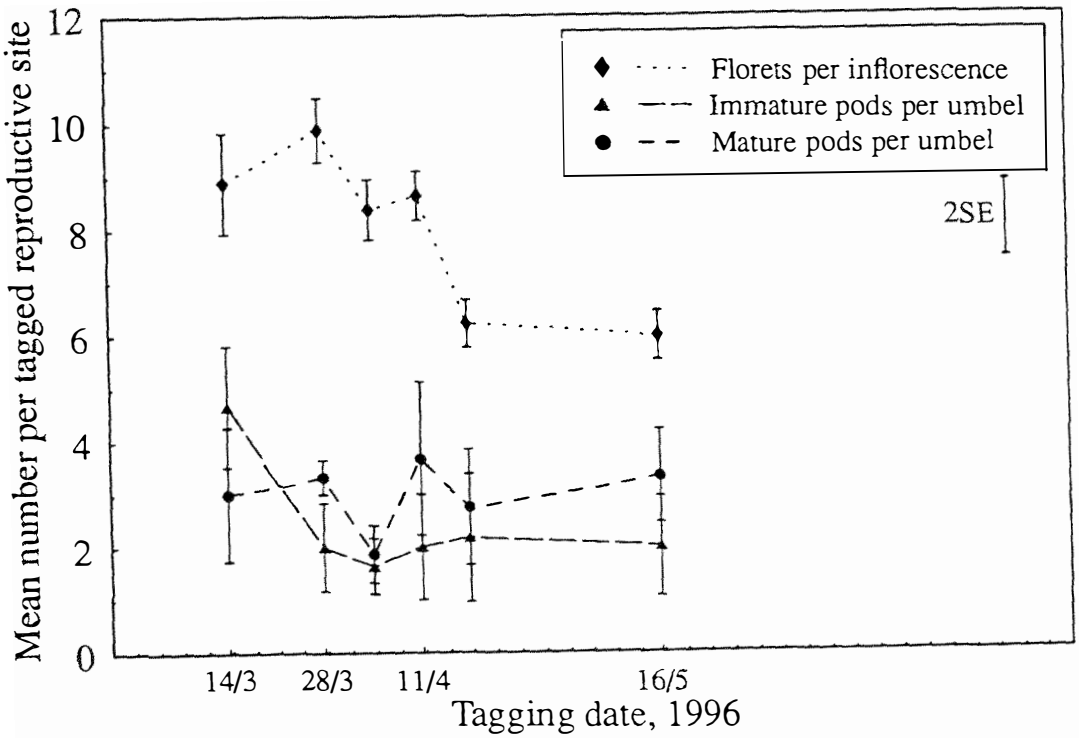
5.3.4.3 SYC Arising from Peak Flowering

The success of the standard commercial practice of combine harvesting desmanthus seed crops requires correct identification of peak presentation yield (kg seed/ha) in order to maximise seed yields. In this study flowering occurred in waves of recognisable peaks (Section 5.3.2.1) the largest of which occurred around 14 March and 16 May in 'Marc' and 'Bayamo' respectively. Because the scale of change of SYC over the season was not as large as changes in inflorescence number per plant it is expected that inflorescences produced at peak flowering contributed most to seed yield. The values of SYC obtained for inflorescences tagged at peak flowering are presented in Table 5.4. Analysis was limited to control plots because PCB had no major effect on SYC and rates of reproductive development.

In both cultivars less than 50% of inflorescences formed immature pods but subsequent losses were insignificant. 'Marc' pods which developed successfully to the mature pod stage dehisced about 10 days later whereas no 'Bayamo' pods dehisced.

Figure 5.7 Seasonal distribution of selected seed yield components of paclobutrazol treated plants of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.

A. Cultivar 'Marc'



B. Cultivar 'Bayamo'

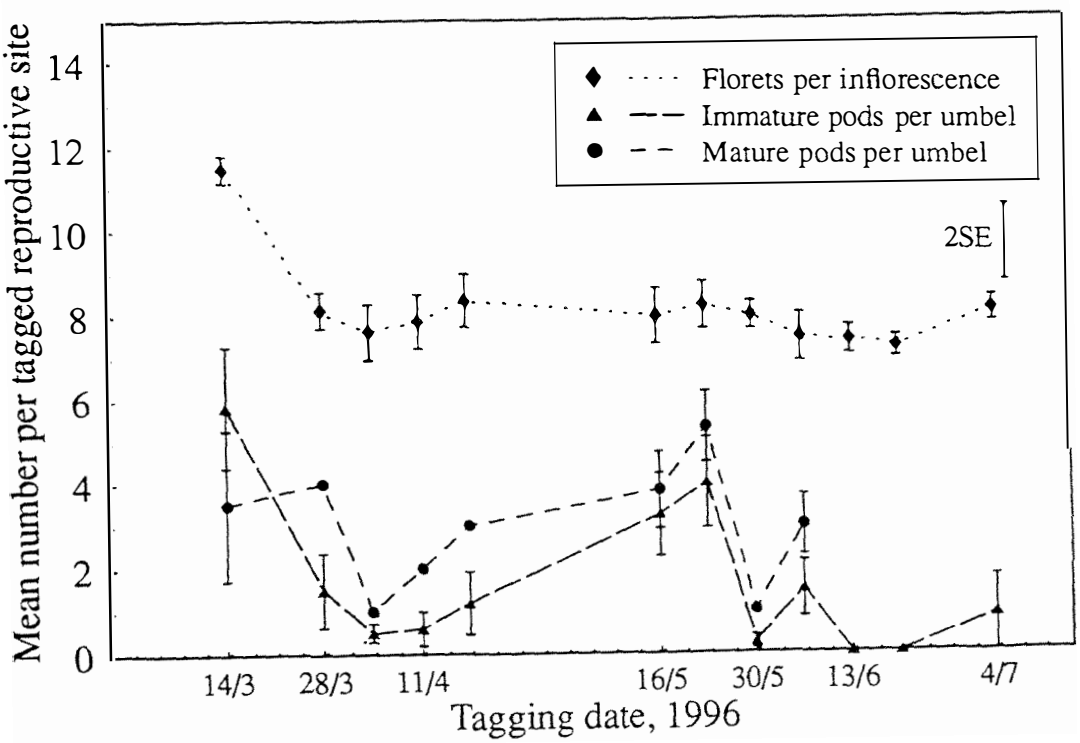


Table 5.4 **Seed yield components of inflorescences tagged at peak flowering of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

Seed yield component	'Marc' (14 March 1996)	'Bayamo' (16 May 1996)
florets/inflorescence	**10.75**	**8.88**
	0.45 (8)	0.56 (8)
immature pods/umbel	**4.57**	**3.50**
	1.21 (7)	0.68 (8)
mature pods/umbel	**6.20**	**3.25**
	0.37 (5)	0.56 (8)
seeds/pod	**8.78**	**9.18**
	1.09 (5)	1.38 (8)
peduncle expansion (PE) to anthesis (days)	**5.4**	**7.1**
	0.4 (5)	0.7 (8)
PE to immature pod (days)	**7.0**	**23.0**
	0.0 (5)	1.1 (8)
PE to mature pod (days)	**32.6**	**59.4**
	0.6 (5)	2.5 (8)
PE to dehiscence (days)	**41.0**	**no pods dehisced**
	2.0 (5)	-

0.00 Mean
0.00 (0) Standard error (n)

Inflorescences at peak flowering of 'Marc' took 33 days to reach maturity and were harvestable during the following 10 days before pod dehiscence occurred. However, development of 'Bayamo' inflorescences tagged at peak flowering took considerably longer (60 days) to reach maturity. This coincided with the first frost indicating that pods may have pre-maturely abscised due to the cold temperature.

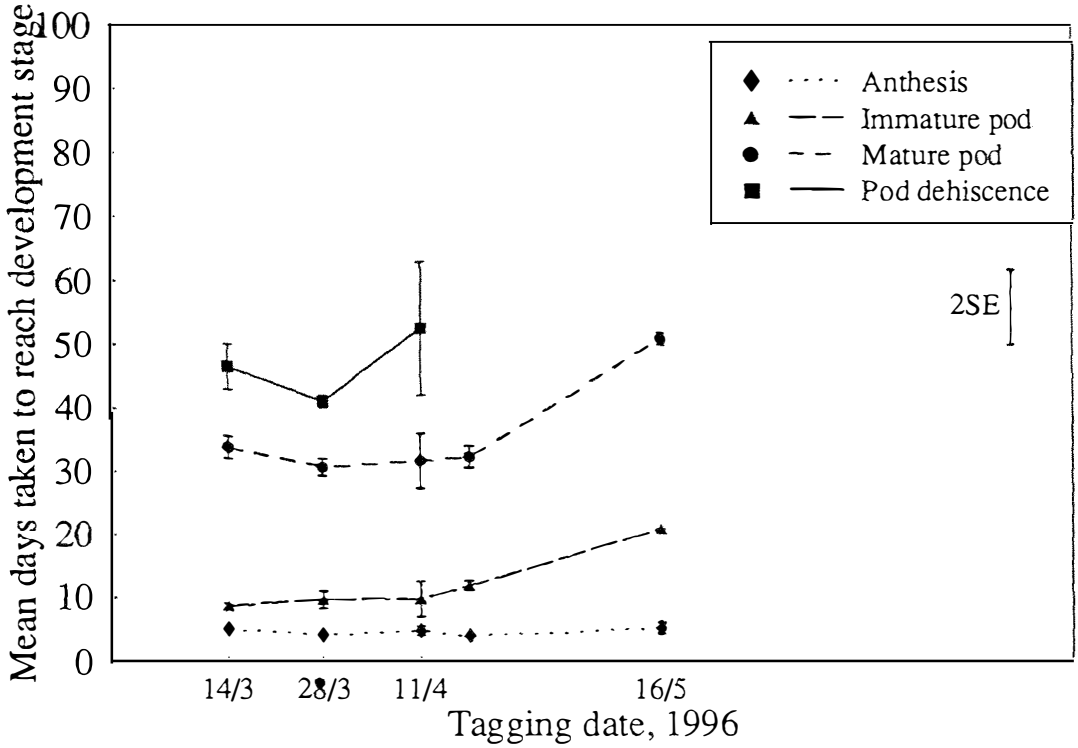
5.3.5 YIELDS OF DEHISCED SEED

5.3.5.1 Seasonal Pattern of Pod Dehiscence in Untreated Plots

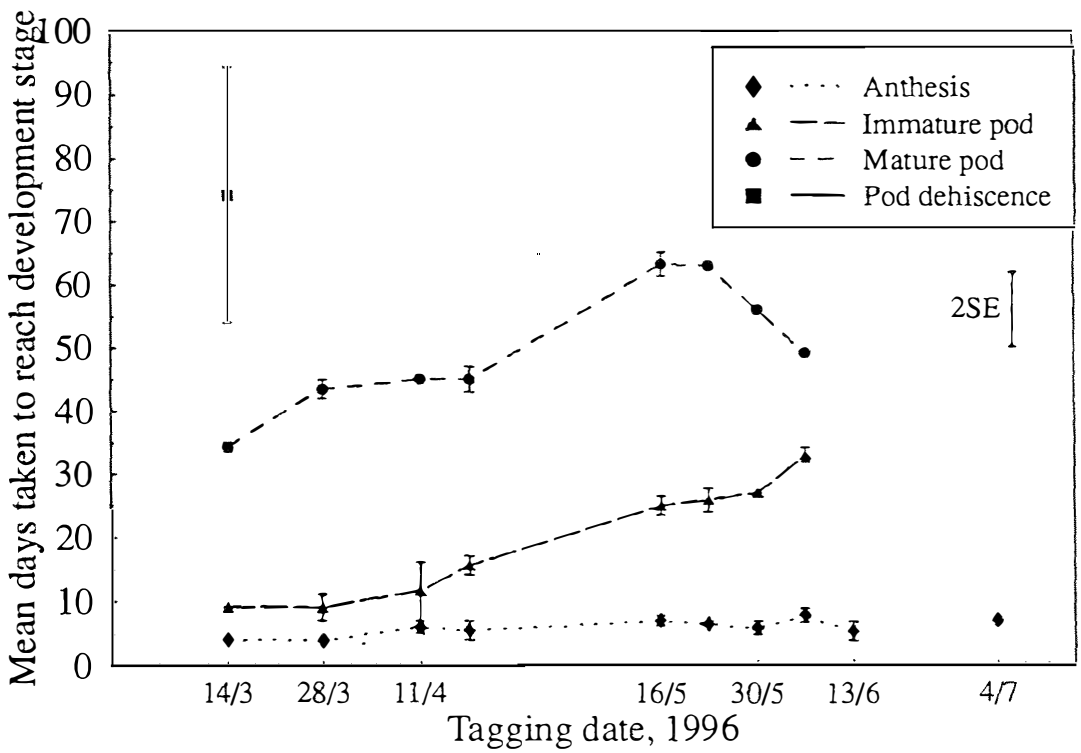
Levels of fallen seed were measured by collection in trays placed in fixed positions under the canopy of control (untreated) and PGR treated plants in both cultivars. 'Marc' and 'Bayamo' had different pod dehiscence patterns, a reflection of genetic differences and environment during pod development (Figure 5.9).

Figure 5.8 Seasonal distribution of times of inflorescence and pod development of paclobutrazol treated plants of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.

A. Cultivar 'Marc'



B. Cultivar 'Bayamo'



Cultivar 'Marc' (Treatment 0)

Pod dehiscence of the first formed inflorescences (14 March) began on 18 April. Most pods eventually dehisced (Section 5.3.4.1). Seed fall showed a similar, but delayed, seasonal distribution to flowering (Figure 5.3). Initial levels of seed fall were high probably reflecting dehiscence of pods arising from the first (and largest) flowering peak (Figure 5.9). High temperatures at this time probably assisted this process. A second wave of seed fall occurred between 23 May and 24 June probably contributed from the second flowering peak. Thereafter pod dehiscence declined to virtually zero reflecting the decline in late inflorescence production.

Total seed collected over the season is represented in Table 5.5. The control treatment (Treatment 0) (1963 kg/ha) represents seed collected over the entire season, and was approximately twice that of plots harvested on 29 April.

Cultivar 'Bayamo' (Treatment 6)

Few 'Bayamo' pods dehisced (Section 5.3.4.1) and numbers of fallen seed were substantially lower (~75%) than for 'Marc' (Table 5.5, Figure 5.9). Seed fall was highest during late July and mid August. This first period coincided with the maturing of pods arising from early (pre-peak flowering) inflorescences. The second peak is probably due to dehiscence of pods which abscised as a result of frost damage during mid and late July.

5.3.5.2 Effects of PCB on Pod Dehiscence

The levels (Table 5.5) and seasonal pattern (data not presented) of fallen seed in PCB treated plots were similar to untreated plots in both cultivars. The more precise effects of PCB on pod dehiscence in desmanthus was further investigated under more controlled (glasshouse) conditions and are presented in Chapter 6.

Figure 5.9 **Seasonal pattern of fallen seed collected in untreated plots of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

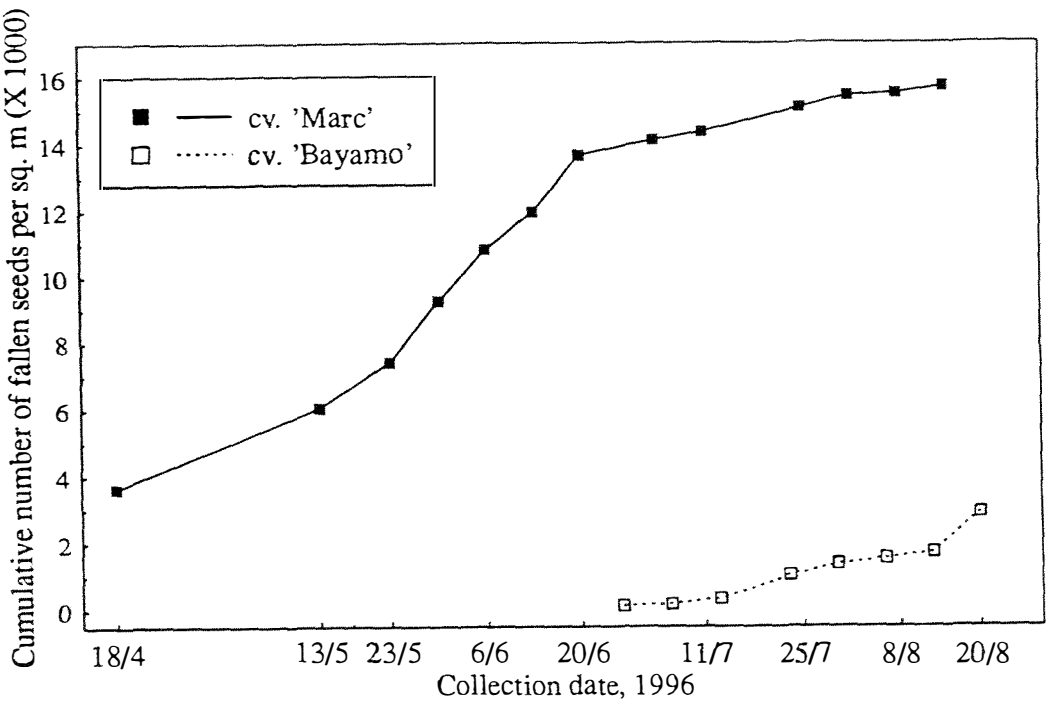


Table 5.5 **Comparison of the amount of fallen seed prior to harvest and actual harvested seed yields (kg/ha) of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' under differing pre-harvest and harvest treatments.**

Treatment number	Treatment combinations	Total fallen seed prior to harvest (A) (kg/ha)	Total harvested seed (B) (kg/ha)	Harvest efficiency index (HEI) B/(A+B)
'Marc'				
0	none/none	1963[2] a[1]	-	-
1	none/combine	889 b	214 ab	0.22 bc
2	PGR/combine	686 bc	243 a	0.27 bc
3	desiccant/combine	940 b	189 ab	0.17 c
4	none/keyhole	822 b	225 a	0.23 bc
5	glue/combine	835 b	153 bc	0.22 bc
'Bayamo'				
6	none/none	409[2] c	-	-
7	PGR/combine	118 c	139 cd	0.61 a
8	none/keyhole	143 c	73 d	0.30 b
9	none/combine	347[2] c	-	-
10	none/combine	127 c	204 ab	0.62 a

[1] LSMeans of the same letter are not significantly different (P=0.05)
[2] Not harvested

5.3.6 EFFICIENCY OF HARVEST

A harvest efficiency index (HEI) for all treatments is presented in Table 5.5. The calculated value represents the proportion of total seed yield presented prior to harvest collected by harvesting processes.

In 'Marc' plots harvested by combine harvester, mean HEI ranged from 0.17 to 0.27 but these were not significantly different (P=0.05). Similarly, the choice of harvest method did not appear to affect harvest efficiency except that it affected the requirement for post-harvest threshing of pods. This is not surprising as total fallen seed prior to and during harvest also showed no significant treatment differences (P=0.05) in 'Marc'.

Harvest efficiencies (0.30 to 0.62) calculated for 'Bayamo' were significantly (P=0.05) higher than for 'Marc' presumedly due to a combination of lower pod dehiscence (Section 5.3.6) and premature harvest. Paclobutrazol did not affect harvesting efficiency. However the use of the keyhole harvester resulted in much lower HEI than when the combine harvester was used. This was due to low seed yield being recovered during harvest rather than to differences in the quantity of seed presented for harvest.

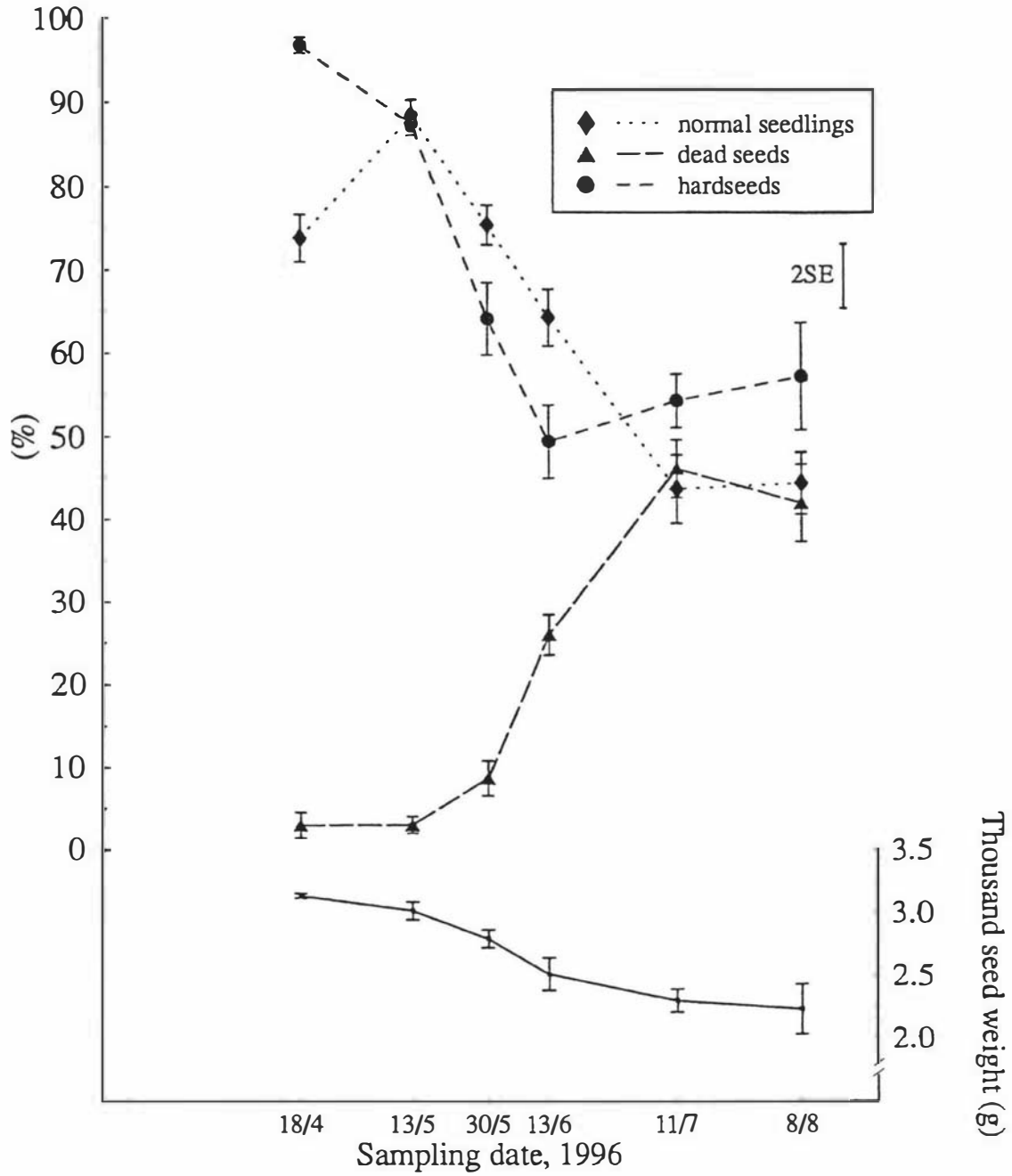
5.3.7 SEED QUALITY OF DEHISCED SEED

Dehisced seed from field collection trays in control treatments was tested for standard germination (acid scarified seed), percentage hardseed and seed weight (Appendix 3.2). Results are presented in Figures 5.10 and 5.11.

5.3.7.1 Cultivar 'Marc'

Normal germination declined over the season from nearly 90% to approximately 45% (Figure 5.10). This was due to a proportionate increase in the percentage of dead seeds. Similarly, percentage hardseed of unscarified seed declined between 18 April and 13 June from nearly 100% to approximately 50% after which no measurable change occurred.

Figure 5.10 **Seasonal pattern of seed quality indices of fallen seed of *Desmanthus virgatus* cv. 'Marc'.**



Mean thousand seed weight declined by 25% over the whole season from approximately 3.2 g/1000 seeds in the earliest seed samples. This decline may be responsible for the increase in the proportion of dead seeds over the season. Frosting did not occur until the end of the sampling period and had no measurable effect on quality.

5.3.7.2 Cultivar 'Bayamo'

'Bayamo' seed quality showed similar trends over time to 'Marc' but had poorer germination characteristics (Figure 5.11). Normal germination declined to less than 20% and thousand seed weight fell from 3.14 to 2.23 g. Hardseed levels were considerably lower than in 'Marc' indicating that the seed coat, particularly in late-season seed, did not form sufficiently to prevent germination or that 'Bayamo' has a genetically lower level of hardseed formation. Other factors which may have contributed to low levels of hardseededness and poor seed quality (dead seeds equalled 80% by 4 September) in late season seed include frost damage or cooler conditions during pod development. 'Bayamo' seed matured later than 'Marc' seed in cooler, drier conditions. Only very early-season seed escaped the effects of frosting.

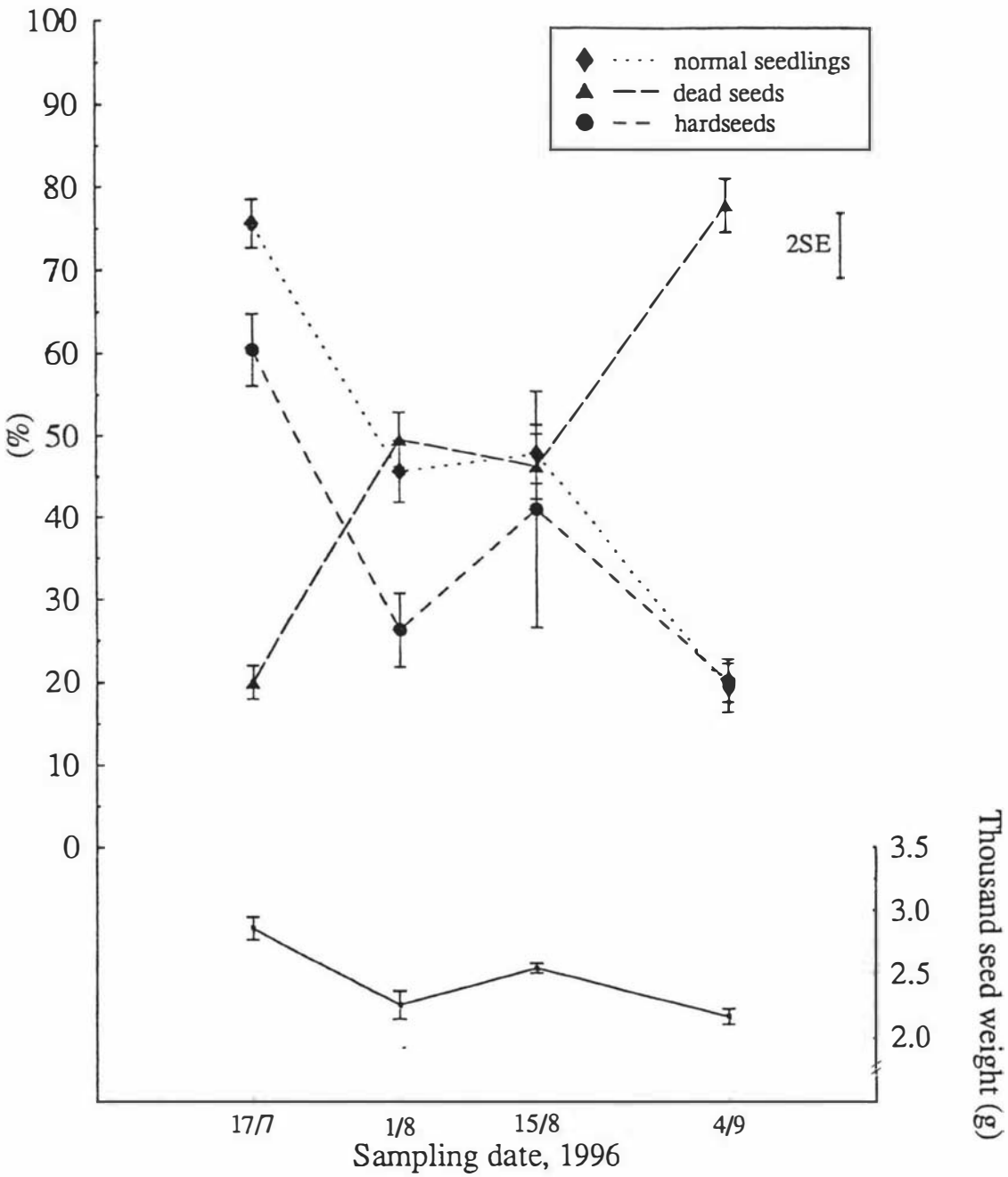
5.3.8 SEED QUALITY OF HARVESTED SEED

Harvesting of the two cultivars occurred at different stages of crop development. Harvested (29 April) 'Marc' seed represented mainly early formed inflorescences which had fully developed with no frost damage. Conversely, harvested (1 August) 'Bayamo' seed had undergone significant stress (frost) before seed arising from peak flowering had completed seed fill.

5.3.8.1 Cultivar 'Marc'

Mean normal germination of acid scarified 'Marc' seed direct from the combine harvester ranged from 48% (PGR) to 76% (desiccant) (Table 5.6a). Glue and control treatments significantly (P=0.05) increased germination over the PGR treatment. The

Figure 5.11 **Seasonal pattern of seed quality indices of fallen seed of *Desmanthus virgatus* cv. 'Bayamo'.**



percentage of abnormal seedlings in the PGR treatment (9.4) was significantly higher than the control (6.4) whereas the glue treatment was significantly lower (3.6). The majority of ungerminated seeds in each treatment were dead with very few viable ungerminated seeds or hard seeds. Seed collected by the keyhole harvester had very similar germination characteristics to seed collected by combine harvester (also receiving no pre-harvest treatment).

Hardseed levels in 'Marc' seeds direct from machine harvest varied widely from 42 to 76%. Seed collected by keyhole harvester (76.4%) had a much higher proportion of hardseed than seed collected by combine harvester (50.0%). This simply reflects the relative difference in abrasion to the seed incurred by these two different threshing mechanisms and their difference in pod threshing efficiency. Pre-emergence treatment had less effect on hardseed levels than harvest treatment but some differences were significant (5%). Of note is the relatively low proportion (41.8%) of hardseed in PGR treatments. This was associated with low seed weights (2.33 g/1000 seeds) indicating that a relatively high proportion of immature seed was harvested. These results both indicate that harvest may have occurred at an earlier stage of seed development in PGR treated plots than in other treatments a situation which may have masked any promotion of seed yield by PGR.

Desiccant and glue treatments had slightly, but significantly (P=0.05), higher hardseed content than untreated and combine harvested plots indicating that these processes promoted seed drying and the formation of hard seed coats. The desiccant and glue treatments had no obvious effect on mean seed weight compared to untreated and combine / harvested plots. Mean seed weight was not affected by harvest method.

Threshing of pods with the peg drum thresher was only required in the PGR and keyhole 'Marc' treatments. Peg drum threshing of seed produced in the PGR treatment significantly reduced germination performance of acid scarified seed (14.6% normal germination) and reduced the proportion of both hardseed and seed weight. Peg drum threshing of seed harvested by keyhole thresher also reduced germination performance, hardseededness or seed weight but not to the same extent. The difference is attributed to

the differing levels of threshing during harvest which altered the proportion of fully developed seed and the degree of mechanical scarification of this seed i.e. seed threshed by the peg drum in the PGR treatment consisted of relatively under-developed and partly scarified seed (due to combine harvesting) whereas more seed in the keyhole treatment had dehydrated following maturity to the point where a hard seed coat was formed. Acid damage following seed scarification during harvest may also have contributed to the low germination of combine harvested seed.

5.3.8.2 Cultivar 'Bayamo'

'Bayamo' seed direct from machine harvesting had very poor germination (11.1 to 16.4% normal germination), a low proportion of hardseeds (3.5 to 6.7%) and low seed weight (1.76 to 2.09 g/1000 seeds). This is most likely due to frost damage to developing pods i.e. inflorescences present after mid May took approximately 60 days to reach maturity (Figure 5.6b) and represent approximately 50% of total inflorescences produced over the season (Figure 5.4). Very few of these would have reached maturity before frosts, and therefore abscission, began (mid July). Also, some early produced pods had dehisced (Figure 5.6b) further reducing the amount of fully developed seed on plants at harvest. Low levels of water imbibition of unscarified (acid) seed and low seed weights indicate that seeds had not completed seed fill and that fewer seeds had formed hardseed coats. Acid used during germination tests may therefore have further damaged seeds with particularly poorly developed seed coats.

Preharvest and harvest treatments had little effect on germination characteristics or hardseed levels presumedly because the above factors were more dominant. However, seed weight in the keyhole treatment was significantly higher than for seed harvested by combine.

The small fraction of seed which required post-harvest threshing (peg drum) was of even lower quality (Table 5.6). Again any significant treatment difference was limited to seed weight although this was slight.

Table 5.6 **Seed quality indices of harvested seed of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' under different pre-harvest and harvest treatments (TM).**

A Seed receiving no post-harvest threshing

Treatment number and description		Normal (%)	Ab-normal (%)	Hard (%)	Fresh (%)[3]	Dead (%)	Hard-seed (%)	Seed weight (g/1000)
'Marc'								
0	none(n)/n[4]	88.4	3.1	5.1	0.3	3.1	87.4	3.02
1	n/combine (c)	57.8	6.4	0.0	0.0	35.8	50.0	2.88 a[1]
2	PGR/c	48.3	9.4	0.5	0.3	41.5	41.8	2.33 c
3	desiccant/c	76.5	4.6	0.9	0.0	18.0	61.5	2.70 b
4	n/keyhole	63.7	5.0	0.4	0.4	30.5	76.4	2.83 a
5	glue/c	56.4	3.6	0.8	0.3	39.0	57.6	2.82 ab
'Bay.'								
6	n/n[4]	45.7	4.8	0.0	0.0	49.5	26.4	2.26
7	PGR/c	12.6	0.9	9.6	0.3	76.5	5.8	1.84 e
8	n/keyhole	16.4	0.4	11.0	0.1	72.1	6.7	2.09 d
9	desiccant/c[2]	-	-	-	-	-	-	-
10	n/c	11.1	0.6	6.0	0.2	82.1	3.5	1.76 e
$LSD_{0.05}$		6.3	2.0	2.1	0.4	7.1	5.5	-

B Seed receiving post-harvest threshing

Treatment number and description		Normal (%)	Ab-normal (%)	Hard (%)	Fresh (%)[3]	Dead (%)	Hard-seed (%)	Seed weight (g/1000)
'Marc'								
0	none(n)/n	-	-	-	-	-	-	-
1[2]	n/combine (c)	-	-	-	-	-	-	-
2	PGR/c	14.6	7.1	0.0	0.2	78.1	8.9	1.73 b
3[2]	desiccant/c	-	-	-	-	-	-	-
4	n/keyhole	45.2	5.3	0.1	0.1	49.2	28.2	2.85 a
5[2]	glue/c	-	-	-	-	-	-	-
'Bay.'								
6	n/n	-	-	-	-	-	-	-
7	PGR/c	4.5	0.0	2.4	0.1	93.0	1.3	1.31 d
8	n/keyhole	3.3	0.0	1.9	0.0	94.8	1.0	1.53 c
9	desiccant/c[2]	-	-	-	-	-	-	-
10	n/c	3.4	0.4	1.2	0.0	95.0	0.7	1.42 cb
$LSD_{0.05}$		4.4	1.3	1.0	0.3	4.4	2.4	-

1 Means with the same letter are not significantly different (P=0.05)

2 Not applied because of frost damage

3 Fresh ungerminated seed

4 Seed collected in trays at harvest. Not included in analysis of variance.

Standard germination test

5.4 Discussion

5.4.1 DEVELOPMENT OF SEED YIELD

Combine harvested seed yields obtained from plots with no pre-harvest treatment were considerably lower (approximately 200 kg/ha) than those obtained by similar methods in commercial stands on the Atherton Tableland (Hopkinson pers. comm., 1995) and was a result of low presentation of seed at harvest. In comparison, total fallen seed collected over the trial period (January-October, 1996) was equivalent to 1963 kg/ha and 409 kg/ha for cvs. 'Marc' and 'Bayamo' respectively. Cultivar differences in the amount of seed produced and the proportion recovered at harvest were due to differences in the time of onset and duration of flowering and consequently on environmental conditions during seed development and pod dehiscence.

5.4.1.1 Flowering Pattern

Flowering in the day-neutral cv. 'Marc' began in early March and continued until frosts in mid July extensively defoliated plants. Few new inflorescences were produced after mid June however. Initiation of flowering occurred on 27 February (40 days after sowing) in the harvesting trial which was more rapid than in the previously described density trial. This difference is probably due to more rapid plant vegetative development arising from exposure to longer daylengths (later sowing than the radial trial) and superior growing conditions (Section 5.3.1).

Peak flowering in 'Marc' coincided with high water applications and high temperatures while late flowering occurred under declining temperatures, reduced photoperiod and limited water supply (Appendix 5.2). Flowering pattern may also have been affected by genetic limitations of plant structure to produce inflorescences. The main stem and secondary branches had a limited ability to grow and produce inflorescences. It is likely that this also occurred in tertiary branches which contributed most to total inflorescence number (Section 5.3.2.1). Thus as reproductive nodes were utilised a point was reached where no, or very few, new nodes were being produced and flowering on tertiary branches ceased.

Inflorescences occurred two weeks later in cv. 'Bayamo' than cv. 'Marc'. It seems likely from observation that cv. 'Bayamo' does not flower until photoperiod is declining whereas growth stage of cv. 'Marc' dictates the onset of flowering. This further suggests that there are different mechanisms controlling floral induction and / or initiation in these two cultivars.

High numbers of inflorescences were produced before temperature and moisture began to decline in May. Thereafter, a continued decrease in photoperiod, temperature and moisture resulted in declining inflorescence numbers per plant. Frosts in July ceased flowering, an effect which was particularly deleterious to the later flowering 'Bayamo'. This suggests that cv. 'Bayamo' may be better grown for seed in lower latitudes where temperature stress during reproductive development is less likely i.e. Atherton Tableland in Queensland. Certainly, flowering in 'Bayamo' was strongly influenced by environment, but limitations due to plant structure as occurred in cv. 'Marc' are also possible.

5.4.1.2 Development of Seed Yield Components

Greatest loss of potential seed yield occurred during seed set with less than 45% of florets forming pods at any stage of the season. This is considerably lower than that reported for *D. illinoensis* (75%) (Latting, 1961). It can also be inferred from the cultivar description (Cook *et al.*, 1995) of cvs. 'Marc' and 'Bayamo' that seed set is typically higher (approximately 60 to 70%) than was achieved in this trial. The mean number of seeds per pod was also lower than reported by Cook *et al.*, (1995) for these two cultivars. Possible reasons include poor pollination or abortion shortly after pollination, aspects which are discussed in Chapter 6.

The rate of inflorescence development was considerably faster in cv. 'Marc' than in cv. 'Bayamo' at all tagging dates (Figures 5.6a and 5.6b) when monitored over the same period. This implicates genetic control. Cultivar 'Bayamo' originates from a moister and warmer environment than cv. 'Marc' (Section 2.1.4.2). It is possible therefore that differences in development rate may be less in warmer (e.g. Atherton Tableland) or moister environments more similar to those in which cv. 'Bayamo' is edaphically suited.

Environmental factors appear to have affected development of inflorescences over the season. The seasonal decline in florets per inflorescence and pods per umbel in both cultivars (Section 5.3.4.1) coincided with declining temperature, photoperiod and moisture supply to the crop (Appendix 5.2). The number of reproductive sinks present on tagged plants increased over the season. Therefore it is likely that decreasing assimilate supply and increasing demand for assimilate may have combined to cause a decline in floret and pod numbers. The decline in growth rate, particularly between anthesis and the immature pod stage over the season supports this hypothesis. This feature of seed development efficiency is typical of legumes (e.g. Tabora and Hill, 1991).

5.4.1.3 Pod Dehiscence

Pod dehiscence occurred readily in 'Marc' pods approximately 10 days after they reached the 'mature' stage. Environmental conditions during this time did not have any obvious effect on pod dehiscence, suggesting that management techniques such as delayed sowing to reduce heat effects on pod dehiscence may not be appropriate to overcome this problem in cv. 'Marc'.

While virtually all pods of cv. 'Marc' dehisced, this was a feature of only a few cv. 'Bayamo' pods and was resticted to only early formed pods which had sufficient time to develop prior to frosting (Figure 5.6b). Some later formed pods may have dehisced if development had not been interrupted by frost damage.

5.4.2 IDENTIFICATION OF OPTIMUM DATE FOR HARVEST

Presentation of inflorescences occurred in marked peaks, the largest of which occurred around 14 March and 16 May in cvs. 'Marc' and 'Bayamo' respectively. This indicates that single destructive harvesting of pods arising from inflorescences produced at peak flowering, if correctly timed, has the potential to produce moderate seed yields. Harvest date was timed so that pods present at peak flowering had reached the mature pod stage. This stage was characterised by having at least half of the pod being brown as opposed to green (cv. 'Marc') or red/green (cv. 'Bayamo'). The pod at this stage had abscised seed had reached maximum dry weight and was already well into the dehydration phase. It was presumed that seed quality was at an optimum level at this point as dry matter accumulation was complete.

Inflorescence numbers per m^2 of cv. 'Marc' at peak flowering agreed with results of plants grown in similar population densities (density trial) indicating that similar effects of population on plant structure occurred (Table 3.4). Much greater numbers of inflorescences were produced at peak flowering in cv. 'Bayamo' plants (Figure 5.4) probably because of a more developed canopy structure (more tertiary branches) at the onset of flowering. This indicates that seed yield recovery from a single pass harvest of cv. 'Bayamo' should be higher than for cv. 'Marc', particularly when differences in seed retention are considered.

Values of SYC for inflorescences produced at peak flowering were favourable for good seed yields for both cultivars. This is because flowering peaks occurred relatively early in the season when environmental conditions were more favourable for growth (assimilate production) and when relatively few alternative reproductive sinks (e.g. other pods) existed (Table 5.4).

'Marc' inflorescences produced at peak flowering took approximately 27 days from anthesis to reach seed maturity and dehisced 10 days later. Thus a relatively small 'harvest window' occurred requiring accurate timing of harvest if maximum recovered seed yields were to be achieved. Approximately 20% of seed presented prior to harvest,

or 12% of seed produced over the entire season, was recovered by combine harvest (Table 5.5). Seed collected by hand at the time of harvest had high germination (~85% normal seedlings), high seed weight (~2.8 g/1000 seed) and high hardseed levels (85%) indicating that seed development had been complete.

In this trial reproductive development of cv. 'Bayamo' inflorescences present at peak flowering was interrupted by frost damage resulting in the harvesting of seed of low seed weight (2.25 g/1000 seeds) and poor quality (low normal germination ~45%; hardseeds ~45%). In the absence of environmental constraints (e.g. if grown in a frost-free environment) cv. 'Bayamo' should produce substantially more seed than cv. 'Marc' due to its higher flowering density. Of note is that the period between maturity for harvest and pod dehiscence was considerably longer for cv. 'Bayamo' than cv. 'Marc'. Thus the proportionately more cv. 'Bayamo' seed arising from inflorescences produced before peak flowering will be harvested along with seed arising from peak flowering. There is also less risk of mis-timing the harvest date. This situation may be different in hotter (30+°C) and drier environments however, where pod dehiscence and the rate of pod development may be greater.

There is clearly a need to find a cue which accurately identifies the correct time of harvest. Although pod colour, as used to identify 'mature' pods in this trial, is a good indicator of readiness to harvest of an individual umbel, visual appraisal of the proportion of mature pods present at one time is a risky method of estimating harvest date. This is because flowering occurred over an extended period and flowering, pod development and pod dehiscence were all occurring at the optimum harvest date.

Regular counting of inflorescences is an easy, if time consuming, method of identifying the date of peak flowering. If peak flowering is identified and the period taken for inflorescences present at peak flowering to become harvestable pods is known, the optimum harvest date is identified.

5.4.3 EFFECTS OF PRE-HARVEST TREATMENTS ON RECOVERED SEED YIELDS

5.4.3.1 Paclobutrazol Application to Modify Crop Development

Application of PCB (1.0 kg ai/ha) during early flowering to cv. 'Marc' grown in the field did not measureably increase harvested seed yields but affected seed quality. Almost half of the total seed collected in the PCB treatment required post-harvest threshing compared to virtually none in the other combine treatments. This indicates that pod structure of 'Marc' pods arising from peak flowering was altered by PCB application or that duration of pod filling was affected. Increased seed retention has been reported in grasses with similar effects on combine harvesting (Martins and Gamble, 1993a; Hampton and Hebblethwaite, 1985a) but not in legumes. The comparatively lower yields of PCB-treated 'Bayamo' plots were similar to the control treatments and post-harvest threshing provided a similar proportion of seed. Frost during seed fill of pods arising from peak flowering probably interfered with PCB effects in 'Bayamo'.

The mean number of inflorescences per plant 24 days after PCB application was nearly double other 'Marc' treatments (Section 5.3.2.2). Duration of a flowering peak 25 days after PCB application to 'Bayamo' plots appeared to be increased compared to other 'Bayamo' treatments. Paclobutrazol applied at similar rates during early reproductive development has increased the number of inflorescences per unit area and reduced flowering spread in legumes with similar growth habits to desmanthus e.g. *Lotus uliginosus* (Tabora and Hill, 1992; Hampton *et al.*, 1989). This was due to an increase in the number of reproductive shoots per unit area (Tabora and Hill, 1992). Similarly, alteration of vegetative structure and the proportion of reproductive sites on the vegetative framework has resulted in increased inflorescence numbers per unit area in more indeterminate legumes e.g. *Trifolium repens* (Section 5.1.2.1). Numbers of branches on different tiers were not counted in this trial so comment on the cause of the changes in inflorescence number would be purely speculative. Despite this, there was no evidence of PCB reducing seasonal flowering duration in this trial.

Increased pod set and retention of pods in *T. repens* (Boelt and Nordestgaard, 1993) and *Medicago sativa* (Askarian *et al.*, 1994) and decreased ovule abortion in *L. uliginosus* (Hampton *et al.*, 1989) have occurred after PCB application. In this trial, however, paclobutrazol had no measurable effect on mean numbers of florets/inflorescence, pods/umbel, seeds/pod (Section 5.3.4.2), rate of pod development, pod dehiscence (Section 5.3.5.2) or efficiency of combine harvest (Section 5.3.6) in either cultivar.

Seed quality of combine harvested 'Marc' seed was poorer in PCB-treated plots than untreated plots for both combined and peg drum threshed seed (Section 5.3.8.1). The effects in cv. 'Bayamo' seed were generally not significant (P=0.05). Mean 'Marc' seed weight (2.33 g/1000 seeds) was low compared to untreated seed (2.88 g/1000 seeds). This was associated with decreased normal germination and increased numbers of abnormal seedlings in acid scarified seed (Table 5.6). Hardseed levels were also 18% lower than in control treatments at harvest. Where it has been reported, PCB has generally had no effect on (Tabora and Hill, 1992; Rijckaert, 1991), or improved, germination performance (Marshall and Hides, 1991b) in forage legumes. Seed weight is also generally increased (Marshall and Hides, 1991b) if any change occurs at all (Tabora and Hill, 1992). Comparison of seed quality findings in this study with the literature indicate that PCB application slowed seed development so that the majority of seed presented at harvest was less developed than in untreated plots i.e. seed was harvested prematurely. However this was not detected in the tagging study (Figures 5.6 and 5.8). The second flowering peak (early April) in PCB treated plots (Appendix 5.4) was higher than in untreated plots (Figure 5.3). Thus at harvest, a higher proportion of less developed seeds is expected in the PCB treatment because proportionately more seeds represent later formed inflorescences. This is considered to be the most likely reason for the high post-harvest threshing requirement and low seed weight, level of hardseed and normal germinations of harvested seed in the PCB treatment.

Application rate of PCB has been shown to be less important than application time in similar legumes e.g. *L. uliginosus* (Tabora and Hill, 1992). The rate used in this trial has previously been shown to affect development in a number of forage legumes (Section 5.1.2.1). Response to PCB in *L. uliginosus* was higher when applied during early

flowering (as in this trial) than when applied during vegetative growth (Tabora and Hill, 1992). This suggests that application occurred at an appropriate time and rate. Paclobutrazol is root absorbed and translocated in the xylem and may be less effective if soil is dry after application (O'Connor, 1994). However, this factor is considered unlikely because water supply to the two cultivars was relatively high after application (Appendix 5.2).

Although PCB appeared to affect reproductive development, results from this trial were inconclusive. Thus a more detailed investigation on the effects of PCB applied at differing rates on plant structure, flowering and development of SYC in the two cultivars used in this trial was conducted in more controlled (glasshouse) conditions (Chapter 6).

5.4.3.2 Chemical Desiccation Prior to Harvest

Chemical desiccation is used in some herbage legume seed crops to reduce vegetative bulk and therefore assist combining ability (Hampton, 1988b). The diquat (0.9 kg ai/ha) applied 11 days prior to the combine harvest of cv. 'Marc' caused widespread defoliation, cessation of flowering and abscission of immature pods 3 to 4 days after application. However desiccation did not increase combine harvested yields compared to the control treatment (Table 5.2).

Instead differences in seed quality were more likely. Combine harvested seed of desiccated plots had significantly higher normal germination (76.5%) than all other cv. 'Marc' treatments (Table 5.6). The proportion of hardseed (61.5%) was significantly higher than all other 'Marc' / combine treatments except the glue treatment. These results most likely reflect the presence of fewer immature pods at harvest due to induced green pod abscission in desiccant treatments. As a result less damage probably occurred from threshing during combine harvesting, hence the higher percentage normal germination compared to other 'Marc' treatments. Mean seed weight in the desiccant treatment was significantly ($P=0.05$) lower than that of the control. Premature abscission approximately 5 days before harvest probably contributed to this because it would have interrupted seed fill in immature pods. Similar effects of diquat application (0.5 kg ai/ha

+ wetter) on hardseededness, germination and seed weight have been reported in combine harvested *Medicago sativa* (Moyer *et al.*, 1996).

5.4.3.3 Use of Adhesive Sprays to Decrease Pod Dehiscence Losses

Glue (PVA 133 1 product/ha; 1:10 dilution in water and spraying to runoff) was applied 11 days prior to harvest of cv. 'Marc' in an attempt to increase seed yields by reducing pod dehiscence. The treatment was only conducted on cv. 'Marc' because pod dehiscence was not widespread in cv. 'Bayamo' plots. The glue formed a dense layer on foliage and pods as evidenced by a 'whitening' of the plots. Plant growth and flowering prior to harvest were visually not affected.

Mean inflorescence numbers per plant were typically low in this treatment (Appendix 5.7) even before glue application. Thus low harvested yields would be expected. The harvest efficiency index, however, was similar to other cv. 'Marc' treatments (Table 5.5) indicating that the glue treatment provided no advantage over untreated plots. All seed quality indices were very similar to untreated plots (Table 5.6) indicating that the glue treatments had no effect on seed quality.

Pod dehiscence occurred during harvest indicating that at least some advantage (particularly of harvest efficiency) would be expected if increased seed retention occurred. As this did not occur, it must be assumed that the glue was ineffectual. One possible reason is that pods are located throughout the canopy and therefore many may not have been adequately covered by the glue during spray application. In seed crops where glues are used (e.g. grasses, carrots and onions), the seedhead is generally presented above the canopy (Loch and Harvey, 1983). Loch and Harvey (1983) suggested that additives such as wetting agents should be added to adhesives to promote penetration into the seed head of grasses. This may also apply to desmanthus. However the potential use of glues to reduce losses associated with pod dehiscence is considered to be limited and is certainly not a priority for further research.

5.4.4 HARVESTING OPTIONS FOR DESMANTHUS SEED CROPS

5.4.4.1 Single Pass Destructive Harvest

The combine harvester and keyhole harvester systems are both included in this category because they either cut or 'leaf stripped' plants allowing little subsequent regrowth.

Cultivar 'Marc'

Relatively low seed yields occurred in cv. 'Marc' plots following the use of either harvest system with only approximately 12% of total seed presented over the season being harvested. Although total seed yields did not significantly differ between harvest methods nearly 45% of the seed finally recovered in the keyhole treatment was obtained by rethreshing intact pods (peg-drum) whereas combine harvesting threshed virtually all pods (Table 5.3). The seed recovered by post-harvest threshing was of moderate quality (~45% normal germination) and should therefore be recovered if possible. This recovery could be completed commercially by some form of post-harvest threshing or possibly by sweating pods and collecting fallen seed.

Germination characteristics and percentage hardseededness were higher in keyhole harvested seed than when harvested by combine. Seed weight was not affected presumedly because both treatments had identical management prior to harvest and thus had similar seed development characteristics. The lower level of hardseededness is probably due to mechanical scarification occurring during threshing with the combine harvester. Mechanical scarification of desmanthus seed results in water entry through damage to the otherwise impermeable seed coat or disruption of the strophiole (Hopkinson, 1993). Microscopic examination of seed showed evidence of damage to the seed coat but relatively few strophioles breached. Currently desmanthus seed is mechanically abraded prior to sale to increase the rate and extent of germination. Abrasion of the seed coat during combine harvesting will reduce this requirement but further abrasion may still be likely in order to reduce the proportion of hardseeds prior to sale. Harvest treatment differences in hardseed levels point to the need to measure hardseed levels prior to abrasion in order to avoid over- or under-abrading seed. The

slightly lower proportion of normal seedlings present in combine harvested plots is probably due to damage to (soft, immature) seed during threshing, a situation which would be further exacerbated by subsequent acid scarification. Widening the concave clearance and / or reducing drum speed may overcome this problem but may also decrease seed recovery and threshing effectiveness.

Cultivar 'Bayamo'

Total seed yields of keyhole harvested seed were much lower than combine harvested seed. Again, however, post-harvest threshing of keyhole harvested pods produced similar amounts of seed in both treatments (Table 5.3). Pods arising from peak flowering were less developed (thinner) than for cv. 'Marc'. The keyhole harvester removed these pods less efficiently from the standing crop (Table 5.5) than the combine harvester. Seed germination characteristics, percentage hardseed and seedweight did not differ significantly between harvest treatments, being generally poor due to abscission of pods. It is suggested that keyhole harvesting of a 'Bayamo' stand whose development had not been interrupted by frost would have produced similar, perhaps even greater seed yield than cv. 'Marc'.

5.4.4.2 Multiple Pass Systems

Both cultivars presented seed over a prolonged period (> 80 days). This may have even been longer in the day-neutral cv. 'Marc' if sowing had occurred earlier. This suggests that more than one harvest could be obtained from the same crop in one season, particularly in cv. 'Marc'. Regrowth and flowering after destructive harvest by either combine or keyhole harvesting of both cultivars was poor probably due to low temperatures, declining photoperiod and moderate water supply to the crop (Appendix 5.2). Adjei and Pitman (1993) reported poor spring regrowth of desmanthus when plants were cut late during reproductive development whereas regrowth was more vigorous if cutting occurred during early reproductive growth. Cutting of 'Marc' earlier than occurred in this trial (e.g. at maturation of early formed seed when basal buds are still present), in combination with earlier sowing, may provide the opportunity for two harvests per season because regrowth is more likely to occur.

Earlier sowing (November) of cv. 'Marc' in the radial trial resulted in seed being presented from mid-February although seed arising from peak flowering was presented around 20 April. Harvest during this period would allow regrowth in warmer conditions with greater photoperiods. Heavy irrigation after harvest would also encourage regrowth of another vegetative framework. Two harvests, one during February/March and another during June/July, may therefore be feasible. Harvesting of cv. 'Marc' may occur even earlier at warmer sites such as the Atherton Tableland because crops can be sown earlier and rate of development is expected to be higher. However there would be more risk of harvesting (first harvest) in wetter conditions because of the high incidence of summer rains in this district (Table 4.34) and more risk of cold temperatures and frost slowing or prematurely terminating pod development of inflorescences arising after the first harvest. Choice of site to avoid these conditions is important.

The use of the keyhole harvester for the first harvest should also improve the rate of regrowth because more stem material (the height of the original canopy) remains intact than with the combine harvester (reduced to cutting height). The potential to improve keyhole-type harvesting is considered to be limited because, unlike most other stripper harvested crops, desmanthus pods are presented throughout the canopy. This results in considerable amounts of vegetative matter needing to be removed to maximise seed yield. Alteration of stripper speed or keyhole size is unlikely to improve this.

Further work will be required before multiple cropping of desmanthus seed can be recommended. The potential for this, however, is limited to day-neutral flowering types such as cv. 'Marc'.

5.4.4.3 Recovery of Fallen Seed

The final harvesting option is to collect fallen seed from the ground by either brush or vacuum harvester, a technique recommended for use in other strongly indeterminate seed crops which present only a small proportion of seed for destructive harvest e.g. *Macroptilium atropurpureum* (Hopkinson and Loch, 1973). This is an attractive alternative because it provides the opportunity to collect a large amount of seed which has reached harvest maturity. In this trial nearly 90% of 'Marc' seed presented was not collected by other harvesting processes (Table 5.3). Whereas multiple-cropping may improve seed recovery it is still likely that most of the seed produced for harvest in cultivars which have high levels of pod dehiscence will not be recovered.

Wet soil conditions can interfere with vacuum harvesting (Hopkinson and Vicary, 1974). However, dry conditions at the end of the desmanthus seed production period (June / July) are conducive to ground recovery (Table 4.34). Beating (to promote the fall of any remaining seed) and removal of trash would be easy to conduct e.g. by mowing into windrows and moving these as required. Obtaining a suitable vacuum or brush harvester may be difficult although an experimental vacuum harvester has been used in desmanthus seed crops with some success (Hopkinson pers. comm., 1995). When available, vacuum harvesting may be limited by other machinery e.g. small tractors (<45 kW brake power) have been inadequate in previous vacuum harvesting attempts (Hopkinson and Vicary, 1974).

Other disadvantages associated with fallen seed recovery include slowness of harvest, a high cleaning requirement, loss of, or damage to, topsoil and the collection of weed seeds which were present prior to, as well as during, crop development. Consideration of cultivar purity is also clearly important i.e. once one cultivar has been produced on one site, another cultivar cannot be produced on that site. This is not so much a problem in destructive harvesting systems provided there is adequate control of the previous crop because fallen seed is not being collected.

Vacuum or brush harvesting will also not recover all fallen seed. Some will inevitably be lost down cracks, blown or washed away or removed by animals. Some seed can become scarified by movement in the soil (Hopkinson, 1993) and germinate before harvest. Between 55 and 80% of fallen *Macroptilium atropurpureum* seed has been recovered from soil by vacuum harvest although there were considerable post-harvest cleaning losses (Hopkinson and Vicary, 1974). Seed recovery of this magnitude indicates that recovery of fallen seed by vacuum harvesting is likely to be beneficial in desmanthus seed crops.

5.5 Conclusion

Environmental conditions in South-East Queensland are considered marginal for seed production of late flowering desmanthus cvs. 'Bayamo and 'Uman' but are suited to the earlier flowering cv. 'Marc'. Despite this, combine harvested seed yields of cv. 'Marc' were low (~200 kg seed/ha) which represented approximately 12% of seed produced by the stand over the season. Combine harvesting can also damage seed during threshing and reduce hardseededness altering the requirement for post-harvest scarification of seed.

Methods used to increase combine harvested seed yields had limited success. Application of paclobutrazol during early flowering appeared to increase flowering intensity but did not increase harvested seed yields. However, more detailed evaluation of this chemical is required. Chemical desiccation of cv. 'Marc' plots with diquat 11 days before harvest increased seed quality and may improve recovered seed yields in commercial practice. The use of a glue to reduce pod dehiscence has little potential in desmanthus seed crops.

Harvest by keyhole harvester showed no significant benefits over combine harvesting and had the disadvantage of requiring post-harvest threshing of pods. Collection of fallen seed by vacuum or brush harvesting during winter has the potential to considerably increase harvested seed yields. Studies need to completed on seed dynamics in the soil and the effectiveness of seed recovery by these methods. Two destructive harvests per season may also increase seed yield in early flowering desmanthus types such as cv. 'Marc' sown during November / December. Later sowings can only be destructively harvested once.

CHAPTER SIX
THE EFFECTS OF PACLOBUTRAZOL ON REPRODUCTIVE DEVELOPMENT OF EARLY AND LATE FLOWERING DESMANTHUS CULTIVARS

6.1 Introduction

Results from Chapter 5 indicated that paclobutrazol (PCB) applied during early flowering to 'Marc' and 'Bayamo' plants altered flowering intensity and duration respectively, approximately 25 days after application. Paclobutrazol may therefore have potential to increase combine harvested seed yields, particularly in 'Marc' which readily sheds seed. However, the field trial was inconclusive because of high variability.

Changes in flowering intensity and duration as a result of PCB application are usually associated with changes in the vegetative structure of the plant. These changes may also alter the harvesting characteristics of the plant and influence recovered seed yield (Section 5.1.2.1). Vegetative measurements were not taken in the field trial. This is a significant omission when studying the effects of plant growth regulators.

One application rate of PCB (1.0 kg ai/ha) and one application time (onset of flowering) was used in the field evaluation of PCB on desmanthus. However, application rate and date have been shown to affect seed yield response to PCB in legumes (Askarian *et al.*, 1994; Tabora and Hill, 1992; Rijckaert, 1991). These features have likely contributed to the high variability and hence the inconclusiveness of the field trial. Despite this, the potential for altering plant architecture, seeding ability and improved harvest efficiency following the PCB application was sufficiently promising to warrant more intensive study under more controlled conditions. For this reason a further trial was completed in a glasshouse to determine the effects of application rate and date of PCB on vegetative and reproductive development in desmanthus. Self-pollination rates, and therefore the need for pollinators for seed production, could also be assessed because the glasshouse was free from insect pollinators.

6.2 Materials and Methods

6.2.1 DESIGN

Six treatments were replicated eight times in a randomised complete block design. Both cultivars were expected to be similarly affected by PCB application because both have extended flowering periods and present most of their inflorescences on similar parts of the plant canopy (i.e. secondary and tertiary branches). Therefore investigation into the effect of application rate (0, 0.5 and 1.0 kg ai/ha) and application time (early flowering and peak flowering) was only conducted on cv. 'Marc' in order to minimise measurements (Table 6.1). Paclobutrazol application to 'Bayamo' was limited to a single treatment, 1.0 kg ai/ha applied at early flowering. This treatment is identical to that used in the field trial (Chapter 5) and is similar to PCB applications which have increased seed yields in other legumes (Section 5.1.2.1).

6.2.2 MANAGEMENT

'Marc' and 'Bayamo' seed was acid scarified (Appendix 3.2) and germinated (top of paper; 20/35°C (16/8 hr), 12/12 L/D) on 1 July 1996. When the radicle had emerged (48 hours) seeds (2 per pot) were sown to a depth of 5 mm into sterilised (3% solution of sodium hypochlorite) pots (3 l capacity) containing 5 cm of washed gravel covered with topsoil collected from the site of the harvest trial (see Section 5.2.2 for details). The pots were placed in blocks in an elevated (1 m) and central position in the glasshouse. There were no evident environmental gradients within the glasshouse. Pots were spaced approximately 45 cm apart to allow for expansion during growth and to reduce tangling of branches which could interfere with monitoring. Glasshouse temperature and humidity were controlled by thermostat (25°C constant), however fluctuations (+/- 5°C maximum) occurred on some days. These were recorded using a thermo-hygrograph.

Table 6.1 **Date and rate of paclobutrazol application to *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

Treatment	Cultivar	Application date	Stage of plant development	Rate (kg ai/ha)
1	'Marc'	-	-	-
2		28 August	onset of flowering	0.5
3		28 August	onset of flowering	1.0
4		15 October	peak flowering	1.0
5	'Bayamo'	-	-	-
6		28 August	onset of flowering	1.0

At the time of sowing (3 July 1996) short-day conditions (~11 hours) prevailed. Artificial light (99 minutes using 16 X 75 W incandescent bulbs 30 to 40 cm apart and located along the apex of the glasshouse roof) was provided just after sunset to extend daylength to 12 to 13 hours. This left a dark period of 11 to 12 hours, allowing flowering in both 'Marc' and 'Bayamo'. *Rhizobium* (CB3126) was applied by pouring 50 ml of inoculum / water solution (20 g/l water) into each pot after 7 days. Plants were thinned to one healthy plant per pot when they reached the two true leaf stage (17 July). Each pot was irrigated for 5 seconds every 2 days by hand held sprinkler. No moisture deficiency symptoms were observed. The glasshouse used had only one major entry point (door) which included two doors in sequence, at least one of which was closed at virtually all times. The only insects observed in the glasshouse were cockroaches *(Periplaneta americana)* which were controlled when sighted by insecticide (bendiocarb at 12 g ai/5 l water sprayed to surfaces) (Loch pers. comm., 1997). Both cultivars grew vigorously.

Timing of PCB application was determined by measuring flowering appearance rate. In order to apply the PCB, plants to be sprayed were removed from the glasshouse and placed in two lines 1.5 m apart. Paclobutrazol (Cultar) was applied using a propane pressurised 'Azo' chest-mounted boom sprayer at a constant spray pressure of 200 kPa. Eight taper fan (Delavan LF2-80) nozzles offset at 10° provided a swath width of 2.65 m. After calibration, constant rate of travel was achieved using a metronome to regulate walking speed for a comfortable stride length. Sufficient spray to cover 10 m was mixed with water and walking speed calibrated with the metronome. The plants were sprayed

between 3 and 7 m of the spray-run. Spraying was always conducted in still, warm conditions. Inspection of pots after application showed the soil to be moist indicating that the chemical had reached the soil surface. Once returned to the glasshouse all pots were lightly watered to ensure PCB penetration into soil.

6.2.3 MEASUREMENTS

Flower pattern was determined by counting and marking all fully expanded inflorescences and fully expanded young pods on different branching tiers of all plants. Expanded inflorescences and young pods were tagged with different coloured correcting fluid to avoid double counting. Flower counts were conducted every 3 or 4 days over the season beginning on 22 and 28 August for the 'Marc' and 'Bayamo' pots respectively.

At the time of PCB application, and again 2 weeks later, two reproductive sites per plant which contained swelling florets but which had not fully expanded, were tagged on the stem immediately below the peduncle with different coloured tape to differentiate between the two. The number of florets per inflorescence at tagging was recorded. The tagged sites were monitored every 2 days and seed yield components (SYC) recorded as they occurred. These included:

(a) numbers of immature (just fully expanded) pods, mature pods (>50% brown) and seeds per immature and mature pod

(b) times (days) to 'pollination' (first sign of pod emergence), young pod, late pod and dehisced pod.

At the end of the trial (11 November, when pods arising from peak flowering of 'Marc' plants reached maturity) plants were cut at the soil surface and dissected into structural components which were then measured. Branch number per tier was recorded before the plants were divided into leaf and stem, and immature, mature and dehisced pods. Pod number (immature, mature and dehisced) was recorded separately by tier and averaged by the number of sites from which they came. Leaf and stem matter was dried to constant weight (60°C for 48 hours, forced draft) and weighed by tier.

6.2.4 STATISTICS

Data was analysed using SAS statistical software. Means and standard errors were generated and graphed to identify trends. Means were compared using analysis of variance (complete data) and general linear model (incomplete data) procedures. Treatment means with a significant F value were compared using Fischer's protected least significant difference test (P=0.05). If data was incomplete LSmeans were generated and compared using the 'PDIFF' option.

6.3 Results and Discussion

6.3.1 FLOWERING

6.3.1.1 Untreated Plants

Flowering began 44 (16 August) and 54 (26 August) days after sowing in 'Marc' and 'Bayamo' respectively. Over 80% of plants of both cultivars carried at least one fully expanded inflorescence 10 days after the beginning of flowering. However, plant growth stage at the start of flowering was different between cultivars. 'Marc' began to flower after 8 or 9 leaves had been produced on the main stem and generally before branching had begun. In 'Bayamo' however, flowering did not occur until at least 13 leaves were produced on the main stem and at least 4 branches had been produced from basal leaf axils.

Peak flowering occurred approximately 103 and 89 days after sowing in 'Marc' (Figure 6.1a) and 'Bayamo' (Figure 6.1b) respectively. Secondary branches contributed more than 70% of total inflorescence number per plant at peak flowering in both cultivars (Table 6.2) although 'Bayamo' plants produced significantly more inflorescences at peak flowering and over the season than 'Marc'. Flowering continued until the end of the trial (131 days after sowing) (Figure 6.1a) although at a lower level. At harvest, secondary branches contained most inflorescences (Table 6.3).

6.3.1.2 Treated Plants

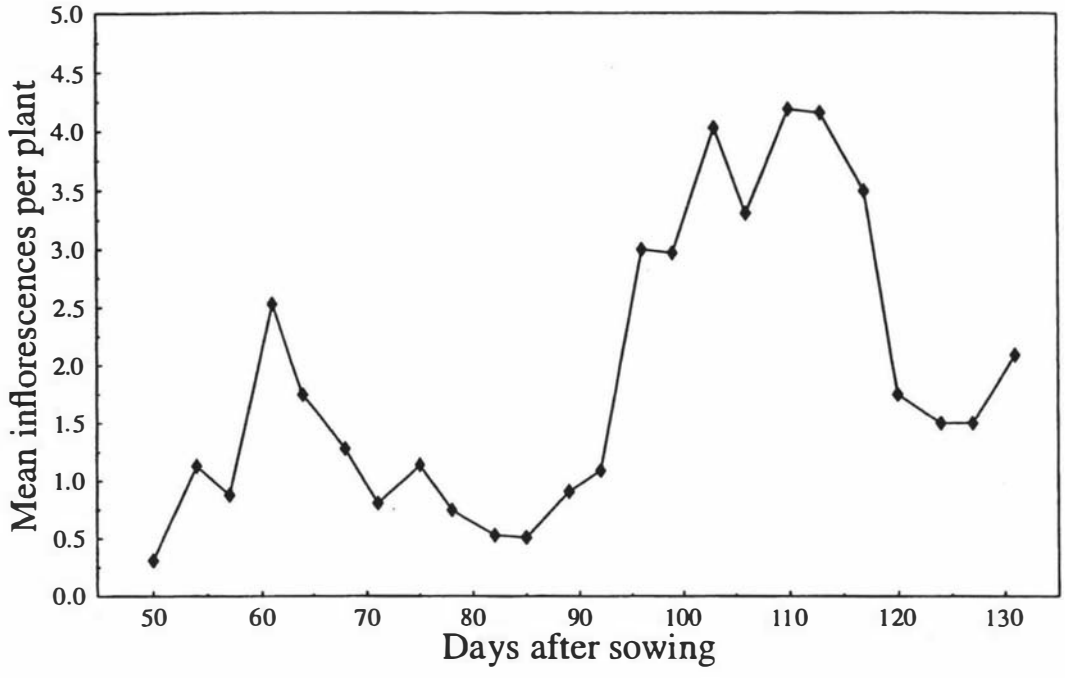
Flowering patterns for treated and untreated plants were similar for both cultivars (Figures 6.1a and 6.1b). For this reason it was decided to evaluate treatment effects on:

(a) mean inflorescence number per plant at peak flowering to estimate the benefits of PCB for use under conventional destructive harvest systems, and

(b) mean total inflorescence number produced by plants over the trial period to estimate benefits for harvest systems involving recovery of the fallen seed (e.g. vacuum harvest systems).

Figure 6.1 **Flowering patterns in *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' averaged over all paclobutrazol treatments.**

A. Cultivar 'Marc'



B Cultivar 'Bayamo'

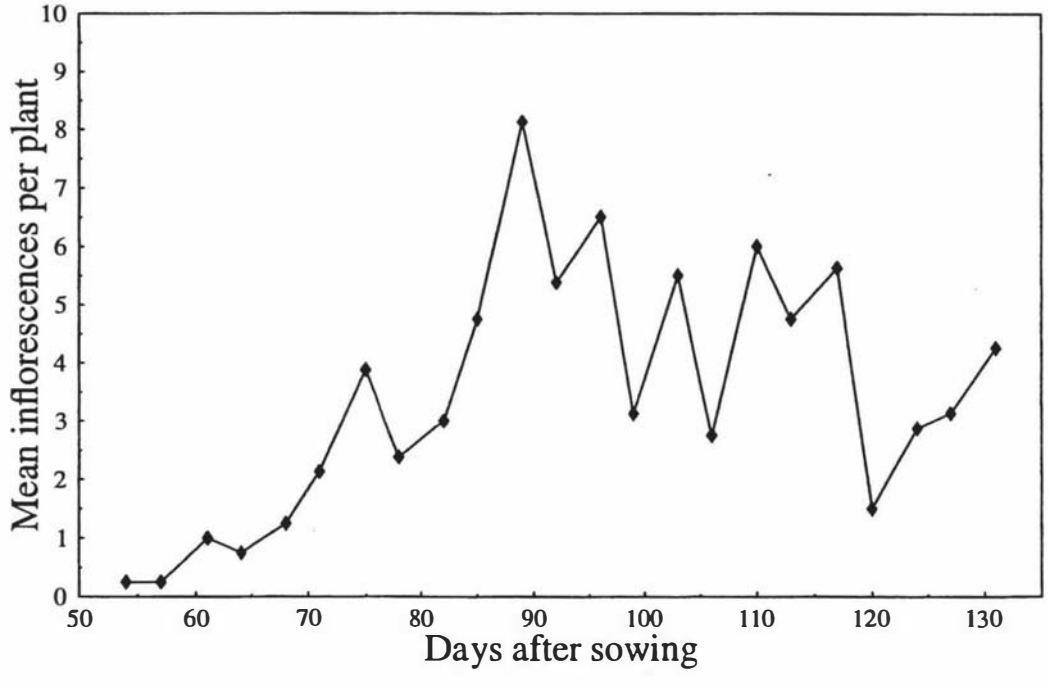


Table 6.2 **Effects of paclobutrazol application on mean inflorescence number per plant at peak flowering and total inflorescences presented over the season of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' grown in a glasshouse.**

Treatment	Mean inflorescences per plant at peak flowering				Total inflorescences presented per plant			
	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
'Marc' 28 August (0 kg ai/ha)	0.63 b[1]	3.25 b	0.00 b	3.88 b	14.00 b	26.38 d	0.13 c	37.50 d
'Marc' 28 August (0.5 kg ai/ha)	0.13 b	4.25 b	0.00 b	4.38 b	13.38 b	41.13 bc	0.13 c	50.50 c
'Marc' 28 August (1.0 kg ai/ha)	0.13 b	4.00 b	0.00 b	4.13 b	12.63 b	36.13 c	0.00 c	46.00 c
'Marc' 15 October (1.0 kg ai/ha)	0.50 b	3.63 b	0.25 b	4.38 b	15.13 b	27.50 d	0.25 c	42.50 cd
'Bayamo' 28 August (0 kg ai/ha)	1.03 ab	4.16 b	0.31 ab	5.50 b	23.21 a	47.09 b	2.31 b	74.00 b
'Bayamo' 28 August (1.0 kg ai/ha)	1.78 a	7.66 a	0.81 a	10.25 a	23.21 a	62.35 a	6.81 a	95.75 a

[1] LSmeans with the same letter are not significantly different (P=0.05)

Paclobutrazol application to 'Marc' plants at the onset of flowering resulted in similar inflorescence number per plant at peak flowering (110 days after sowing) as untreated plants (Table 6.2). However, at the date identified as peak flowering (89 days after sowing) 'Bayamo' plants treated with PCB (1.0 kg ai/ha) had substantially higher inflorescence numbers than untreated plants (Table 6.2).

Total season inflorescence number was significantly (P=0.05) higher in all PCB treatments in both cultivars except when applied during peak flowering to 'Marc' (Table 6.2). These closely reflected inflorescence numbers arising on the secondary branches. However, first application of PCB occurred when inflorescences were being produced on the main stem only. This indicates that PCB delayed inflorescence production. Paclobutrazol significantly increased secondary branches in 'Marc' but not 'Bayamo' (Table 6.3). Mean branch length was not affected by PCB application. This is surprising because PCB inhibits gibberellic acid biosynthesis (Hedden, 1990 as cited by Budhianto *et al.*, 1994a) and therefore generally decreases apical dominance. Increases in inflorescence numbers appear to be due to a combination of increased numbers of reproductive sites due to increased branching ('Marc') and increased utilisation of available sites ('Marc' and 'Bayamo'). Measurements which would differentiate between the two were not conducted, however.

Paclobutrazol increased inflorescence number over the season by approximately 30% in both cultivars, indicating that it has potential to increase seed yields in desmanthus seed crops. It should be remembered that this trial was conducted under controlled conditions and that factors encountered in the field may interfere with responses e.g. branching of desmanthus plants is strongly influenced by plant population (Section 3.3.2.2). In this trial plants were spaced approximately 50 cm apart. This is substantially further apart than in commercial practice and branching was not restricted as would be expected to occur when seed was sown at recommended rates. Closer plant spacings would probably decrease the effect of PCB on flowering and may partially explain the smaller flowering response to PCB application recorded in the field trial (Section 5.3.2.2).

Table 6.3 **Effects of paclobutrazol treatments on plant structural components at final harvest of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' grown in glasshouse conditions.**

Treatment	Branch number Tier 2	Branch number Tier 3	Total branch number	Branch length (cm)	Branch weight (g DM)	Leaf weight (g DM)
'Marc' 28 August (0 kg ai/ha)	8.12 c[1]	0.25 ab	8.38 b	43.02 a	8.43 b	4.29 bc
'Marc' 28 August (0.5 kg ai/ha)	13.25 a	0.25 ab	13.50 a	39.65 a	8.34 b	4.95 b
'Marc' 28 August (1.0 kg ai/ha)	10.50 b	0 b	10.50 b	39.93 ab	6.96 c	4.40 bc
'Marc' 15 October (1.0 kg ai/ha)	8.00 c	0 b	8.00 b	34.91 ab	8.12 bc	3.68 c
'Bayamo' 28 August (0 kg ai/ha)	9.50 bc	1.37 ab	10.85 ab	25.85 c	11.20 a	7.82 a
'Bayamo' 28 August (1.0 kg ai/ha)	8.75 bc	1.63 a	10.34 ab	34.11 abc	8.18 bc	7.20 a

[1] LSmeans with the same letter are not significantly different (P=0.05)

6.3.2 EFFECTS OF PACLOBUTRAZOL ON SEED YIELD COMPONENTS

In legumes, paclobutrazol generally has a greater effect on inflorescence number per plant than other seed yield components (Section 5.1.2.1) but has also been shown to influence seed weight and seeds per floret in *Trifolium repens* (Marshall and Hides, 1991b) and seeds per pod in *Lotus* spp. (Hampton *et al.*, 1989). Paclobutrazol had little effect on SYC and rates of pod development in this trial.

6.3.2.1 Numbers of Reproductive Structures

Mean numbers of florets per inflorescence and immature and mature pods per umbel of untreated plants (Table 6.4) were lower than earlier recorded in the field at similar stages of growth (Figures 5.8a and 5.8b). Nevertheless floret and pod survival was similar. The PCB treatments slightly increased numbers of florets per inflorescence in both cultivars but this was only significant (P=0.05) in 'Marc' at the first application date (Table 6.4, Appendices 6.1 and 6.2). Although floret numbers per inflorescence showed some response to PCB, this did not result in increased numbers of immature pods or mature pods per umbel (Table 6.4, Appendices 6.1 and 6.2).

Mean numbers of seeds per pod were generally lower in 'Bayamo' than 'Marc' (Table 6.4) and were not affected by PCB (Table 6.4, Appendices 6.1 and 6.2). Seed weight was not measured because of inadequate sample size.

6.3.2.2 Pod Development

'Bayamo' pods arising from the onset of flowering took about 10 days longer to develop (approximately 40 days from anthesis to pod dehiscence) than 'Marc' pods (Table 6.4, Appendix 6.1). This is similar to comparative rates recorded in the field during early flower development (Section 5.3.4.1). Paclobutrazol treatments had no measurable effect on pod development in both cultivars (Table 6.4, Appendix 6.1).

Table 6.4 **Effects of paclobutrazol treatments on selected seed yield components of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' grown in glasshouse conditions.**

Cultivar	Treatment	Florets/ inflorescence	Immature pods (IP) /umbel	Mature pods(MP) /umbel	% florets that form IP	% IP that form MP	Days from anthesis to IP	Days from IP to MP	Days from MP to dehiscence	Seeds/ pod
'Marc'	28 August (0 kg ai/ha)	4.47 c[1]	2.64 ab	2.41 a	40.42 a	94.42 a	8.48 cd	14.77 ab	8.77 bc	22.51 ab
	28 August (0.5 kg ai/ha)	4.87 bc	2.51 b	2.59 a	46.06 a	90.77 a	7.19 de	16.65 a	4.98 c	22.63 ab
	28 August (1.0 kg ai/ha)	5.41 ab	2.31 b	2.30 a	38.43 a	91.77 a	8.55 c	15.54 ab	9.28 b	20.12 b
	15 October (0 kg ai/ha)	5.36 ab	2.90 ab	-	31.34 a	-	5.37 f	15.20 ab	-	23.80 ab
	15 October (1.0 kg ai/ha)	6.03 a	2.29 b	-	28.40 a	-	6.79 ef	13.25 b	-	25.53 a
'Bayamo'	28 August (0 kg ai/ha)	6.00 a	3.54 a	3.17 a	47.41 a	84.77 a	10.56 b	15.18 ab	16.40 a	16.14 c
	28 August (1.0 kg ai/ha)	6.38 a	3.09 ab	3.08 a	41.48 a	93.83 a	10.74 a	13.73 b	13.55 ab	19.29 bc

[1] LSmeans with the same letter are not significantly different (P=0.05)

6.3.3 EFFECTS OF PACLOBUTRAZOL ON PLANT STRUCTURE AT TRIAL COMPLETION

6.3.3.1 Vegetative Structures

Paclobutrazol increased secondary branches in 'Marc' but not in 'Bayamo'. Paclobutrazol also had no effect on mean branch length, branch mass or leaf mass although the cultivar effect was significant (Table 6.3).

6.3.3.2 Reproductive Structures

The numbers of immature and mature pods on each branching tier present at the end of the trial are presented in Tables 6.5a and 6.5b. Measurements were conducted when inflorescences arising from peak flowering of 'Marc' had formed mature (harvestable) pods (Appendix 6.1). Thus immature pods present at the end of the trial represent pods that developed after the second (October 15) application of PCB (1.0 kg ai/ha). This application did not affect the number of immature 'Marc' pods present at the end of the trial (Table 6.5a). This would be expected if the branching, and therefore flowering, response was delayed similarly to when PCB was applied at the onset of flowering. August PCB applications (0.5 and 1.0 kg ai/ha) both increased the number of immature 'Marc' pods present at final harvest, however. This reflects the flowering response observed in these treatments at peak flowering (Section 6.3.1.2). Similar results occurred in August treated 'Bayamo' plants (1.0 kg ai/ha) (Table 6.5a).

Dehisced pods present at the end of the season arose from inflorescences present before peak flowering of 'Marc' (and therefore prior to the later PCB application) and during, or prior to, peak flowering of 'Bayamo'. 'Marc' plants treated with PCB during early anthesis had more mature pods present at final harvest than untreated plants (Table 6.5b) even though differences were not large and were only significant (P=0.05) in the 0.5 kg ai/ha application.

Treatment effects were much stronger in 'Bayamo' where PCB application (1.0 kg ai/ha) doubled the number of mature umbels. This is simply a result of the effect of PCB on 'Bayamo' inflorescence number per plant at peak flowering and subsequent development of these inflorescences (Section 6.3.1.2).

The mean number of immature and mature pods per reproductive site at completion of the trial was not affected by the PCB treatments (Table 6.5a and 6.5b). This confirms results in the tagging study conducted as part of this trial (Section 6.3.2.1).

6.3.3.3 Other Factors Which Could Affect Paclobutrazol Performance

Paclobutrazol is most effective when applied directly to soil (O'Connor, 1994). In both of the trials in this study PCB was sprayed onto foliage although soil contact was observed in the glasshouse trial. Alternative application methods (e.g. trickle irrigation systems) may increase soil contact and therefore effectiveness, as well as reducing required application rates.

The delayed effect of PCB suggests that application at the onset of flowering or earlier will best increase seed yields. Application of PCB to legumes with similar obstacles to seed production as desmanthus (e.g. *Lotus* spp.) has shown greater seed yield responses when reproductive nodes are present (just before the onset of flowering) than when applied earlier at reproductive node initiation (Hampton *et al.*, 1989). This suggests that an application at the onset of flowering is most likely to benefit seed production. Further research will be required to confirm this.

Table 6.5 **Effects of paclobutrazol treatments on mean number of umbels and mean number of pods per umbel of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo'.**

A. Immature Pods

Treatment	Umbels containing immature pods				Pods per umbel
	Tier 1	Tier 2	Tier 3	Total	
'Marc' 28 August (0 kg ai/ha)	0.13 b[1]	7.13 c	0.13 ab	7.38 c	2.30 a
'Marc' 28 August (0.5 kg ai/ha)	0 b	12.25 ab	0 b	12.25 ab	2.26 a
'Marc' 28 August (1.0 kg ai/ha)	0.88 b	10.88 ab	0 b	11.75 b	2.45 a
'Marc' 15 October (1.0 kg ai/ha)	0.50 b	5.12 c	0 b	5.63 c	2.35 a
'Bayamo' 28 August (0 kg ai/ha)	0.63 b	8.28 bc	0.72 a	9.63 bc	1.95 a
'Bayamo' 28 August (1.0 kg ai/ha)	0.38 a	14.03 a	0.72 a	17.13 a	2.22 a

B. Mature Pods

Treatment	Umbels containing mature pods				Pods per umbel
	Tier 1	Tier 2	Tier 3	Total	
'Marc' 28 August (0 kg ai/ha)	1.75 d[1]	7.75 c	0 b	9.50 c	2.50 a
'Marc' 28 August (0.5 kg ai/ha)	2.25 bcd	12.37 b	0 b	14.63 b	2.32 ab
'Marc' 28 August (1.0 kg ai/ha)	1.38 d	10.25 bc	0 b	11.63 bc	2.12 b
'Marc' 15 October (1.0 kg ai/ha)	3.25 bc	8.50 bc	0 b	11.75 bc	2.49 a
'Bayamo' 28 August (0 kg ai/ha)	1.84 bcd	12.09 bc	0 b	13.94 bc	2.32 ab
'Bayamo' 28 August (1.0 kg ai/ha)	7.84 a	18.09 a	0.75 a	26.69 a	2.10 b

[1] Means with the same letter are not significantly different (P=0.05)

6.3.3.4 Economic Benefits of Using Paclobutrazol

Cultar (250 g PCB/l product) retails at A$289.02 (22 April, 1998; IAMA, Gympie). Thus application rates of 0.5 kg ai/ha and 1.0 kg ai/ha as used in this trial will cost $578/ha and $1156/ha respectively for the chemical alone. At the current contract seed price to growers of $5 per kg of clean seed (Wrightson Seeds Ltd. pers. comm., 1995) an extra 231 kg of seed would need to be produced in PCB treated plots just to recoup 1.0 kg ai/ha chemical costs. Since most desmanthus seed crops yield less than 1000 kg seed/ha, PCB application would need to increase recovered seed yield by at least 25% to be profitable. Even under 'perfect' growing conditions (glasshouse) the addition of PCB only increased inflorescence numbers by approximately 30% over the entire season. This suggests economic benefits would be marginal. Consequently, the use of PCB in desmanthus is unlikely to be economically viable.

One consideration is the possible effect of PCB on subsequent harvests. Paclobutrazol residue in soil has affected growth (decreased plant height and DM) of legume crops (*Vicia faba*) sown 200 days after PCB application (1.0 kg ai/ha) to *Lolium perenne* (Hampton, 1988a). All cultivars of desmanthus will either be resown or begin second season growth within 200 days of harvest. This suggests that PCB could affect desmanthus growth if resown in the same site or produced as a perennial crop. This could affect the economic benefit of PCB application to desmanthus. Poor second year growth of desmanthus suggests that crops will be annual in which case PCB residues are more likely to affect seedling desmanthus, an area which has not been studied. Residual activity of PCB could also affect the growth of other crops sown in the season after desmanthus seed crops. This limits the number of crops which can be sown after desmanthus seed crops.

6.3.4 SELF-POLLINATION RATES OF 'MARC' AND 'BAYAMO'

In this trial selfing rates, interpreted as the proportion of perfect florets per inflorescence which formed immature (fully expanded but not abscised) pods, ranged from 0 to 100% (data not presented). Mean floret survival was highest at the beginning of flowering (43.75 to 61.27% in 'Marc' and 48.08 to 48.54% in 'Bayamo') and declined 2 weeks later, particularly in 'Marc' (Appendix 6.1). Floret survival at peak flowering and 2 weeks after peak flowering ('Marc' only) was lower (28.04 to 39.35%) than floret survival at the beginning of flowering (Appendix 6.1).

No insects were observed on the plants during the trial and it is considered unlikely that any insect pollination occurred. Consideration of previous literature (Luckow, 1993; Latting, 1961) and results from this study leaves little doubt that *D. virgatus* is self-compatible. The extent and regulation of cross fertilisation is less certain. Leguminous plants range from autogamous plants to obligatory cross pollinating species (Kalin Arroyo, 1981). In field trials in this study, where plants were observed to be visited regularly by native bees, average pod set was less than 45% at all stages of the season in both cultivars (Section 5.3.4.1). Thus exposure to pollinating insects at the trial site did not appear to benefit seed set. This does not mean, however, that *D. virgatus* is an obligatory self-pollinator. Cross pollination may have occurred but with some other factor limiting the number of pods formed per umbel. This could be caused, for example, by competition for assimilate between larger developing pods and newly formed pods as occurs in many dicotyledonous plants (Wolswinkel, 1992) or genetic load (Burd, 1994). The poorer selfing rates observed later in the season when pod numbers on plants were increased indicates that the former is most likely influential.

More detailed studies are required to determine the extent of cross pollination in *D. virgatus*. However, this study indicates that pollination is not a major limitation to seed yield.

6.4 Conclusions

Paclobutrazol applied at the onset of anthesis increased total inflorescence numbers in 'Marc' and 'Bayamo' plants grown in pots in a glasshouse. The flowering response was delayed until approximately 45 days after application in 'Marc' and 35 days after application in 'Bayamo' but coincided with peak flowering in both cultivars. This delayed flowering response was probably due to a combination of increased branching which provided more potential reproductive sites (leaf axils) and an increased utilisation of available reproductive sites. This flowering response was transferred to numbers of umbels per plant and, because PCB did not affect seeds per pod or pods per umbel, would have contributed to increased seed yields.

Although the number of florets per inflorescence was the only other SYC which was influenced by PCB application, this did not translate into increased numbers of pods per umbel and therefore did not affect seed yield. Rate of pod development was also not affected by PCB application.

Although PCB increased SYC (mainly inflorescence number per plant) and will therefore increase seed yield, the benefits are unlikely to compensate for the cost of the chemical and its application.

Both cultivars of desmanthus used in this trial readily self-pollinated and provided similar self-pollination rates in the (insect-free) glasshouse to the field. The introduction of pollinating insects is not expected to greatly increase seed set in these cultivars.

CHAPTER SEVEN

GENERAL DISCUSSION AND CONCLUSIONS

7.1 Introduction

Desmanthus (*Desmanthus virgatus*) is a productive and persistent pasture legume in its native habitat (Burt, 1993b) and is well adapted to the extensive low rainfall area of neutral or alkaline clay soils in Central Queensland (Cook *et al.*, 1993), an area which previously lacked a persistent pasture legume. Although the three cultivars of desmanthus released in Queensland perform well as a forage (Cook *et al.*, 1995), commercial seed yields have been inconsistent (Hopkinson pers. comm., 1995; Anon, 1993a, 1993b). Virtually no previous research had been conducted on desmanthus seed production. Therefore this study initially investigated the growth of the plant and development of seed yield from a seed yield component perspective. Areas identified as limiting to seed yield were subsequently investigated. Key results from the study and their application to commercial seed production of desmanthus seed in Queensland are presented in the following discussion.

7.2 Plant Growth and Development of *Desmanthus virgatus* in Relation to Seed Production

7.2.1 ESTABLISHMENT AND VEGETATIVE GROWTH

Rapid and even germination of sown seed benefits seed production, particularly in indeterminate legumes, by synchronising canopy development which helps to smother weeds and synchronise reproductive development (Hill and Loch, 1993). Desmanthus seed has a very high hardseed content which requires that seed for sowing must be scarified in order to imbibe water (Hopkinson, 1994). The acid scarification method (Appendix 3.2) used in this study invariably allowed imbibition of water into seed of all three cultivars in samples of up to 500 g. Inspection of seed under the microscope revealed that damage was predominantly to the seed coat rather than through breaching the strophiole. Even though the seed coat was damaged by acid scarification, the

process did not overly increase the numbers of abnormal seedlings in germination tests of mature seed i.e. seed which had formed a hardseed coat. This agrees with previous evaluations of acid on desmanthus seed (Loch and Harvey, 1992) and suggests that acid scarification may be suitable for treating small seed samples.

Scarified 'Marc' and 'Bayamo' seeds took at least 14 days to reach the 2 true leaf stage even when grown in glasshouse conditions. Canopy development involved three branching tiers in both cultivars and canopy closure occurred 8 to 10 weeks after emergence. In unweeded plots (45 plants/m^2) weeds established in the period before canopy closure resulting in reduced desmanthus plant vigour and depressed flowering (Section 4.4.3.5). This indicates that selective chemicals are required to control weeds in desmanthus crops in Queensland.

Most legumes form root nodules which have the ability to fix atmospheric N which can then be used for plant growth (Allen and Allen, 1981). Nodulation of desmanthus is improved by inoculation with various *Rhizobium* strains (Date, 1991). Although inoculation is considered advantageous when desmanthus is sown as a forage it is less important when sown for seed production because the higher value of the seed crop allows application of N if necessary. Although *Rhizobium* inoculation of seed effectively supplies N to most legume seed crops, Humphries and Riveros (1986) report positive seed yield responses to fertiliser N applied during reproductive development of nodulated *Desmodium uncinatum.* Seed used in this study was inoculated with a specific *Rhizobium* (CB3126) but not all plants formed nodules (data not presented). Despite this there were no signs (yellowing of leaf and stem tips) of nitrogen deficiency in both nodulated and non-nodulated plants sampled at the sites used in the study. This probably reflects the high fertility status of these sites (Appendices 3.1 and 5.1) resulting from previous cropping history, both sites having been planted with legumes in the seasons immediately prior to growing desmanthus. Although inoculation did not appear to benefit desmanthus growth in this study, it may do on less fertile sites, particularly if N from rhizobial N-fixation is available to the plant during late vegetative or reproductive growth when soil N reserves may have been utilised during vegetative growth and there is increased demand for N during seedfill as in *D. uncinatum* (Humphries and Riveros,

1986). Inoculation is a low cost activity and is therefore recommended as it may reduce the requirement of adding more expensive fertiliser N.

7.2.2 FLOWERING

Flowering pattern was the key determinate of presentation of mature (harvestable) seed in 'Marc' and 'Bayamo' (Sections 3.3.10 and 5.3.5). Flowering began on the main stem in all cultivars. Floral initiation of 'Marc' plants was not affected by photoperiod and generally began 6 to 9 weeks after sowing in all trials regardless of sowing date (13 November to 14 January). 'Bayamo' plants began flowering when photoperiods were declining (mid March) and occurred even later in 'Uman' (mid to late April). Cultivar differences in floral induction also occur in other tropical forage legumes e.g. *Stylosanthes guianensis* (Trongkonsin and Humphries, 1988; Ison and Humphries, 1984). All cultivars flowered prolifically with most inflorescences being produced on the secondary branches.

Flowering of 'Marc' plants consistently occurred in two flowering peaks: the first arising from inflorescences located on the main-stem (branching tier 1) and seconary branches, and a second, generally larger, peak from secondary and tertiary branches. Conversely only one clear peak was recorded in 'Bayamo' plants, principally contributed to by inflorescences on secondary and tertiary branches. Although clear flowering peaks were observed in 'Marc' and 'Bayamo', the protracted flowering period meant that presentation of mature seed occurred over an extended (90+ days) period presenting similar problems to seed production as indeterminate legumes e.g. *Lotus corniculatus* (McGraw *et al.*, 1986). 'Bayamo' plants generally produced a greater number of inflorescences per plant at peak flowering than 'Marc' plants at similar population densities and had a shorter flowering season. Flowering in 'Uman' was not investigated because preliminary cultivar comparisons indicated that it has a similar flowering pattern to 'Bayamo'. Despite this, seed production in these two late flowering cultivars was still strongly influenced by a protracted flowering period.

7.2.3 SEED YIELD COMPONENTS

Inflorescence number per plant in 'Marc' and 'Bayamo' were strongly influenced by plant density effects on vegetative structure. Increasing plant population (3 to 160 plants/m^2) resulted in a reduction in branch number and consequently inflorescence number per plant, agreeing with results in *Medicago sativa* (Askarian, 1993; Kowithayakorn, 1978). Flowering duration was shorter in plants grown at higher population densities because of reduced branching and consequently fewer reproductive sites. This increased the population density effect on total inflorescences per plant which, when totalled over the entire season, resulted in a 21-fold increase between 3 and 160 plants per m^2 compared to peak flowering (17-fold increase).

Other seed yield components were not affected by population density again agreeing with studies in *M. sativa* (Askarian, 1993; Kowithayakorn, 1978). As a result potential seed yield (PSY) per plant showed a similar response to population density as flowering. At peak flowering, PSY per plant increased five-fold from 45 to 3 plants per m^2 while higher densities had similar PSY per plant as at 45 plants/m^2.

Plant density had its main effect on PSY per unit area (m^2). Increasing density from 3 to 160 plants/m^2 resulted in a three-fold increase in PSY/m^2. Increasing plant population from 3 to 160 plants/m^2 increased PSY in a linear fashion (Figure 3.13) indicating that high population densities will most benefit seed yield. The linear PSY response to plant density indicates that higher plant populations than 160 plants/m^2 may further increase seed yields. However, seed yield typically has a parabolic or asymptotic response to increasing plant density (Willey and Heath, 1969) indicating that seed yield of desmanthus will also decline at some plant density above 160 plants/m^2 under similar growing conditions (high fertility and irrigation). This point needs to be identified, preferably in combine harvestable plots, before firm recommendations of sowing rate can be made.

High levels of floret abortion (> 50% of perfect florets) occurred during anthesis in both 'Marc' and 'Bayamo' plants and few reproductive sites contained more than eight pods

(Sections 5.3.4.1). Similar results (60% pod set) have been reported in legumes with indeterminate growth habit e.g. *Lotus corniculatus* (Hill and Supanjani, 1993). This may be a result of either poor pollination or abortion of pods before they had fully expanded and were counted. Decreased pod set as more pods were developing on the plant suggests that the latter is more likely. Similarly, abortion of ovules (28 per 'Marc' floret) increased (from 30%) over the season (Section 3.3.5) but abortion of seed after pods had become fully expanded was minimal. Hill and Supanjani (1993) suggested that *L. corniculatus* pods containing few seeds tend to abort. Factors which most likely contributed to post-anthesis abortion of young pods or ovules / seeds in the study on *L. corniculatus* and the current study include competition from alternative sinks for assimilate and / or a decrease in assimilate supply. Wolswinkel (1992) suggested that once established, reproductive structures such as pods become a strong sink, receiving assimilate in preference to other less developed structures. This mechanism would support the results observed in this study i.e. high rates of floret / ovule abortion before full pod expansion and little thereafter. Latting (1961) noted increased abortion of young pods of *Desmanthus illinoensis* when plants were under water stress. During field trials in this study, water supply to the crop was reduced towards the end of the season. This also coincided with declining temperatures. Both factors could reduce assimilate supply to plant organs with low sink strength such as florets or pods just after anthesis compared to more mature pods. A more detailed study is required to identify the fate of florets and ovules prior to full pod expansion, particularly the influence of alternative sinks and factors which can affect assimilate supply.

Luckow (1993) found all *Desmanthus* spp. except *D. covillei* capable of autogamy but that artificial crossing (by hand) resulted in higher levels of pod set indicating that there is potential to increase seed set by introducing pollinators (e.g. *Apis* sp.). Autogamy in *D. virgatus* was confirmed in this study but there were no measurable benefits of exposing *D. virgatus* plants to pollinators (mainly native bees) (Section 6.3.4). This agrees with findings in other forage legumes in Queensland (Hopkinson, 1988) and indicates that the benefit of introducing pollinators is likely to be minimal.

Pod development from inflorescences at peak flowering of 'Bayamo' plants was consistently slower than 'Marc', particularly in the field. Slower development of 'Bayamo' pods in identical (glasshouse) conditions indicates that this difference is, in part, genetic. Pod development in both cultivars slowed as the season progressed, coinciding with increasing pods on plants (and therefore alternative sink demand) and declining temperatures. It seems likely that the slower rate of 'Bayamo' pod development under field conditions (59 days compared to 33 days in 'Marc') was due to peak flowering occurring later than in 'Marc' when more competitive alternative sinks were present and both temperature and moisture were declining. This clearly has implications for late sown 'Bayamo' seed crops grown in frost prone areas such as South-East Queensland as slow pod development may result in frost damage occurring before maturation of seed arising from peak flowering.

Pod dehiscence occurred readily in 'Marc' plants, usually within ten days of pods reaching maturity. Dehiscence was less of a problem in 'Bayamo' and 'Uman' plants. Pod dehiscence occurred readily in hot conditions because pods dried more rapidly. Surprisingly, poorly formed pods containing few (less than 5) seeds often failed to dehisce even under hot conditions. Perhaps pod malformation prevented cleavage along the septum. Rapid pod dehiscence combined with an extended flowering period resulted in a low (< 10%) proportion of 'Marc' seed presented at any one time and recovered by combine harvest even in seed arising from peak flowering. This is typical of other indeterminate forage legumes e.g. *Macroptilium atropurpureum* (Hopkinson and Loch, 1973). Information on pod dehiscence and the period of seed presentation in 'Bayamo' was limited by frost damage to plants after peak flowering. However lower levels of pod dehiscence and a shorter flowering period in 'Bayamo' and 'Uman' plants observed at Kilkivan (1994/1995) are likely to result in a greater proportion of total seed being presented at any one time. Thus the use of a conventional single-pass harvest system (combine harvesting) is likely to be more suitable for harvesting these cultivars than 'Marc'. Issues relating to harvesting procedures are discussed in Section 7.3.4.

Cutting 'Marc' plants in a manner typical of combine-harvesting (10 to 15 cm above the ground after reproductive development) resulted in poor second season growth and

sporadic flowering (Section 5.3.2.3). This agrees with previous reports (Muir and Pitman, 1991) which have shown that desmanthus regrows poorly after winter defoliation or when defoliated at maturity (Michaud *et al.*, 1989). Keoghan (pers. comm. as cited by Adjei and Pitman, 1993) suggested that the improved survival of desmanthus after defoliation at earlier stages of growth was due to an enhanced viability of basal buds which senesce after extended periods of apical dominance (i.e. when not defoliated). Muir and Pitman (1991) suggested that threshold levels of carbohydrates are required for rapid regrowth and that defoliation could interfere with this. This study supports both of these views. Random sampling of plants revealed no pest or disease problems. This suggests that there is little potential for treating 'Marc' as a perennial seed crop when using single-pass harvest systems. Although not studied in detail, regrowth of 'Bayamo' and 'Uman' plants after defoliation was also not vigorous suggesting that they may also be better suited to first year production only.

7.3 Management of *Desmanthus virgatus* for High Seed Yields

The preliminary studies revealed that 'Marc' has the potential to produce relatively high seed yields (over 2000 kg seed/ha) but that extended flowering and ready pod dehiscence result in low levels of seed presented for harvest at any one time. Improving seed yield through either :

(a) improved seed presentation (contracted flowering pattern or decreased pod dehiscence) or,

(b) improved recovery during harvest

were seen to be the most likely avenues for increasing commercial seed yields. The similarity of performance of both 'Bayamo' and 'Uman' in terms of flowering duration and pod dehiscence prompted the inclusion of 'Bayamo' only in the seed recovery trial. Results are discussed in Sections 7.3.4 and 7.3.5.

Other agronomic areas of seed production identified as important for desmanthus seed production included the location of seed production, management during establishment and crop hygiene. These are discussed in appropriate sections below.

7.3.1 LOCATION OF SEED PRODUCTION

'Marc' has shown good persistence in areas of Queensland which experience up to 40 frosts per year (Graham *et al.*, 1991a). Early flowering in (spring / summer sown) 'Marc' meant that frosts did not influence seed yields. However, the requirement of 'Bayamo' plants to be exposed to short-day conditions before flowering meant that frosts reduced seed yields when this cultivar was grown in the frost-prone environment of South-East Queensland. Commercial desmanthus seed crops (all cultivars) are located in the frost-free environment of the Atherton Tableland, the only area in Queensland other than South-East Queensland with a well established seed production infrastructure. Results from this study suggest that 'Marc' seed could also be produced in South-East Queensland. Benefits of this would be the availability of more 'clean' sites (i.e. sites which have not previously been used for seed production of other cultivars of desmanthus) and minimisation of risks associated with growing all crops in the one geographic area (i.e. climatic effects and crop hygiene).

7.3.2 ESTABLISHMENT OF SEED CROPS

Sowing dates used in this study varied from early November to mid January with no obvious effect on plant development. This was not surprising because temperature did not vary greatly over this period and water supply was regulated by irrigation rather than rainfall. The sowing dates used ensured that establishment occurred when temperatures were high (mean minimum temperature 16°C and mean maximum temperature 30+°C). Much of the time temperatures ranged between 26°C and 33°C which is considered to be optimum for desmanthus seed germination (Njarui *et al.*, 1992). Sowing date had no appreciable effect on time of onset of flowering in 'Marc', suggesting seed production stands of this cultivar could be reliably established from sowings from early November to mid January. The later developing cultivar 'Bayamo' could be sown later in January, since canopy closure occurred before short day conditions induced flowering, although relatively few tertiary branches were present. Vegetative growth generally increases with temperature to some point where temperature damages the plant (Biscoe and Willington, 1982). This suggests that sowings of 'Bayamo' and 'Uman' should not take place after

January since declining temperatures are likely to reduce growth rates. In this study desmanthus was not sown before November. However, long term mean minimum and maximum temperatures at the two trial sites used in this study (Appendices 3.3 and 5.2) suggest that temperature before November is likely to be below the optimum temperature for desmanthus seed germination (Njarui *et* al., 1992) resulting in slow initial growth rates which reduces competitiveness with weeds (Loch, 1994).

The sowing depth used in this study (less than 1.0 cm) was similar to commercial recommendations (Wrightsons Seeds Ltd., 1994a). Seedlings generally produced cotyledons above the soil surface indicating that planting depth was appropriate. Deeper sowing increases the risk of poor establishment because seed reserves in small-seeded legumes such as desmanthus may not be sufficient to support seedling growth prior to emergence from soil (Cook, 1980). Seedlings grown on germination paper generally produce a hypocotyl 2 to 3 cm long indicating that slightly deeper sowing than commercially recommended may also produce suitable establishment under good field conditions.

Plant density in annual crops (or first year perennial crops) is invariably important for seed production but is less so in perennial crops (after the first year) because vegetative growth often compensates for initial plant number (Humphries and Riveros, 1986). It is more likely that, because of poor second season regrowth after cutting, desmanthus will be grown as an annual crop . Therefore plant density is considered very important. In this study, PSY of desmanthus grown on a high fertility site under irrigation increased linearly with population density up to 160 plants/m^2 indicating that there is potential to further increase seed yields at higher plant densities. Sowing rates (4 kg seed/ha) in commercial desmanthus seed crops (also irrigated and on high fertility soils, Murat pers. comm., 1995) provide densities of approximately 90 plants/m^2 (80% emergence and TSW = 3.5 g) indicating that sowing rates are adequate for the production of moderate seed yields of desmanthus but may further benefit from higher sowing rates. Plant densities above 45 plants/m^2 also decreased flowering duration and subsequently increased the proportion of seed presented for harvest at one time. This feature has been reported in other herbage legumes (e.g. *Medicago sativa*, Askarian, 1993) and indicates

that there is greater potential to increase combine harvest recovery of mature seed by using high plant densities. High plant densities also provide a competitive advantage over weeds by encouraging more rapid canopy closure and shortening the time of bare ground exposure (Fryer and Makepeace, 1977).

Soil fertility (particularly N supply), moisture supply and stand age can all modify plant responses to population density (Humphries and Riveros, 1986). However, based on current practice, commercial production of desmanthus is expected to occur under similar conditions to those in this study (i.e. high fertility sites under irrigation and growing the crop as an annual). Thus PSY / density responses are not expected to be affected by these factors in commercial practice.

7.3.3 CROP HYGIENE

Crop hygiene refers to the control of organisms which can impair normal crop development and therefore affect seed yield. These organisms principally affect seed yield by: reducing population density (insects, disease or other plants); impairing the extent of vegetative and hence reproductive development by directly damaging the plant (insects and disease) or competing for resources (other plants); or damaging developing reproductive structures (insects and disease).

Weed control

Selective herbicides which are non-damaging to 'Marc' seedlings and which control many of the weeds commonly found in cropping systems in South-East Queensland and the Atherton Tableland, have been identified (Section 4.6.2). In most situations the best pre-emergence herbicides are trifluralin, pendimethalin or imazethapyr while the best post-emergence herbicides are bentazone, bromoxynil and haloxyfop. Problem weed species in crop situations in North Queensland not effectively controlled by these herbicides include leguminous species such as *Crolataria goreensis* and *Neonotonia wightii*. *Aeschynomene americana*, another legume, is also a problem weed in desmanthus seed crops not controlled by the herbicides evaluated. However, these should all be controlled by crop rotation which targets these legumes e.g. sowing of at

least one graminaceous crop prior to sowing desmanthus and controlling legumes with selective herbicides such as 2,4-D or 2,4-DB which are damaging to these species at seedling stages (Hawton *et al.*, 1990). Another future possibility for control of legume weeds lies with the imidazolenone herbicides which have so far been non-damaging to desmanthus (Sections 4.3.3 and 4.4.3) and which appear to have appropriate weed control spectra.

Sowing at high plant densities (160 plants m^2) might be expected to increase PSY and should also reduce weed competition by ensuring rapid canopy closure. Other approaches to weed control (Section 4.6.4), such as combining delayed sowing with cultivation and / or knockdown herbicides, should also decrease weed populations.

Most of the chemicals identified as 'safe' for use on one year old desmanthus stands provide poor control of mature perennial weeds (Section 4.6.2.3). However, poor regrowth and subsequent low seed yields of desmanthus after cutting during reproductive development suggest that it is not well suited to seed production as a perennial crop. This suggests there will probably be little need for selective control of mature weeds present in desmanthus seed crops provided weed control prior to canopy closure has been effective.

The 'off-label' use of chemicals is illegal under current Australian legislation (Section 4.6.3) and chemicals are unlikely to be registered for use in desmanthus seed crops in the future because the annual volume of desmanthus seed produced is low relative to the production of other crops. However, these restrictions are not enforced and at least two chemicals (bentazone and trifluralin) are being used in commercial desmanthus seed crops (Murat pers. comm., 1995). There is no obvious reason for this changing in the future. Therefore all weed control recommendations from this study are considered to be available for commercial practice.

Pest control

Seed crops provide a more favourable environment for the build-up of pests than in pasture because a heavy crop is grown which may stand for some months (Humphries

and Riveros, 1986). The native psyllid (*Acizzia* sp.) found to cause extensive damage to desmanthus (all cultivars) in this study has not been reported on desmanthus in pasture situations. Infestation occurred in both seasons at both trial sites and was most severe between February and April agreeing with previous observations (Loch pers. comm., 1995). Infestation at this time indicates that psyllid damage cannot be avoided by adjusting sowing date. Large infestations resulted in defoliation, damage to stem tips and cessation of flowering. This occurred only in the radial trial because of the delay in identification.

Similar and widespread psyllid (*Heteropsylla cubana*) damage has also been sustained by other forage legumes in Queensland e.g. *Leucaena leucocephala* (Davidson, 1987). Although potentially very damaging to seed crops the psyllid can be easily identified and inexpensively controlled (dimethoate) (Section 3.3.1.3). Damage to the seed crop should be minimal provided psyllid identification occurs early. When using insecticides there is a danger of removing beneficial insects (Humphries and Riveros, 1986). As seed set in desmanthus was not affected by pollinator presence, application of dimethoate is not expected to adversely affect reproductive growth of desmanthus.

Surprisingly there have been no reports of psyllid damage in seed crops on the Atherton Tableland. The reason for this is unclear although it is not known if the psyllid is present in the area. The only other pest commonly found on desmanthus in this study was the green vegetable bug (*Nezara* sp.). Numbers were relatively low, however, and there were no obvious signs of damage to the plant.

7.3.4 ENHANCEMENT OF HARVESTABLE SEED YIELDS

Combine harvesters are used to harvest desmanthus seed (Murat pers. comm., 1995). This process results in damage to desmanthus seed crops because a low cut (less than 20 cm above the ground) is required to collect all the seed pods distributed throughout the canopy. A short seed presentation period is required to maximise seed uptake by the combine harvester (Hopkinson and Clifford, 1993). However, the presentation of seed in the desmanthus cultivars included in this study occurs over an extended period

because of a prolonged flowering period and ready pod dehiscence, particularly in cv. 'Marc'. This suggests that any management system which contracts flowering and can identify the point of highest presentation yield would potentially increase harvest recovery yield.

7.3.4.1 Synchronising Flowering

In this study (Section 3.3.10.2) plant populations greater than 45 plants/m^2 decreased the flowering period in cv. 'Marc' so that a greater proportion of total inflorescences were present at peak flowering (~90% 74 to 114 days after germination) compared to lower population densities (~75%).

Defoliation of plants during the growing season can be used to synchronise seed presentation in legumes (Marshall *et al.*, 1993), although the benefits of defoliation for seed production of *D. virgatus* have been shown to differ with genotype (Adjei and Pitman, 1993). It also seems unlikely that defoliation will benefit seed production of short-day responsive cultivars such as 'Bayamo' and 'Uman' because there will be insufficient time for a second flowering flush before the end of the season. Conversely, the prolonged flowering behaviour of cv. 'Marc' suggests that defoliation during the summer may well be beneficial provided defoliation occurs early in the flowering phase and it has time to recover its vegetative and reproductive structures and possibly produce another flowering peak. This possibility may better synchronise flowering. More importantly however, it offers the theoretical potential to harvest two seed crops (Section 5.4.4.2).

The use of plant growth regulators (PGR), particularly paclobutrazol (PCB), to alter flowering onset and duration has been sporadically successful in a wide range of forage legumes including those with similar growth habits to desmanthus (e.g. *Medicago sativa* and *Lotus* spp.). In this study its effects were investigated on 'Marc' and 'Bayamo' plants (Section 5.1.2.1).

Paclobutrazol was identified from the literature as the chemical with the most potential to increase desmanthus seed yields. In a field trial (Chapter 5) PCB (1.0 kg ai/ha)

application to 'Marc' at the onset of flowering resulted in increased inflorescences at peak flowering (25 days after application) but not higher combine-harvested seed yields. Pods required greater threshing during harvest to remove seed (Section 5.4.3.1) and harvested seed from PCB plots had a lower seed weight and poorer germination once scarified. This is probably because seed was harvested when a lower proportion of seed had reached maturity (i.e. those arising from the second flowering peak) and were therefore smaller and more susceptible to damage during threshing or scarification. No other SYC were affected. It is possible therefore that PCB application could have increased 'Marc' seed yield had the PCB treatments been harvested later. Although flowering of 'Bayamo' plants ceased prematurely because of frost damage, PCB appeared to increase inflorescence number prior to frosting.

In the more detailed trial under controlled (glasshouse) conditions and varying application time (onset of flowering and peak flowering) and application rate (0.5 kg ai/ha and 1.0 kg ai/ha), PCB application did not alter seasonal flowering pattern (Section 6.3.1.2) although inflorescences present at peak flowering were slightly higher in 'Marc' and markedly higher in 'Bayamo'. Total inflorescence production over the season was 30% higher in plants when PCB was applied at the onset of flowering in both cultivars ('Marc' 0.5 kg ai/ha; Bayamo 1.0 kg ai/ha). Results from this trial suggest that increased inflorescence number was due to an increase in the number of reproductive sites present because of increased branching (Section 6.3.1.2). These responses to PCB are similar to those reported with *Lotus uliginosus* (Tabora and Hill, 1992) and *Medicago sativa* (Askarian *et al.*, 1994), species with similar growth patterns to desmanthus. Paclobutrazol application at peak flowering did not affect inflorescence number possibly because the trial was completed before PCB-branch stimulation was manifest in changes in inflorescence number. Paclobutrazol application did not affect other SYC or rate of pod development (Section 6.3.2), results which are consistent with other work on forage legumes (Askarian *et al.*, 1994; Tabora and Hill, 1992). Application of PCB at the onset of flowering as used here (or slightly earlier) has produced reliable increases in seed yield

in legumes (*Trifolium repens*, Budhianto *et al.*, 1994a, 1994b and Rijckaert, 1991; *Lotus uliginosus*, Tabora and Hill, 1992; *Lotus corniculatus*, Hampton *et al.*, 1989).

The effect of PCB was greater in the glasshouse than under field conditions. This agrees with previous attempts to transfer promising glasshouse PGR responses in tropical legumes to field conditions (Edey and Byth, 1970). However, the benefits of PCB in the glasshouse were not large enough to warrant commercial application (Section 6.3.3.4).

7.3.4.2 Reducing Losses Due to Pod Dehiscence

A glue, applied 11 days before combine harvest, was used to try to increase the number of mature seeds presented at harvest. This treatment was only applied to 'Marc' plants because pod dehiscence is a significant problem in this cultivar.

Adhesive sprays have been used successfully to increase seed retention in some vegetable species (carrot, onion) which readily dehisce (Williams, 1978) and with variable success in some herbage grasses (*Chloris gayana* and *Setaria sphacelata*) (Loch and Harvey, 1983). A quick setting polyvinyl acetate was applied to 'Marc' plants 11 days before combine harvest. Application was conducted to maximise penetration into the pod (PVA 133 l product/ha; 1:10 dilution in water and soaking until runoff) in a similar fashion to that conducted successfully on *Setaria sphacelata* (Loch and Harvey, 1983). Despite this, glue application had no measurable effect on (combine) harvested seed yield (Section 5.3.3.1), nor on the amount of seed harvested as a proportion of presented seed (Section 5.3.6) or other SYC or seed quality of 'Marc' desmanthus (Section 5.3.8.1). Lack of success in reducing seed fall was probably caused by lack of glue access to pods often buried deep within the vegetative canopy (Section 5.4.3.3). This avenue for research has limited potential for commercial seed production.

7.3.4.3 Chemical desiccation prior to harvest

Chemical desiccation of seed crops shortly before harvest can be used to increase seed yields through:

(a) reducing vegetative bulk which can increase combine harvesting efficiency (Hopkinson and Clifford, 1993) and / or

(b) causing premature abscission of late developed seeds making them more suitable for harvest (Moyer *et al.*, 1996; Sedivy, 1987).

Diquat (0.8 kg ai/ha) application, 11 days before harvest, resulted in rapid defoliation, cessation of flowering and pod abscission. Seed yields were not affected by this but seed quality (percentage normal germination) following scarification was improved by desiccation and the proportion of hardseeds was increased. This is probably a result of having fewer mature seeds present at harvest. Seed weight declined slightly probably because seed fill was interrupted by pod abscission (Section 5.4.3.2). Timing of application was considered optimal (Section 5.4.3.2) and the application rate was similar to those used effectively on similar legumes during active growth (e.g. *Medicago sativa*, Moyer *et* al., 1996; Sedivy, 1987). The cost of diquat (Reglone) when applied at 0.8 kg ai/ha is approximately A$76/ha, (22 April 1998; IAMA, Gympie) excluding wetter (less than A$25/ha, (22 April 1998; IAMA, Gympie)) and time, machinery and labour costs. Therefore, gains in seed yield need not be high (less than 50 kg/ha at 1996 prices, Wrightsons pers. comm., 1996) to recoup costs. Results from this study suggest that diquat application before combine harvest increases seed quality and but gave no reliable information on its effect on seed yield under commercial harvest conditions. This needs to be conducted before recommendations can be made for commercial practice.

7.3.5 HARVESTING METHODS

Seed yields can be increased by increasing the harvest recovery of presented seed. Combine harvesting was compared with other harvesting techniques in an attempt to increase recovery of presented seed (Chapter 5).

'Marc' seed yields (approximately 200 kg/ha) achieved by either combine or keyhole stripper harvest of pods arising from peak flowering represented approximately 12% of total seed produced over the season and only 25% of seed produced prior to harvest. This is typical of other forage legumes (Hampton, 1991; Clifford and McCartin, 1985; Foster *et al.*, 1962).

Combine harvest slightly decreased seed quality (germination) and reduced the proportion of hardseed by scarifying seedcoats during threshing. Physical damage of this type is inevitable when combine harvesting but can be minimised by appropriate machine settings (Hopkinson and Clifford, 1993). Conversely keyhole stripper harvesting resulted in little seed damage (Section 5.4.4). However, pods recovered by keyhole threshing needed more (45%) post-harvest threshing than combine harvested pods (Section 5.4.4.1). Both techniques were damaging to plants and regrowth was poor. The potential to improve regrowth after harvesting at peak presentation by minimising damage by these techniques is limited by the need to harvest a large proportion of the canopy in order to access all pods.

The use of combine harvesting systems in commercial desmanthus seed crops demands identification of optimum harvest date. In legumes this is related to flowering period but in some species (e.g. *Trifolium pratense* and *Medicago sativa*, Hopkinson and Clifford, 1993) can be modified by the availability of wild pollinators. As percentage seed set of desmanthus was not influenced by pollinator presence in this study, and other SYC did not change as much as inflorescence number, optimum time of harvest is most likely best identified by monitoring inflorescence numbers. Pod dehiscence of 'Marc' plants within 10 days of maturity and a relatively sharp flowering peak means that correct identification of time of harvest is important in single-pass harvest systems. It is suspected that inconsistent combine harvested seed yields in commercial desmanthus crops have been, at least in part, due to poor identification of the correct time to harvest with decisions being based only on visual appraisal. In other forage legumes with extended flowering period (e.g. *Lotus* spp., Hare and Lucas, 1984) pod colour changes are used to identify optimum time for harvest. Such colour changes were not useful for identifying harvest date in this study. However, two other methods have been identified

(Section 5.4.2). Reasonable estimations of optimum harvest date can be achieved by monitoring the proportions of mature and dehisced pods over time. The most accurate method requires identification of peak flowering and measurement of the time to pod maturity. Although this is time consuming it offers the potential to obtain higher seed yields.

Although regrowth of plants after harvest was consistently poor in this study the option of multiple harvests as used in other indeterminate forage legumes (e.g. *Macroptilium atropurpureum*, Hopkinson and Loch, 1973) is worth investigating in early-flowering desmanthus cultivars such as 'Marc' (Section 5.4.4.2). In Queensland, these systems would require early sowing (November) with the first cut (either keyhole stripper or combine harvester) conducted as the first peak of flowers reached maturity (approximately mid January using reproductive development rates reported in this study). However investigation into the regrowth and flowering response of desmanthus after early cutting would be required.

Mowing followed by windrowing are commonly used to increase subsequent combine harvest recovery by facilitating further ripening of immature seed (Humphries and Riveros, 1986), reducing the risk of losses associated with pod dehiscence (e.g. *Neonotonia wightii*) or ensuring the crop is dry enough for efficient threshing (e.g. *Desmodium intortum*) (Hopkinson and Clifford, 1993). Harvested windrows can be rethreshed if initial threshing is inefficient. This procedure could simulate the beneficial effects of a chemical desiccant on desmanthus (increased proportions of hardseed and normal seedlings) and, through ripening of immature seed, increase seed yields. Also, if high plant densities were used, as appears beneficial for maximising seed yields, plants would have long thin stems conducive to mowing.

Poor recovery of seed by single-pass destructive harvest systems and the production of high quality seed over the entire season suggests there is considerable potential to increase recovered seed yields by the recovery of fallen seed with brush or vacuum harvesters. This technology has been trialed with some success in other legumes e.g. *Lotus pedunculatus* (Baker pers. comm., 1996), *Macroptilium atropurpureum*

(Hopkinson and Vicary, 1974) and *Stylosanthes humilis* (Humphries and Riveros, 1986). Benefits would likely be greater in cultivars with extended flowering periods and ready pod-dehiscence such as 'Marc' (Section 5.4.4.3) although extended flowering periods in 'Bayamo' and 'Uman' indicate that it could also be useful in these cultivars. Recovery of fallen seed could occur exclusively or in combination with destructive harvests, an approach which has had moderate success on the Atherton Tableland (Hopkinson pers. comm., 1995). Although the collection of fallen seed has a number of disadvantages (Section 5.4.4.3), and would require investigation into seed dynamics in soil and the effectiveness of commercial sized vacuum / brush harvesters on recovery of fallen seed, the potential to increase seed yields up to eight-fold over combine harvesting systems suggests that fallen seed recovery systems warrant further study.

7.4 Conclusions

Seed yields of early ('Marc') and late ('Bayamo') flowering desmanthus cultivars grown on fertile irrigated sites in South-East Queensland were affected by genotype and environment. In both cultivars, the factors which most influenced seed yield per plant (in decreasing order of importance) were inflorescence number, abortion (~50% of perfect florets irrespective of pollinator presence) before pods had expanded and decreasing seed weight over the season.

Presentation seed yield at any time was strongly influenced by flowering pattern. Flowering of 'Marc' occurred in two peaks and was of greater duration than 'Bayamo' which produced a single peak. However, 'Bayamo' produced higher presentation yields than 'Marc' because of less pod dehiscence. Frost damage caused defoliation and premature abscission of 'Bayamo' pods which reduced harvested seed yields (139 kg/ha) compared to 'Marc' (205 kg/ha) and decreased the proportion of hardseed in, and normal germination of, harvested seed. These results indicate that late flowering desmanthus cultivars should not be grown for seed in South-East Queensland.

Plant density had a large effect on PSY per plant in 'Marc' by altering canopy structure and inflorescence number per plant. Increasing plant density (3 to 160 plants/m^2) increased plant height and decreased branching, flowering duration and seed yield per plant. Conversion of PSY to per unit area values resulted in a linear increase in PSY (75 to 200 g/m^2) with increasing plant density (3 to 160 plants/m^2). However, collected seed yields were not affected by plant density. This discrepency in response increased with plant density and was probably caused by sampling difficulties at high plant densities.

A psyllid (*Acizzia* sp.) infestation resulted in defoliation and cessation of flowering in 'Marc' indicating high potential to significantly reduce seed yields. However, this psyllid can be quickly controlled by foliar application of dimethoate.

Most crop weeds present in North and South-East Queensland can be selectively controlled during establishment by using combinations of pre-emergence applications of

trifluralin, pendimethalin or imazethapyr followed by post-emergence applications of bentazone, bromoxynil or haloxyfop.

The use of polyvinylacetate (glue), diquat (desiccant) and paclobutrazol (plant growth regulator) on desmanthus failed to increase combine harvested seed yields. However, diquat increased the proportion of hardseeds and normal seedling. Combine harvest recovery of 'Marc' desmanthus seed was low (~22% of seed presented prior to harvest) and damaged seed. The keyhole stripper resulted in similar recovery and resulted in less damage to seed. Combine harvest recovery of 'Bayamo' seed (~60% of seed presented prior to harvest) was higher than 'Marc' because of fewer pods dehisced but seed was of low germination and seed weight. Poor recovery of seed presented over the entire season suggests that recovery of fallen seed will best increase recovered seed yields, particularly in 'Marc'.

Vigour of second year stands was poor after cutting during reproductive growth. This, and the lack of suitable selective herbicides for use on established stands, suggests that desmanthus should be grown as an annual crop.

APPENDICES

Appendix 2.1 Common economically important insect pests of pasture legumes in Queensland.

Pasture species	Common name	Pest species	Common name	Reference
Desmodium intortum *D. uncinatum*	desmodiums (greenleaf) (silverleaf)	*Amnemus* spp. *Leptopius* spp. *Oncopera* spp. *Heliothis*[1] spp.	amnemus weevil leptopius weevil webworms pod borers[1] red spider mites	Cameron, 1984a
Lablab purpureus	lablab	*Ophiomyia phaseoli* *Maruca testulalis* *Heliothis*[1] spp. *Nezara viridula*	bean fly bean pod borer[1] green vegetable bug[1]	Cameron, 1988a
Leucaena leucocephala	leucaena	*Coccus longulus* *Heteropsylla cubana*	long soft scale leucaena psyllid	Cameron, 1988c
Lotononis bainesii	lotononis	*Orosius argentatus* *Heliothis*[1] spp.	jassid	Cameron, 1985b
Macroptilium atropurpureum	siratro	*Amnemus* spp.	amnemus weevil	Cameron, 1985a
Macroptilium lathyroides	phasey bean	*Ophiomyia phaseoli*	bean fly	Cameron, 1985d
Macrotyloma axillare	axillaris	*Ophiomyia phaseoli* *Amnemus* spp.	bean fly amnemus weevil	Cameron, 1986
Neonotonia wightii	glycine	*Amnemus* spp. *Leptopius* spp. *Oncopera* spp.	amnemus weevil leptopius weevil webworms	Cameron, 1984b
Stylosanthes guianensis var. *guianensis*	common stylo	no major insect pests	-	Cameron, 1985c
Stylosanthes guianensis var. *intermedia*	fine stem stylo		seed harvesting ants[1]	Cameron, 1987
Stylosanthes scabra	shrubby stylo	*Platyomopsis pedicornis*	native longicorn beetle	Cameron, 1988a
Trifolium semipilosum	Kenya clover	*Oncopera* spp. *Amnemus* spp.	webworms amnemus weevil	Shaw and Quinlan, 1976 Jones, 1981

[1] Particularly a problem in seed crops

Appendix 2.2 Common diseases of herbage legumes in Queensland.

Pasture species	Common name	Disease species	Common name	Reference
Desmodium intortum *D. uncinatum*	desmodiums (Greenleaf) (Silverleaf)		legume little leaf mycoplasma	Cameron, 1984a
Lablab purpureus	lablab	*Xanthomonas campestris*[2] *Ascochyta phaseolorum* *Sclerotinia sclerotiorum*	bacterial blight ascochyta disease stem rot	Cameron, 1988b
Leucaena leucocephala	leucaena	*Pythium* sp. *Alternaria infectoria*	damping off leaf drop	Cameron, 1988c
Lotononis bainesii	lotononis	*Rhizoctonia solani*	leaf blight legume little leaf mycoplasma	Cameron, 1985b
Macroptilium atropurpureum	siratro	*Pseudomonas syringae* pv. *phaseolicola* *Rhizoctonia solani* *Rhizoctonia crocorum*	halo blight leaf blight root rot	Cameron, 1985a
Macroptilium lathyroides	phasey bean		bean common mosaic	Cameron, 1985d
Macrotyloma axillare	axillaris		legume little leaf mycoplasma	Cameron, 1986
Neonotonia wightii	glycine	*Rhizoctonia* sp. *Cercospora* sp. *Pseudomonas syringae* pv. *phaseolicola* *Sclerotinia sclerotiorum*	leaf blight leaf spot bacterium rot	Cameron, 1984b
Stylosanthes scabra	shrubby stylo	*Colletotrichum gloeosporioides* *Botrytis cinerea*[1]	anthracnose head blight	Cameron, 1988a
Stylosanthes guianensis var. *intermedia*	fine stem stylo	*Colletotrichum gloeosporioides* *Botrytis* cinerea[1]	anthracnose head blight	Cameron, 1987
Stylosanthes guianensis var. *guianensis*	common stylo	*Colletotrichum gloeosporioides* *Botrytis cinerea*[1] *Rhizoctonia* sp.	anthracnose head blight web blight	Cameron, 1985c
Trifolium semipilosum	Kenya clover	*Austrogallia torrida*	rugose leaf curl	Shaw and Quinlan, 1976

[1] Particularly a problem in seed crops

[2] A problem yet to be recorded in Australia

Appendix 3.1 Soil Analysis at Kilkivan, South-East Queensland, October 1994.

Soil component	Units	Value
Electrical conductivity	mS/cm	0.082
Chloride[1]	mg/kg	17
Nitrate nitrogen[1]	mg/kg	12
Phosphorous[2]	mg/kg	9
Sulphur[1]	mg/kg	7
Calcium	meq%	20
Magnesium	meq%	28
Sodium	meq%	0.34
Potassium	meq%	0.29
Copper[1]	mg/kg	4.2
Zinc[1]	mg/kg	0.8
Manganese[1]	mg/kg	35
pH[3]	-	7.2

[1] Extractable
[2] Bicarbonate extractable
[3] Water

note: all measurements to 10 cm depth
note: as reported by the Agricultural Chemistry Branch, Agricultural Research Laboratories, Queensland Department of Primary Industries, Indooroopilly, Queensland.

Appendix 3.2 Standard experimental techniques used in this study.

1. Acid scarification of seed prior to sowing

1 Clean seed samples were divided into samples of less than 100 g as required and placed in either a 200 ml or 500 ml beaker (large samples) or free draining ceramic containers (small samples).

2 Hydrochloric acid (95%) was added to seed to make a slurry and mixed thoroughly with a glass rod and left for 6.5 minutes stirring occasionally. Samples in the ceramic containers were dropped into 50 ml beakers containing acid.

3 Samples were drained for one minute on a 2 mm mesh sieve.

4 Samples were vigorously flushed with water for 40 seconds and air dried on blotting paper in ambient conditions.

2. Innoculation of seed with *Rhizobium*

1 Acid scarified seed was placed in a bucket and sufficient methyl-celloluse glue added to just coat the seed.

2 Commercial innoculum (CB3126) was added to the 'slurry' at commercially recommended rates and mixed thoroughly by hand.

3 Innoculated seed was spread out onto blotting paper to dry in shaded conditions.

3 Germination Testing

1 Representative seed samples were obtained by repeated halving in a soil divider when necessary.

2 Samples were acid scarified as in 1.

3 A between paper, short roll method was used: 50 seeds were counted out and placed 1 cm from the edge of a water moistened sheet of blotting paper. The paper was then folded over to cover the seeds and rolled up leaving the seeds towards the uppermost edge. The roll was secured with a rubber band, labelled and placed in a rack which was sealed in a plastic bag.

4 Replications per sample: five

5 Incubation conditions: 20/35°C for 14/10 hr
light/dark for 12/12 hr

6 Evaluation dates: days four and ten

7 Specifications of normal seedlings, abnormal seedlings, fresh ungerminated, hard and dead seeds as detailed in ISTA International Rules for Seed Testing, 1993 (International Seed Testing Association, 1993) were used.

4 Testing for hardseededness

As for the standard germination test except no prior scarification of seed. In some trials all standard germination categories were measured.

5 Seed Weight

Representative samples were obtained by halving samples in a soil divider until seed samples approximated the required amount. This depended on the amount of seed available. In most cases five replicates of 200 seeds were counted and weighed to the nearest 0.01 g. In a few cases small sample sizes meant that five replicates of 100 seeds were used. Results were presented as weight of 1000 seeds.

Appendix 3.3 Climatic data at Kilkivan, South-East Queensland

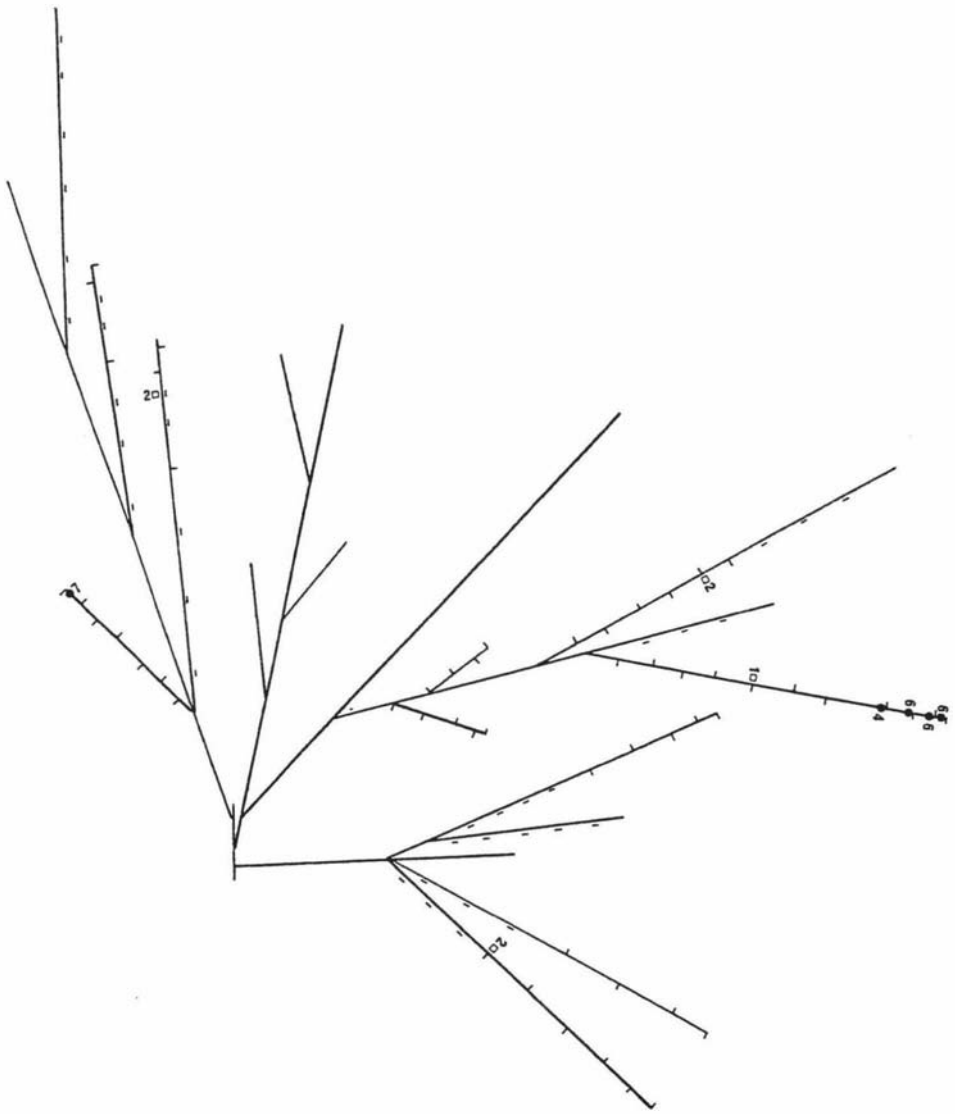
1994/1995

Month	1994/95 rainfall (mm)	1994/95 Irr. (mm)	Total water applied (mm)	Long term rainfall (mm)	1994/95 min. temp. (°C)	1994/95 max. temp. (°C)	Long term min. temp (°C)	Long term max. temp. (°C)
Sept.	20.4	-	20.4	46.7	8.8	26.7	10.1	25.9
Oct.	27.6	-	27.6	72.4	12.5	27.9	13.8	28.3
Nov.	33.7	160	193.7	89.2	16.7	31.5	16.5	30.3
Dec.	52.5	160	212.5	135.7	17.7	30.6	18.5	31.3
Jan.	17.3	160	177.3	164.7	18.7	29.8	19.6	31.2
Feb.	140.8	40	180.8	167.4	19.6	28.9	19.6	30.3
March	63.0	40	100.3	147.3	17.7	29.8	18.1	29.8
April	20.0	40	60.0	85.3	14.0	26.5	14.6	27.4
May	10.5	-	10.5	72.5	13.3	23.9	10.9	24.6
June	14.3	-	14.3	61.7	8.9	21.5	7.8	22.0
July	6.8	-	6.8	55.0	5.8	22.3	6.3	21.8
Aug.	8.8	-	8.8	39.6	8.8	23.3	7.1	23.3

1995/1996

Month	1995/96 rainfall (mm)	1995/96 Irr. (mm)	Total water applied (mm)	Long term rainfall (mm)	1995/96 min. temp. (°C)	1995/96 max. temp. (°C)	Long term min. temp (°C)	Long term max. temp. (°C)
Sept.	22.3	-	22.3	46.7	11.6	26.4	10.1	25.9
Oct.	79.5	80	159.5	72.4	14.0	28.0	13.8	28.3
Nov.	152.3	40	192.3	89.2	19.0	30.8	16.5	30.3
Dec.	89.0	80	169.0	135.7	17.7	30.1	18.5	31.3
Jan.	221.3	-	221.3	164.7	19.9	30.4	19.6	31.2
Feb.	25.7	120	145.7	167.4	18.3	30.9	19.6	30.3
March	28.6	80	100.6	147.3	17.2	29.1	18.1	29.8
April	45.7	-	45.7	85.3	14.8	29.0	14.6	27.4
May	97.1	-	97.1	72.5	13.1	24.3	10.9	24.6
June	25.3	-	25.3	61.7	9.9	22.8	7.8	22.0
July	21.0	-	21.0	55.0	6.8	21.5	6.3	21.8
Aug.	14.6	-	14.6	39.6	7.7	23.6	7.1	23.3

Appendix 3.4 **Schematic diagram of *Desmanthus virgatus* cv. 'Marc' sampled 14 December 1996 showing regrowth after cutting during reproductive development.**



Appendix 3.5 **Plant population effects on mean leaf mass per plant (g) in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**0.11**	**0.78**	**1.19**	**1.06**	**0.61**	**2.26**	**0.84**
	0.08	0.04	0.16	0.48	0.39	0.41	0.63
74	**0.18**	**1.67**	**2.53**	**2.32**	**4.76**	**3.42**	**1.87**
	0.08	0.66	1.07	1.06	1.72	0.74	0.91
96	**1.53**	**3.60**	**3.22**	**4.71**	**8.07**	**12.86**	**14.40**
	0.61	0.24	0.31	0.90	2.47	1.32	2.62
114	**1.88**	**2.98**	**2.72**	**7.30**	**8.24**	**10.93**	**22.32**
	0.67	0.37	0.57	2.49	1.78	3.75	2.01
128	**1.89**	**1.15**	**4.03**	**4.20**	**9.37**	**17.51**	**18.01**
	0.35	0.21	0.60	0.03	2.10	5.58	1.32
142	**1.17**	**1.73**	**2.60**	**2.97**	**7.91**	**17.92**	**27.94**
	0.24	0.25	0.99	0.45	1.31	3.10	7.44
156	**1.08**	**1.44**	**1.41**	**5.96**	**7.11**	**7.39**	**14.61**
	0.64	0.43	0.55	2.54	1.89	4.40	1.42
170	**0.16**	**0.19**	**0.43**	**0.89**	**1.59**	**3.13**	**2.49**
	0.05	0.03	0.13	0.07	0.68	1.10	0.92
184	**0.22**	**0.19**	**0.18**	**0.19**	**0.43**	**1.99**	**0.34**
	0.12	0.16	0.04	0.17	0.20	0.98	0.20
198	**0.00**	**0.00**	**0.19**	**0.24**	**0.08**	**0.66**	**3.02**
	0.00	0.00	0.10	0.12	0.08	0.19	1.76
212	**0.00**	**0.07**	**0.27**	**0.34**	**0.33**	**0.90**	**1.33**
	0.00	0.05	0.04	0.06	0.07	0.63	0.27

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.6 **Plant population effects on mean plant height (cm) in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**15**	**28**	**23**	**18**	**2**	**13**	**19**
	8	1	2	1	2	1	7
74	**25**	**35**	**36**	**3**	**27**	**22**	**22**
	5	2	3	2	1	3	2
96	**59**	**59**	**58**	**48**	**44**	**52**	**34**
	7	1	3	4	5	15	3
114	**73**	**75**	**7**	**48**	**44**	**37**	**3**
	8	6	6	9	3	10	5
128	**64**	**58**	**72**	**4**	**44**	**25**	**26**
	7	8	7	4	7	4	5
142	**74**	**72**	**61**	**58**	**51**	**31**	**27**
	4	6	9	6	5	6	1
156	**66**	**83**	**8**	**67**	**51**	**36**	**2**
	1	3	26	4	9	7	5
170	**55**	**8**	**79**	**67**	**39**	**28**	**22**
	5	2	2	4	3	2	2
184	**75**	**71**	**7**	**58**	**44**	**36**	**31**
	6	1	8	9	3	4	3
198	**79**	**67**	**7**	**54**	**49**	**32**	**4**
	3	1	3	5	7	6	3
212	**62**	**63**	**67**	**55**	**36**	**31**	**37**
	5	6	5	1	4	4	2

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.7 **Plant population effects on mean plant breadth (cm) in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**5**	**13**	**21**	**19**	**12**	**33**	**18**
	3	2	**4**	6	3	2	**9**
74	**7**	**24**	**35**	**43**	**56**	**53**	**31**
	3	8	3	13	12	11	9
96	**54**	**49**	**53**	**98**	**93**	**93**	**112**
	4	9	**4**	19	7	25	4
114	**56**	**59**	**90**	**117**	**123**	**145**	**157**
	25	9	11	37	16	29	7
128	**47**	**57**	**100**	**117**	**162**	**181**	**191**
	11	6	14	19	8	11	9
142	**42**	**72**	**60**	**76**	**140**	**148**	**158**
	17	9	3	5	8	2	10
156	**71**	**45**	**70**	**105**	**106**	**116**	**151**
	22	2	7	28	25	12	6
170	**33**	**36**	**69**	**81**	**103**	**115**	**146**
	17	7	2	4	13	9	5
184	**43**	**48**	**72**	**102**	**111**	**149**	**148**
	10	10	6	14	**4**	11	9
198	**45**	**54**	**72**	**119**	**116**	**151**	**152**
	11	7	6	21	20	9	9
212	**21**	**27**	**65**	**100**	**122**	**153**	**15**
	11	13	11	8	16	**14**	15

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.8 **Plant population effects on mean branch number per plant in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**0.00**	**4.67**	**5.67**	**4.67**	**2.00**	**6.33**	**1.33**
	0.00	0.33	0.33	2.33	2.00	0.33	1.33
74	**0.00**	**6.00**	**5.00**	**10.33**	**11.67**	**14.67**	**7.67**
	0.00	1.52	1.52	4.91	4.41	2.96	1.86
96	**3.67**	**6.67**	**12.00**	**8.33**	**18.00**	**24.67**	**27.33**
	1.86	1.33	2.00	1.45	5.77	1.67	3.38
114	**4.00**	**5.67**	**6.00**	**13.67**	**9.00**	**14.33**	**23.33**
	1.52	0.33	0.58	4.91	3.51	3.17	3.52
128	**5.67**	**3.67**	**6.33**	**6.67**	**10.67**	**21.67**	**29.33**
	0.67	1.33	0.88	2.33	1.76	6.38	4.37
142	**4.66**	**4.33**	**4.33**	**7.33**	**14.00**	**21.33**	**22.66**
	0.88	1.20	1.67	0.88	1.15	4.67	1.33
156	**7.00**	**4.67**	**6.33**	**10.67**	**18.67**	**17.33**	**40.67**
	1.53	1.20	2.03	2.73	3.53	6.36	9.33
170	**2.00**	**5.33**	**7.33**	**7.67**	**16.67**	**26.67**	**46.00**
	1.15	0.88	1.45	0.33	4.05	5.33	13.11
184	**5.37**	**5.67**	**9.00**	**11.00**	**18.30**	**28.66**	**22.67**
	0.33	0.33	1.15	1.52	2.73	3.52	4.37
198	**3.33**	**5.67**	**5.66**	**7.00**	**10.66**	**19.33**	**36.00**
	0.88	0.67	1.20	1.00	1.67	4.48	10.00
212	**2.00**	**3.33**	**8.66**	**15.00**	**26.00**	**32.67**	**44.00**
	1.00	1.67	1.20	2.08	2.00	3.52	6.11

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.9 **Plant population effects on mean total branch length (m) of *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**0.13**	**0.46**	**0.62**	**0.53**	**0.33**	**0.80**	**0.42**
	0.07	0.02	0.09	0.21	0.13	0.11	0.19
74	**0.21**	**1.56**	**1.73**	**1.80**	**2.48**	**1.80**	**8.15**
	0.04	0.54	0.65	0.95	0.82	0.36	6.93
96	**2.22**	**2.92**	**3.76**	**4.51**	**7.67**	**9.62**	**9.15**
	0.18	0.59	0.16	0.32	1.99	1.01	1.07
114	**2.40**	**3.71**	**3.13**	**6.55**	**6.65**	**8.78**	**14.52**
	0.87	0.36	0.42	2.00	0.69	2.30	1.64
128	**2.83**	**1.38**	**2.30**	**3.31**	**7.66**	**8.41**	**10.91**
	0.61	0.44	0.32	0.71	2.51	4.66	1.82
142	**2.77**	**3.16**	**2.84**	**3.57**	**5.83**	**11.07**	**11.28**
	0.83	0.64	1.07	0.09	0.61	1.00	0.31
156	**4.09**	**3.11**	**3.89**	**6.08**	**8.90**	**5.23**	**13.69**
	0.76	0.34	1.18	0.60	1.77	1.59	2.70
170	**1.26**	**4.70**	**4.38**	**4.56**	**7.23**	**9.81**	**15.53**
	0.48	1.64	0.59	0.17	1.56	1.80	3.73
184	**3.54**	**3.16**	**4.54**	**6.29**	**7.23**	**12.86**	**9.96**
	0.39	0.23	0.33	0.60	0.63	1.53	2.00
198	**2.25**	**3.66**	**3.80**	**4.41**	**6.00**	**11.23**	**14.82**
	0.64	0.45	0.59	0.46	1.67	3.39	1.41
212	**1.60**	**2.07**	**4.16**	**5.03**	**9.47**	**11.03**	**18.18**
	0.47	0.74	0.32	0.43	1.36	0.76	1.95

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.10 **Plant population effects on mean branch mass per plant (g) in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**0.12**	**0.41**	**0.53**	**0.49**	**0.31**	**0.87**	**0.39**
	0.06	0.00	0.09	0.19	0.11	0.11	0.17
74	**0.14**	**1.08**	**1.65**	**1.25**	**2.38**	**1.49**	**0.70**
	0.05	0.40	0.72	0.64	0.97	0.41	0.38
96	**1.92**	**4.26**	**3.89**	**5.83**	**9.59**	**11.09**	**10.64**
	0.79	0.46	0.54	1.26	2.63	0.93	1.76
114	**3.36**	**4.62**	**4.05**	**11.49**	**11.81**	**15.15**	**29.96**
	1.51	0.81	0.88	4.63	2.29	7.53	8.59
128	**4.52**	**2.38**	**7.40**	**6.70**	**17.43**	**22.72**	**22.21**
	0.65	0.65	0.78	0.34	2.94	5.46	0.28
142	**3.87**	**5.55**	**4.83**	**5.56**	**12.33**	**25.69**	**27.84**
	1.46	0.57	1.81	0.72	1.38	2.59	5.25
156	**7.17**	**4.79**	**5.80**	**12.00**	**17.19**	**14.11**	**23.41**
	2.09	0.17	2.17	1.76	5.11	6.94	3.11
170	**2.06**	**4.50**	**7.25**	**8.34**	**11.99**	**16.43**	**26.61**
	0.59	0.54	1.07	0.54	2.31	3.06	7.32
184	**6.41**	**5.15**	**8.39**	**11.66**	**10.61**	**26.00**	**18.22**
	1.64	1.04	1.84	2.52	0.59	2.90	3.12
198	**4.64**	**5.38**	**7.18**	**8.65**	**10.74**	**20.62**	**31.85**
	1.05	0.89	1.41	2.01	3.62	2.61	6.83
212	**2.41**	**3.68**	**7.19**	**6.83**	**16.72**	**19.13**	**47.10**
	0.71	1.87	0.55	0.32	2.01	4.32	9.21

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

Appendix 3.11 **Plant population effects on mean number of seeds per immature pod in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
74	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
96	**24.30**	**22.48**	**23.07**	**23.10**	**24.64**	**24.27**	**24.45**
	0.35	1.13	0.72	0.71	0.56	0.90	0.57
114	**19.27**	**21.79**	**20.97**	**24.00**	**22.06**	**21.89**	**23.16**
	2.65	1.69	1.20	0.05	0.24	0.54	0.15
128	**22.43**	**21.63**	**23.43**	**19.38**	**22.33**	**22.72**	**21.11**
	1.15	0.07	1.11	0.84	1.37	0.44	0.36
142	-	**20.00**	**15.00**	-	**23.00**	**26.00**	**19.90**
	-	-	-	-	-	-	2.56
156	-	-	-	**21.39**	**18.80**	**18.78**	**21.77**
	-	-	-	-	1.47	2.78	0.67
170	-	-	**12.00**	**18.33**	**22.32**	**20.99**	**18.12**
	-	-	-	-	-	0.01	2.79
184	-	**21.00**	**10.00**	**14.78**	**15.16**	**12.57**	**15.97**
	-	-	1.83	2.77	1.96	3.49	-
198	-	-	-	-	**20.50**	**16.20**	**21.54**
	-	-	-	-	0.50	2.32	0.46
212	-	-	**13.50**	-	**19.00**	**18.50**	**15.50**
	-	-	-	-	-	2.00	3.00

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- No value

Appendix 3.12 Numbers of reproductive indices per plant in *Desmanthus virgatus* cv. 'Marc'.

t[1]	Mean branch number	Mean total number of reproductive sites	Mean number of inflorescences	Mean number of immature umbels	Mean number of mature umbels	Mean number of florets per inflorescence	Mean number pods per umbel	Mean number of seeds per immature pod	Mean number of seeds per mature pod
60	**3.520**	**1.333**	**0.905**	**0.429**	**0.000**	**4.760**	**3.110**	-	-
	0.642	0.340	0.248	0.147	0.000	0.271	0.386	-	-
74	**7.905**	**12.952**	**11.095**	**2.286**	**0.000**	**6.470**	**3.455**	-	-
	1.366	3.383	2.855	0.727	0.000	0.401	0.441	-	-
96	**14.381**	**72.524**	**35.190**	**36.905**	**0.429**	**6.969**	**3.202**	**23.760**	**19.225**
	2.106	13.869	7.863	7.393	0.202	0.391	0.170	0.294	0.924
114	**10.857**	**73.286**	**5.190**	**39.333**	**28.667**	**6.914**	**3.028**	**21.878**	**22.565**
	1.691	17.153	2.854	9.590	6.675	0.853	0.172	0.516	0.443
128	**12.000**	**64.619**	**0.905**	**16.381**	**52.095**	**5.867**	**2.654**	**21.875**	**21.443**
	2.250	15.180	0.507	3.509	15.981	0.296	0.098	0.411	0.900
142	**11.238**	**57.333**	**11.095**	**3.190**	**43.048**	**5.122**	**2.437**	**20.529**	**19.469**
	1.803	13.286	3.493	1.390	9.591	0.303	0.141	1.600	1.109
156	**15.048**	**41.762**	**2.286**	**13.333**	**24.952**	**5.100**	**2.385**	**20.234**	**16.000**
	2.992	11.387	0.969	5.599	6.654	0.392	0.170	0.838	-
170	**15.952**	**30.333**	**0.190**	**5.429**	**24.714**	**4.500**	**2.490**	**18.699**	-
	3.695	8.008	0.191	2.737	6.527	-	0.102	1.422	-
184	**14.429**	**34.381**	**0.190**	**3.905**	**30.286**	**4.000**	**2.881**	**14.221**	**14.000**
	2.011	5.842	0.131	1.577	5.132	0.000	0.196	1.249	-
198	**12.523**	**37.095**	**0.000**	**6.810**	**29.952**	**-**	**2.813**	**18.954**	**-**
	2.756	10.346	0.000	5.512	6.959	-	0.276	1.328	-
212	**18.810**	**30.667**	**0.476**	**4.143**	**22.667**	**5.900**	**1.377**	**16.750**	**18.123**
	3.427	7.131	0.203	2.664	5.210	0.678	0.309	1.302	2.052

[1] Time (days) after germination (13 November 1994) **0.00** Mean (n=21)

\- No value 0.00 Standard error (n=21)

Appendix 3.13 **Plant population effects on mean number of seeds per mature pod in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
74	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
96	**18.60**	-	**21.30**	**17.00**	**20.00**	-	-
	-	-	-	-	-	-	-
114	**20.03**	**22.95**	**22.49**	**22.90**	**22.64**	**21.80**	**24.27**
	1.63	0.96	0.33	1.09	1.20	1.32	1.45
128	**19.00**	**24.78**	**22.18**	**17.35**	-	**23.22**	**21.60**
	-	-	1.52	0.65	-	2.06	1.55
142	**25.00**	**20.59**	**17.00**	**18.75**	**13.50**	**20.06**	**18.03**
	2.00	-	-	2.75	-	1.94	1.91
156	-	-	**16.00**	-	-	-	-
	-	-	-	-	-	-	-
170	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
184	-	-	-	-	-	-	**14.00**
	-	-	-	-	-	-	-
198	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
212	-	-	-	**13.33**	**17.50**	-	**20.83**
	-	-	-	-	-	-	2.50

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- No value

Appendix 3.14 **Plant population effects on mean number of immature umbels per plant in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**-**	**0.33**	**1.00**	**0.67**	**-**	**0.67**	**0.33**
	-	0.33	0.58	0.33	-	0.67	0.33
74	**-**	**3.67**	**3.00**	**2.00**	**5.00**	**1.33**	**1.00**
	-	3.18	2.52	1.52	2.89	0.88	0.58
96	**9.67**	**12.66**	**13.33**	**22.33**	**60.67**	**91.67**	**48.00**
	3.93	3.76	2.40	9.67	16.76	19.81	11.53
114	**6.33**	**10.00**	**6.33**	**26.00**	**30.33**	**74.33**	**122.00**
	4.37	3.51	1.76	9.45	8.01	17.17	16.65
128	**7.33**	**3.00**	**6.67**	**8.67**	**16.00**	**30.00**	**43.00**
	1.20	1.73	2.03	1.33	2.00	8.72	10.82
142	**-**	**0.67**	**0.33**	**-**	**3.00**	**0.67**	**17.67**
	-	0.33	0.33	-	2.08	0.67	2.18
156	**-**	**-**	**-**	**1.00**	**20.00**	**7.67**	**64.67**
	-	-	-	1.00	14.19	3.84	16.71
170	**-**	**-**	**0.67**	**1.33**	**6.67**	**9.33**	**20.00**
	-	-	0.67	0.88	3.53	4.67	18.04
184	**-**	**0.67**	**1.67**	**2.33**	**2.67**	**16.66**	**3.33**
	-	0.67	0.88	0.33	0.88	7.86	3.33
198	**-**	**-**	**-**	**0.33**	**1.00**	**2.33**	**44.00**
	-	-	-	0.33	0.58	0.33	36.30
212	**-**	**-**	**0.33**	**-**	**0.67**	**16.67**	**11.33**
	-	-	0.33	-	0.67	15.68	10.35

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- No umbels

Appendix 3.15 **Plant population effects on mean number of mature umbels per plant in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
74	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
96	**0.67**	-	**1.00**	**0.67**	**0.67**	-	-
	0.67	-	1.00	0.67	0.67	-	-
114	**7.66**	**8.00**	**11.00**	**42.33**	**26.00**	**74.33**	**70.00**
	4.98	2.00	3.00	15.30	16.17	28.18	15.01
128	**9.67**	**4.00**	**10.00**	**16.00**	**60.67**	**146.67**	**117.67**
	1.76	1.15	2.51	3.21	16.56	85.58	2.33
142	**10.33**	**12.67**	**14.33**	**17.00**	**39.33**	**99.00**	**108.67**
	3.18	5.46	7.06	0.58	19.89	16.65	14.25
156	**5.00**	**12.00**	**9.67**	**23.66**	**27.00**	**15.00**	**82.33**
	3.61	3.61	4.41	6.89	11.93	6.66	26.86
170	**5.00**	**7.67**	**11.00**	**21.00**	**25.33**	**26.33**	**76.66**
	1.73	0.67	3.79	3.00	11.46	12.73	29.49
184	**13.00**	**9.33**	**18.00**	**25.33**	**28.33**	**59.66**	**58.33**
	2.08	2.19	2.89	8.84	5.61	7.45	19.43
198	**6.00**	**11.00**	**16.67**	**17.67**	**23.00**	**50.66**	**84.67**
	1.53	2.52	4.91	5.24	9.71	24.55	16.33
212	**2.67**	**5.00**	**11.33**	**15.67**	**38.67**	**32.33**	**53.00**
	0.88	2.31	2.67	1.20	9.91	7.31	25.58

[1] Time (days) after germination (13 November 1994)
0.00 Mean (n=3)
0.00 Standard error (n=3)
- No umbels

Appendix 3.16 **Plant population effects on mean number of florets per inflorescence in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	**4.00**	**6.00**	**4.43**	**4.00**	**6.00**	**5.15**	**-**
	0.00	-	0.43	-	-	0.15	-
74	**4.00**	**6.15**	**7.13**	**6.67**	**6.73**	**8.60**	**4.87**
	-	0.35	0.76	0.91	0.72	1.60	0.55
96	**6.77**	**7.06**	**7.28**	**5.37**	**7.77**	**7.33**	**7.20**
	1.08	0.48	0.86	2.51	0.50	0.44	0.15
114	**4.75**	**-**	**5.30**	**-**	**7.00**	**8.40**	**9.10**
	1.75	-	-	-	-	-	0.60
128	**-**	**-**	**-**	**5.30**	**6.00**	**-**	**6.30**
	-	-	-	-	-	-	-
142	**-**	**-**	**-**	**4.84**	**5.21**	**4.76**	**6.12**
	-	-	-	0.05	0.27	0.26	0.92
156	**-**	**-**	**-**	**-**	**5.33**	**5.50**	**4.89**
	-	-	-	-	-	-	0.67
170	**-**	**-**	**-**	**-**	**-**	**-**	**4.50**
	-	-	-	-	-	-	-
184	**-**	**-**	**-**	**-**	**-**	**4.00**	**-**
	-	-	-	-	-	0.00	-
198	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	-	-	-	-	-	-	-
212	**-**	**-**	**6.50**	**6.50**	**6.00**	**-**	**4.00**
	-	-	-	1.50	-	-	-

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- No value

Appendix 3.17 **Plant population effects on mean number of pods per umbel in *Desmanthus virgatus* cv. 'Marc'.**

t[1]	Density group						
	1	2	3	4	5	6	7
60	-	**3.00**	**4.00**	**1.75**	-	**5.15**	**4.00**
	-	-	0.00	0.25	-	0.15	-
74	-	**3.00**	**6.00**	**0.00**	**3.68**	**2.65**	**1.50**
	-	0.00	0.00	0.90	0.48	0.35	0.50
96	**2.47**	**2.83**	**2.73**	**3.33**	**2.93**	**3.87**	**4.25**
	0.27	0.49	0.12	0.49	0.24	0.27	0.26
114	**2.60**	**2.93**	**2.83**	**2.50**	**2.80**	**3.97**	**3.57**
	0.37	0.54	0.26	0.15	0.43	0.65	0.60
128	**2.94**	**2.74**	**2.84**	**2.32**	**2.88**	**2.41**	**2.42**
	0.29	0.26	0.20	0.24	0.40	0.10	0.24
142	**2.32**	**1.86**	**1.87**	**2.78**	**2.29**	**3.07**	**2.86**
	0.45	0.29	0.46	0.37	0.12	0.17	0.16
156	**2.30**	**1.70**	**2.25**	**1.90**	**2.04**	**3.17**	**3.32**
	0.33	0.20	0.32	0.36	0.59	0.27	0.16
170	**2.24**	**2.16**	**2.61**	**2.68**	**2.65**	**2.57**	**2.51**
	0.38	0.36	0.12	0.16	0.05	0.23	0.47
184	**2.77**	**1.87**	**3.31**	**2.99**	**2.55**	**3.13**	**3.53**
	0.50	0.93	0.38	0.24	0.40	0.36	0.40
198	**3.09**	**3.05**	**2.35**	**1.72**	**3.25**	**2.92**	**3.29**
	1.73	0.34	0.58	0.86	0.05	0.37	0.12
212	**0.00**	**0.67**	**0.00**	**1.41**	**2.09**	**2.37**	**3.08**
	0.00	0.67	0.00	0.79	1.04	0.30	3.00

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- No value

Appendix 3.18 **Pearson correlation co-efficients of selected vegetative structures and seed yield components in *Desmanthus virgatus* cv. 'Marc'.**

	t(days)[1]	Correlation co-efficient				
		ht	bh	bnch/pl	bm/pl	ln/pl
bnch/pl	96	-0.41	0.52*		**0.81***	**0.92***
	114	-0.64*	0.64*		**0.84***	**0.86***
	128	-0.63*	0.68*		**0.81***	**0.87***
inf/pl	96	-0.47*	0.57	**0.92***	**0.78***	**0.91***
	114	-0.43	0.48*	0.44*	0.38	0.65*
	128	-0.25	0.22	0.13	0.31	0.36
flt/inf	96	0.11	-0.07	0.13	0.27	0.18
	114	-0.61	**0.87***	**0.80***	**0.79***	0.72
	128	-0.68	**0.99***	0.69	**0.96***	**0.96***
imm/pl	96	-0.45*	0.69*	0.69*	**0.84***	**0.82***
	114	-0.71*	0.67*	**0.86***	**0.88***	**0.95***
	128	-0.62*	0.67*	0.74*	0.71*	0.73*
mat/pl	96	0.23	0.05	-0.24	-0.01	-0.13
	114	-0.57*	**0.78***	0.68*	0.70*	**0.77***
	128	-0.57*	0.59*	**0.81***	**0.89***	**0.93***
pds/um	96	-0.34	0.50*	0.59*	0.63*	0.69*
	114	-0.15	0.52*	0.53*	0.54*	0.53*
	128	0.52*	-0.15	-0.39	-0.26	-0.35
sd/imm	96	-0.46*	0.43*	0.34	0.35	0.47*
	114	-0.23	0.30	0.33	0.29	0.27
	128	0.23	-0.05	-0.08	0.05	0.09

[1] time (days) after germination (13 November 1994)

* **P = 0.05**

Correlation co-efficient > 0.75

Correlation co-efficient 0.40-0.75

ht	mean plant height
bh	mean plant breadth
bnch/pl	mean number of branches/plant
bm/pl	mean branch mass/plant
ln/pl	mean leaf number/plant
inf/pl	mean inflorescence number/plant
flt/inf	mean number of florets/inflorescence
imm/pl	mean number immature umbels/plant
mat/pl	mean number of mature umbels/plant
pds/um	mean number pods/umbel
sd/imm	mean number of seeds/immature pod

Appendix 3.19 Values used to calculate potential seed yields of *Desmanthus virgatus* cv. 'Marc' grown in a range of population densities.

Density group	Population density (plants/m^2)	Replicate	First flowering peak			Second flowering peak		
			Inflorescence per plant	Potential seed yield[1] (g/plant)	Potential seed yield (g/m^2)	Inflorescence per plant	Potential seed yield[2] (g/plant)	Potential seed yield (g/m^2)
1	159.85	1	10	1.90	303.72	0	0	0
		2	8	1.52	242.97	0	0	0
		3	2	0.38	60.74	0	0	0
2	84.93	1	4	0.76	64.55	1	0.12	10.19
		2	11	2.09	177.50	0	0	0
		3	12	2.28	193.64	0	0	0
3	45.22	1	18	3.42	154.65	0	0	0
		2	6	1.14	51.55	0	0	0
		3	14	2.66	120.29	0	0	0
4	24.07	1	25	4.75	114.33	0	0	0
		2	15	2.85	68.60	9	2.19	52.71
		3	13	2.47	59.45	13	1.58	38.03
5	12.81	1	39	7.41	94.92	9	1.09	13.96
		2	16	3.04	38.94	6	0.73	9.35
		3	49	9.31	119.26	12	1.46	18.70
6	6.82	1	90	17.10	116.62	26	3.16	21.55
		2	69	13.11	89.41	8	0.97	6.61
		3	55	10.45	71.27	30	3.65	24.89
7	3.17	1	80	15.20	48.18	28	3.40	10.78
		2	122	23.18	73.48	64	7.78	24.66
		3	94	17.86	56.62	26	3.16	10.02

[1] Calculated using:
mean number of pods per umbel (114 days) = 3.02
mean number of seeds per immature pod (114 days) = 21.88
mean thousand seed weight (142 days) = 2.82 g

[2] Calculated using:
mean number of pods per umbel (156 days) = 2.38
mean number of seeds per immature pod (156 days) = 20.19
mean thousand seed weight (184 days) = 2.53 g

Appendix 3.20 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 1.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**-**	**-**	**-**	**-**	**4.67**	**-**	**-**	**4.67**	**0.67**	**-**	**-**	**0.67**
	-	-	-	-	2.91	-	-	2.91	0.33	-	-	0.33
74	**-**	**-**	**-**	**-**	**8.00**	**-**	**-**	**8.00**	**0.33**	**-**	**-**	**4.33**
	-	-	-	-	2.52	-	-	2.52	0.33	-	-	3.38
96	**3.67**	**-**	**-**	**3.67**	**21.33**	**53.67**	**-**	**75.00**	**2.67**	**4.00**	**-**	**6.67**
	1.86	-	-	1.86	1.20	26.87	-	26.50	0.33	2.08	-	2.40
114	**4.00**	**-**	**-**	**4.00**	**15.00**	**38.33**	**-**	**53.33**	**0.33**	**0.67**	**-**	**1.00**
	1.53	-	-	1.53	0.58	17.63	-	17.90	0.33	0.67	-	0.58
128	**5.67**	**-**	**-**	**5.67**	**11.67**	**62.33**	**-**	**74.00**	**-**	**-**	**-**	**-**
	0.67	-	-	0.67	1.33	6.74	-	7.81	-	-	-	-
142	**4.67**	**-**	**-**	**4.67**	**10.33**	**31.67**	**-**	**42.00**	**-**	**-**	**-**	**-**
	0.88	-	-	0.88	2.40	9.49	-	7.37	-	-	-	-
156	**6.00**	**1.00**	**-**	**7.00**	**5.67**	**25.00**	**2.67**	**33.33**	**-**	**-**	**-**	**-**
	0.58	1.00	-	1.53	0.67	12.53	2.67	14.84	-	-	-	-
170	**2.00**	**-**	**-**	**2.00**	**3.33**	**5.00**	**-**	**8.33**	**-**	**-**	**-**	**-**
	1.15	-	-	1.15	0.33	2.65	-	2.73	-	-	-	-
184	**5.67**	**-**	**-**	**5.67**	**1.00**	**8.00**	**-**	**9.00**	**-**	**-**	**-**	**-**
	0.33	-	-	0.33	1.00	4.00	-	4.58	-	-	-	-
198	**3.33**	**-**	**-**	**3.33**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	0.88	-	-	0.88	-	-	-	-	-	-	-	-
212	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	-	-	-	-	-	-	-	-	-	-	-	-

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- None present

Appendix 3.21 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 2.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**4.67**	-	-	**4.67**	**13.33**	**18.33**	-	**31.67**	**0.67**	-	-	**0.67**
	0.33	-	-	0.33	0.33	1.67	-	1.33	0.67	-	-	0.67
74	**6.00**	-	-	**6.00**	**13.33**	**44.33**	-	**57.67**	**0.67**	**3.67**	-	**4.34**
	1.52	-	-	1.52	3.48	14.17	-	17.42	0.67	3.67	-	3.38
96	**6.67**	-	-	**6.67**	**19.00**	**74.33**	-	**93.33**	**1.67**	**6.33**	-	**8.00**
	1.33	-	-	1.33	1.15	25.39	-	26.52	0.67	3.29	-	3.51
114	**5.67**	-	-	**5.67**	**15.33**	**86.00**	-	**101.33**	-	-	-	-
	0.33	-	-	0.33	2.73	19.50	-	21.40	-	-	-	-
128	**3.67**	-	-	**3.67**	**18.00**	**24.67**	-	**42.67**	-	-	-	-
	1.33	-	-	1.33	0.58	9.06	-	8.95	-	-	-	-
142	**4.33**	-	-	**4.33**	**12.33**	**53.67**	-	**66.00**	-	**0.67**	-	**0.67**
	1.20	-	-	1.20	2.33	17.14	-	18.93	-	0.67	-	0.67
156	**4.67**	-	-	**4.67**	**10.00**	**35.00**	-	**45.00**	-	-	-	-
	1.20	-	-	1.20	2.08	8.19	-	9.50	-	-	-	-
170	**5.33**	-	-	**5.33**	**0.67**	**11.00**	-	**11.67**	-	-	-	-
	0.88	-	-	0.88	0.67	1.00	-	1.45	-	-	-	-
184	**5.67**	-	-	**5.67**	-	**2.33**	-	**2.33**	-	-	-	-
	0.33	-	-	0.33	-	1.45	-	1.45	-	-	-	-
198	**5.67**	-	-	**5.67**	-	-	-	-	-	-	-	-
	0.67	-	-	0.67	-	-	-	-	-	-	-	-
212	-	-	-	-	**4.00**	**4.67**	-	**8.67**	-	-	-	-
	-	-	-	-	2.08	3.71	-	4.10	-	-	-	-

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- None present

Appendix 3.22 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 3.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**5.67**	**-**	**-**	**5.67**	**13.33**	**28.00**	**-**	**41.33**	**1.00**	**-**	**-**	**1.67**
	0.33	-	-	0.33	0.88	4.93	-	5.81	1.00	-	-	0.67
74	**5.00**	**-**	**-**	**5.00**	**12.00**	**43.33**	**-**	**55.33**	**2.67**	**9.33**	**-**	**12.00**
	1.53	-	-	1.53	6.03	14.71	-	20.67	1.33	3.18	-	4.51
96	**11.00**	**1.00**	**-**	**12.00**	**8.00**	**112.00**	**7.00**	**127.00**	**-**	**12.67**	**-**	**12.67**
	1.73	1.00	-	2.00	1.15	9.64	7.00	11.93	-	3.53	-	3.53
114	**6.00**	**-**	**-**	**6.00**	**39.33**	**66.33**	**-**	**105.67**	**-**	**1.00**	**-**	**1.00**
	0.58	-	-	0.58	20.85	8.21	-	25.58	-	1.00	-	1.00
128	**5.00**	**1.33**	**-**	**6.33**	**13.67**	**78.33**	**15.00**	**107.00**	**-**	**-**	**-**	**-**
	2.08	1.33	-	0.88	5.04	37.57	15.00	18.61	-	-	-	-
142	**4.33**	**-**	**-**	**4.33**	**12.33**	**44.00**	**-**	**56.33**	**-**	**-**	**-**	**-**
	1.67	-	-	1.67	4.91	20.52	-	16.23	-	-	-	-
156	**6.33**	**-**	**-**	**6.33**	**6.00**	**47.33**	**-**	**53.33**	**-**	**-**	**-**	**-**
	2.03	-	-	2.03	2.08	18.77	-	18.68	-	-	-	-
170	**7.33**	**-**	**-**	**7.33**	**-**	**11.67**	**-**	**11.67**	**-**	**-**	**-**	**-**
	1.45	-	-	1.45	-	4.25	-	4.26	-	-	-	-
184	**7.33**	**1.67**	**-**	**9.00**	**-**	**5.67**	**4.67**	**10.33**	**-**	**-**	**-**	**-**
	0.88	1.67	-	1.15	-	0.88	4.67	3.84	-	-	-	-
198	**5.67**	**-**	**-**	**5.67**	**0.33**	**4.67**	**-**	**5.00**	**-**	**-**	**-**	**-**
	1.20	-	-	1.20	0.33	1.86	-	2.08	-	-	-	-
212	**8.67**	**-**	**-**	**8.67**	**4.00**	**4.67**	**-**	**18.33**	**-**	**-**	**0.67**	**0.67**
	1.20	-	-	1.20	2.08	3.71	-	2.03	-	-	0.67	0.67

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- None present

Appendix 3.23 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 4.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**4.67**	**-**	**-**	**4.67**	**11.33**	**23.33**	**-**	**34.67**	**0.67**	**-**	**-**	**0.67**
	2.33	-	-	2.33	3.17	11.68	-	14.86	0.67	-	-	0.67
74	**8.00**	**2.33**	**-**	**10.33**	**15.67**	**51.67**	**5.67**	**73.00**	**2.00**	**10.33**	**-**	**12.33**
	2.64	2.33	-	4.91	2.03	24.55	5.67	31.97	-	8.88	-	8.88
96	**8.33**	**1.00**	**-**	**8.33**	**16.67**	**116.00**	**-**	**133.33**	**1.67**	**16.00**	**-**	**17.67**
	1.45	1.00	-	1.45	1.45	10.44	-	9.26	0.33	3.51	-	3.71
114	**7.67**	**6.00**	**-**	**13.67**	**18.67**	**89.67**	**80.67**	**189.00**	**-**	**-**	**-**	**-**
	2.19	3.06	-	4.91	12.35	21.67	46.19	61.01	-	-	-	-
128	**5.67**	**1.00**	**-**	**6.67**	**14.67**	**79.33**	**4.67**	**98.67**	**-**	**-**	**1.67**	**1.67**
	1.45	1.00	-	2.33	3.38	13.13	4.67	14.08	-	-	1.67	1.67
142	**7.00**	**0.33**	**-**	**7.33**	**4.67**	**62.67**	**3.00**	**70.33**	**-**	**6.00**	**1.33**	**7.33**
	0.57	0.33	-	0.88	2.60	7.31	3.00	7.22	-	3.79	1.33	3.84
156	**7.67**	**3.00**	**-**	**10.67**	**6.67**	**50.67**	**18.00**	**75.33**	**-**	**-**	**-**	**-**
	0.88	2.52	-	2.73	0.88	5.17	15.10	13.57	-	-	-	-
170	**7.67**	**-**	**-**	**7.67**	**1.67**	**23.33**	**-**	**25.00**	**-**	**-**	**-**	**-**
	0.33	-	-	0.33	1.20	2.73	-	3.51	-	-	-	-
184	**9.00**	**2.00**	**-**	**11.00**	**0.67**	**3.33**	**-**	**4.00**	**-**	**-**	**-**	**-**
	1.00	1.15	-	1.53	0.67	3.33	-	4.00	-	-	-	-
198	**-**	**-**	**-**	**-**	**0.33**	**5.67**	**-**	**6.00**	**-**	**-**	**-**	**-**
	-	-	-	-	0.33	2.85	-	3.00	-	-	-	-
212	**10.33**	**4.67**	**-**	**15.00**	**1.33**	**20.33**	**10.67**	**32.33**	**-**	**-**	**1.33**	**1.33**
	1.45	0.88	-	2.08	1.33	4.91	4.63	10.40	-	-	0.88	0.88

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- None present

Appendix 3.24 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 5.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**2.00**	**-**	**-**	**2.00**	**12.33**	**12.00**	**-**	**24.33**	**0.67**	**-**	**-**	**0.67**
	2.00	-	-	2.00	3.18	12.00	-	13.64	0.67	-	-	0.67
74	**8.33**	**3.33**	**-**	**11.67**	**18.33**	**75.33**	**10.00**	**103.67**	**3.33**	**24.00**	**-**	**27.33**
	1.67	3.33	-	4.41	2.03	20.90	10.00	29.81	0.67	11.53	-	12.17
96	**11.67**	**6.33**	**-**	**18.00**	**14.67**	**155.00**	**61.33**	**231.00**	**-**	**22.00**	**9.33**	**31.33**
	3.18	3.18	-	5.77	5.21	14.57	35.80	51.97	-	10.21	5.81	12.99
114	**7.00**	**2.00**	**-**	**9.00**	**7.00**	**128.00**	**8.00**	**143.00**	**-**	**0.33**	**-**	**0.33**
	1.53	2.00	-	3.51	5.13	28.02	8.00	30.99	-	0.33	-	0.33
128	**8.67**	**2.00**	**-**	**10.67**	**10.33**	**140.67**	**83.33**	**234.33**	**-**	**-**	**2.67**	**2.67**
	2.91	2.00	-	1.76	2.85	10.67	83.33	76.65	-	-	2.67	2.67
142	**11.33**	**2.67**	**-**	**14.00**	**6.33**	**128.67**	**14.67**	**149.67**	**-**	**8.33**	**0.67**	**9.00**
	0.67	0.67	-	1.15	0.67	22.40	3.71	19.37	-	2.33	0.67	1.73
156	**8.00**	**10.67**	**-**	**18.67**	**1.33**	**74.67**	**96.00**	**172.00**	**-**	**-**	**4.00**	**4.00**
	1.15	2.91	-	3.53	0.88	28.62	8.72	32.81	-	-	4.00	4.00
170	**10.00**	**6.67**	**-**	**16.67**	**-**	**25.00**	**25.33**	**50.33**	**-**	**-**	**-**	**-**
	-	4.06	-	4.06	-	15.63	21.46	36.83	-	-	-	-
184	**10.66**	**7.67**	**-**	**18.33**	**-**	**6.33**	**3.67**	**10.00**	**-**	**-**	**-**	**-**
	1.33	1.45	-	2.73	-	4.33	1.86	5.29	-	-	-	-
198	**-**	**-**	**-**	**-**	**-**	**0.67**	**2.33**	**3.00**	**-**	**-**	**-**	**-**
	-	-	-	-	-	0.33	2.33	2.52	-	-	-	-
212	**10.67**	**14.67**	**-**	**26.00**	**0.33**	**12.00**	**8.00**	**20.00**	**-**	**-**	**0.67**	**0.67**
	2.40	1.33	-	2.00	0.33	6.11	8.00	12.86	-	-	0.67	0.67

[1] Time (days) after germination (13 November 1994)

0.00 Mean (n=3)

0.00 Standard error (n=3)

\- None present

Appendix 3.25 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 6.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**6.33**	**-**	**-**	**6.33**	**16.00**	**42.00**	**-**	**58.00**	**2.00**	**-**	**-**	**2.00**
	0.33	-	-	0.33	1.15	4.93	-	5.68	1.00	-	-	1.00
74	**12.33**	**2.33**	**-**	**14.67**	**14.67**	**85.67**	**12.00**	**112.33**	**1.00**	**15.00**	**-**	**16.00**
	2.03	1.20	-	2.96	2.19	11.72	6.11	14.89	1.00	7.55	-	8.00
96	**16.33**	**8.33**	**-**	**24.67**	**12.33**	**221.00**	**112.00**	**345.33**	**1.33**	**42.00**	**28.00**	**71.33**
	1.20	1.20	-	1.67	4.06	10.69	13.75	25.21	0.67	7.94	3.06	10.17
114	**10.67**	**3.67**	**-**	**14.33**	**6.00**	**217.67**	**49.67**	**273.33**	**-**	**4.00**	**1.33**	**5.33**
	2.67	1.45	-	3.18	3.21	47.58	17.70	53.24	-	4.00	1.33	5.33
128	**10.67**	**10.67**	**-**	**21.67**	**6.33**	**134.00**	**184.67**	**327.67**	**-**	**-**	**-**	**-**
	0.67	6.36	-	6.39	4.91	24.25	121.58	141.86	-	-	-	-
142	**14.00**	**7.33**	**-**	**21.33**	**4.67**	**197.33**	**75.33**	**162.16**	**0.67**	**15.33**	**5.33**	**21.33**
	2.00	3.33	-	4.67	2.60	4.06	34.10	81.02	0.67	5.21	1.76	6.67
156	**10.67**	**5.33**	**-**	**17.33**	**4.67**	**93.33**	**27.33**	**130.00**	**-**	**0.67**	**0.67**	**3.33**
	0.67	4.37	-	6.36	4.67	18.67	19.06	45.03	-	0.67	0.67	3.33
170	**12.67**	**10.67**	**3.33**	**26.67**	**-**	**36.67**	**44.67**	**96.00**	**-**	**-**	**-**	**-**
	1.33	3.71	3.33	5.33	-	10.48	23.79	37.11	-	-	-	-
184	**12.00**	**16.67**	**-**	**28.67**	**2.00**	**16.00**	**34.00**	**52.00**	**-**	**-**	**1.33**	**1.33**
	1.15	3.33	-	3.53	1.53	8.08	18.58	27.06	-	-	0.67	0.67
198	**-**	**-**	**-**	**-**	**-**	**5.00**	**3.67**	**8.67**	**-**	**-**	**-**	**-**
	-	-	-	-	-	4.04	2.73	6.77	-	-	-	-
212	**14.00**	**14.67**	**4.00**	**32.67**	**1.00**	**11.33**	**26.00**	**38.33**	**-**	**-**	**-**	**-**
	2.00	5.45	4.00	3.53	1.00	9.40	17.00	27.23	-	-	-	-

[1] time (days) after germination (13 November 1994)

0.00 mean (n=3)

0.00 standard error (n=3)

\- None present

Appendix 3.26 **Number of branches, leaves and inflorescences on different branching tiers of *Desmanthus virgatus* cv. 'Marc': Density group 7.**

t[1]	Branch number				Leaf number				Inflorescence number			
	Tier 2	Tier 3	Tier 4	Total	Tier 1	Tier 2	Tier 3	Total	Tier 1	Tier 2	Tier 3	Total
60	**1.33**	**-**	**-**	**1.33**	**9.00**	**10.33**	**-**	**19.33**	**-**	**-**	**-**	**-**
	1.33	-	-	1.33	3.21	10.33	-	12.99	-	-	-	-
74	**7.66**	**-**	**-**	**7.67**	**13.00**	**52.00**	**-**	**65.00**	**2.00**	**3.33**	**-**	**5.33**
	1.86	-	-	1.86	1.53	21.78	-	23.16	1.00	2.03	-	2.33
96	**15.67**	**11.67**	**-**	**27.33**	**10.33**	**285.33**	**55.33**	**351.00**	**1.33**	**69.67**	**15.00**	**98.67**
	4.37	2.96	-	3.38	2.19	22.25	5.45	29.48	0.88	4.06	7.77	12.35
114	**13.00**	**10.33**	**-**	**23.33**	**10.67**	**233.33**	**282.00**	**526.00**	**-**	**12.67**	**16.00**	**28.67**
	1.73	1.86	-	3.53	2.40	26.84	56.96	81.71	-	6.56	8.00	14.44
128	**12.67**	**16.67**	**-**	**29.33**	**5.00**	**164.00**	**232.67**	**368.33**	**-**	**-**	**2.00**	**2.00**
	1.33	4.06	-	4.37	2.65	70.00	46.26	12.03	-	-	2.00	2.00
142	**13.33**	**9.33**	**-**	**22.67**	**4.33**	**202.67**	**144.67**	**351.67**	**-**	**13.33**	**26.00**	**39.33**
	1.76	2.40	-	1.33	3.33	49.02	17.64	67.30	-	11.39	2.00	12.35
156	**9.33**	**17.33**	**14.00**	**40.67**	**0.33**	**76.00**	**97.33**	**236.33**	**-**	**-**	**1.33**	**1.33**
	0.67	8.82	-	9.33	0.33	14.00	16.59	6.84	-	-	1.33	1.33
170	**14.00**	**22.67**	**9.33**	**46.00**	**2.33**	**17.33**	**85.33**	**143.67**	**-**	**-**	**-**	**-**
	2.31	5.70	9.33	13.11	1.45	3.33	38.86	77.15	-	-	-	-
184	**10.67**	**12.00**	**-**	**22.67**	**-**	**4.67**	**12.67**	**17.33**	**-**	**-**	**-**	**-**
	0.67	5.03	-	4.37	-	2.40	8.97	10.41	-	-	-	-
198	**-**	**-**	**-**	**-**	**1.00**	**14.67**	**38.67**	**54.00**	**-**	**-**	**-**	**-**
	-	-	-	-	0.58	5.81	32.85	37.75	-	-	-	-
212	**16.67**	**23.33**	**4.00**	**44.00**	**-**	**8.00**	**8.00**	**16.00**	**-**	**-**	**0.67**	**0.67**
	3.53	5.33	4.00	6.11	-	8.00	3.06	9.45	-	-	0.67	0.67

[1] time (days) after germination (13 November 1994)

0.00 mean (n=3)

0.00 standard error (n=3)

\- None present

Appendix 4.1 Tolerance of *Leucaena leucocephala* to herbicides in 1990 Queensland trials.

Active ingredient	Rate (g ai/ha)	Timing of application	Tolerance
acifluorfen	448	3 wks post sowing[4]	susceptible
		3 wks post emergence[1,3]	susceptible
bentazone	1440	3 wks post sowing[4]	tolerant
		3 wks post emergence[1,3]	very tolerant
dicamba	150	3 wks post sowing[4]	susceptible
dinoseb amine	1600	3 wks post sowing[4]	tolerant
		3 wks post emergence[3]	tolerant
fluazifop-butyl	106 and 212	3 wks post sowing[4]	tolerant
	424 and 848	3 wks post emergence[1,3]	very tolerant
sethoxydim	186 and 372	3 wks post sowing[4]	tolerant
		pre-emergence + oil[2,3]	very tolerant
2,4-D amine	500	3 wks post sowing[4]	tolerant
		3 wks post emergence[3]	moderately susceptible
2,4-DB	800 and 1600	3 wks post sowing[4]	tolerant
		3 wks post emergence[3]	moderately susceptible

1 Plus wetter (Agral 600 @ 0.01%)
2 D-C-Tron @ 2 l/ha in 250 l/ha
3 Hawton *et al.*, 1990
4 Loch and Harvey, 1990

Appendix 4.2 Tolerance of *Leucaena leucocephala* to herbicides in trials prior to 1990.

Active ingredient	Application rate (kg ai/ha)	Timing of application	Tolerance
aciflurofen	0.56	post-emergence	no[1]
alachlor	2.2 - 9.0	pre-emergence	no[3]
atrazine	0.56	pre-emergence	yes[1]
	0.3 - 4.5	pre-emergence	no[3]
bentazon	0.56	post-emergence	yes[1]
cyanazine	0.56	pre-emergence	yes[1]
dalapon + 2,4-D	10.0 7.0	6 - 14 wks post sowing	yes[4]
diuron	0.5 - 4.5	pre-emergence	no[3]
flumeturon	1.12	pre-emergence	yes[1]
glyphosate	1.0	6 - 14 wks post sowing	no[4]
imazequin	0.1	pre-emergence	yes[1]
metribuzin	0.28	pre-emergence	yes[1]
	0.3 - 2.3	pre-emergence	no[3]
MSMA	4.0	6 - 14 wks post sowing	yes[4]
nitrofen	4.5	pre-emergence	yes[3]
norflurazon	0.9	pre-emergence	yes[1]
oryzalin	2.24	pre-emergence	no[3]
paraquat	0.4	6 - 14 wks post sowing	yes[4]
PCP	2.0	6 - 14 wks post sowing	yes[4]
trifluralin	1.13	pre-emergence	yes[2]
	2.2	pre-emergence	yes[3]
2,4-DB	0.5	post-emergence	no[1]

1 Williams and Colvin, 1989
2 Jones, 1970
3 Eduardo, 1980
4 Cooksley, 1983

Appendix 4.3 Herbicide tolerance of seven tropical legumes[0].

Chemical	Species	Tolerance[2]	Citation source
acifluorofen[3]	fine stem stylo	T	Loch and Harvey, 1990[1]
alachlor[4]	mungbean	T	Singh *et al.*, 1971
	cowpea	S	Moody, 1973a
		T	Singh *et al.*, 1975
		MS	Braithwaite and Fergusson, 1974
	asparagus bean	T	Raj and Wong, 1975
	peanut	T	Sundaru and Syam, 1977
	soyabean	T	Butler and Rahman, 1981[1]
ametryn[3]	asparagus bean	T	Kasasian, 1968
	pigeon pea	T	ICRISAT, 1977
bentazone[3]	soyabean	T	Butler and Rahman, 1981[1]
		T	Loch and Harvey, 1990[1]
	fine stem stylo	T	Hawton *et al.*, 1990[1]
bifenox[4]	pigeon pea	T	ICRISAT 1977
butachlor[4]	mungbean	S	Indhaphun *et al.*, 1978
butralin[3]	asparagus bean	T	Braithwaite and Fergusson, 1974
butralin + diphenamid[4]	pigeonpea	T	Moody, 1973b
chloramben[4]	mungbean	T	Ikeda and Nhien, 1978
	cowpea	T	Kasasian and Seeyave, 1969a
	asparagus bean	T	Kasasian, 1968
		MS	Braithwaite and Fergusson, 1974
	pigeon pea	MT	Kasasian and Seeyave, 1969b
	soyabean	T	Kasasian and Seeyave, 1968
chloramben + alachlor[4]	soyabean	T	Moody, 1973b
chloramben + diphenamid[4]	soyabean	T	Moody, 1973b
chloroxuron[4]	pigeon pea	T	Hammerton, 1971
	soyabean	T	Butler and Rahman, 1981[1]
dicamba[3]	fine stem stylo	S	Loch and Harvey, 1990[1]
clorthal dimethyl[3]	pigeon pea	T	Moody, 1973b
dinitramine[4]	pigeon pea	T	ICRISAT, 1976
	soyabean	T	Butler and Rahman, 1981[1]
dinoseb[4]	fine stem stylo	T	Loch and Harvey, 1990[1]
diphenamid[4]	asparagus bean	T	Kasasian, 1968
diphenamid + clorthal dimethyl[4]	asparagus bean	MS	Braithwaite and Fergusson, 1974
	pigeon pea	T	Braithwaith pers. comm.
EPTC[3]	asparagus bean	MS	Braithwaite and Fergusson, 1974
	pigeon pea	T	Kasasian, 1964
fluazifop butyl[4]	fine stem stylo	T	Loch and Harvey, 1990[1]
			Hawton *et al.*, 1990[1]
fluchloralin[4]	cowpea	MT	Moody, 1973b
fluchloralin + diphenamid[4]	cowpea	T	Moody, 1974
fluorodifen[4]	cowpea	MS	Moody, 1973a
	soyabean	MT	Moody, 1973b
linuron[3]	mungbean	T	Indhaphun *et al.*, 1978
	soyabean	T	Butler and Rahman, 1981[1]
metolachlor[3]	mungbean	MT	Indhaphun *et al.*, 1978
metribuzin[3]	soyabean	T	Butler and Rahman, 1978[1]
metribuzin + alachlor[3]	soyabean	T	University of Puerto Rico, 1978
metribuzin + linuron[3]	soyabean	T	University of Puerto Rico, 1978
nitralin[4]	soyabean	T	Butler and Rahman, 1981[1]
nitrofen[4]	mungbean	T	Singh *et al.*, 1971
		T	Panwar and Singh, 1977
	cowpea	MT	Saroha and Gupta, 1975
	asparagus bean	T	Kasasian, 1968

	pigeon pea	T	ICRISAT, 1977
	peanut	T	Gowda and Gowda, 1977
paraquat[3]	pigeon pea	T	Kasasian and Seeyave, 1968
pendimethalin[3]	mungbean	MT	AVRDC, 1976
		MS	Ahmed and Moody, 1978
prometon[4]	pigeon pea	T	Hammerton, 1971
prometryn[3]	asparagus bean	T	Kasasian, 1968
	pigeon pea	T	Kasasian and Seeyave, 1968
propachlor[3]	soyabean	T	Butler and Rahman, 1981[1]
sethoxydim[3]	fine stem stylo	T	Loch and Harvey, 1990[1]
		T	Hawton *et al.*, 1990[1]
sulfallate[4]	asparagus bean	T	Paller and Vega, 1972
terbutryn[3]	pigeon pea	T	Jurgens, 1972
thiobencarb + prometryn[4]	soyabean	T	Sundaru and Syam, 1977
trifluralin[3]	cowpea	T	Aryeetey, 1970
		S	Moody, 1973b
		T	Kasasian, 1968
	asparagus bean	MS	Braithwaite and Fergusson, 1974
	soyabean	T	Butler and Rahman, 1981[1]
vernolate[3]	pigeon pea	MT	Moody, 1973b
2,4-D[3]	fine stem stylo	T	Loch and Harvey, 1990[1]
		T	Hawton *et al.*, 1990[1]
2,4-DB[3]	fine stem stylo	T	Loch and Harvey, 1990[1]
		T	Hawton *et al.*, 1990[1]
K-1441[4]	mungbean	MT	AVRDC, 1976

[0] Mung bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), asparagus bean (*Vigna unguiculata* ssp. *sesquipedalis*), pigeon pea (*Cajanus cajan*), peanut (*Arachis hypogaea*), soyabean (Glycine max) and fine stem stylo (*Stylosanthes guianensis* var. *intermedia*).

[1] References denoted by [1] refer to papers not included in the summary by Moody (1979). Non marked references refer to citations of Moody (1979).

[2] A general indication of herbicide tolerance as indicated by the reference used.

- T tolerant
- MT moderately tolerant
- MS moderately susceptible
- S susceptible

[3] Available in Australia, 1993

[4] Not available in Australia, 1993

Appendix 4.4 Herbicide recommendations for lucerne (*Medicago sativa*) crops in New Zealand.

Herbicide	Application rate (kg ai/ha)	Timing of application	Source
asulam[1]	1.2 - 1.6	mature stands	Meeklah, 1984
bentazone + 2,4-DB[1]	0.5 - 1.0 + 0.8	mature stands	Butler, 1980
carbetamide	2.5 - 3.0	mature - winter	Butler, 1980
chlorpropham[1]	4.4	established	O'Connor, 1994
cyanazine[1]	1.0 - 1.5	post crown devt.	O'Connor, 1994
dalapon	2.2 - 4.4	early spring	O'Connor, 1994
EPTC[1]	4 - 6	preplant	Meeklah, 1984
haloxyfop[1]	target species dependant	all stages	O'Connor, 1994
hexazinone[1]	0.9 - 1.35	mature stands	Meeklah, 1984
metribuzin[1]	0.7	mature - winter	Meeklah, 1984
paraquat + atrazine[1]	0.3 - 0.6 + 0.5 - 0.8	mature - winter	Butler, 1980
paraquat + metribuzin[1]	0.4 + 0.35	mature - winter	Meeklah, 1984
propyzamide[1]	0.5 - 1.0	mature - winter	Meeklah, 1984
quizalofop-P-ethyl[1]	0.025 - 0.1	all stages	O'Connor, 1994
simazine[1]	0.8 - 1.2	mature - winter	Meeklah, 1984
terbacil[1]	0.6 - 1.0	mature - winter	Meeklah, 1984
terbuthylazine	0.75 - 1.0	post emergence	O'Connor, 1994
trifluralin[1]	0.6 - 1.0	preplant	Meeklah, 1984
2,4-DB[1]	0.8 - 1.6	3 - 5 leaf stage	Butler, 1980

[1] Available in Australia (1993)

Appendix 4.5 Herbicide recommendations for seven temperate legumes[1] of economic importance.

Herbicide	Species	Rate (kg ai/ha)	Timing of application	Source
alachlor	sunflower	3.0 - 3.75	pre-emergence	Butler and Rahman, 1981
asulam	red clover	1.2	mature stands	Butler, 1980
	lotus	1.2	mature stands	Butler, 1980
benazolin	white clover	0.2 - 0.25	post-emergence	Butler, 1980
bentazone	white clover	1.4	post-emergence	Butler, 1980
	red clover	1.4	post-emergence	Butler, 1980
bentazone + MCPB	pea	1.0 +1.0	post-emergence	Meeklah, 1981
benzoylprop-ethyl	white clover	1.7	post-emergence	Butler, 1980
carbetamide	white clover	2.5 - 2.8	post-emergence	Butler, 1980
	red clover	2.8 - 3.3	post-emergence	Butler, 1980
clethodim	clovers	2.8 - 4.2	early spring	O'Connor, 1994
	pea	0.06 - 0.12	two - three leaf	O'Connor, 1994
cyanazine	pea	1.3 - 2.0	post emergence	Meeklah, 1981
diclofop-methyl	white clover	1.0	post emergence	Butler, 1980
	pea	0.9 - 1.0	post emergence	Meeklah, 1981
difenzoquat	white clover	1.0	post emergence	Butler, 1980
	tick bean	1.0	post emergence	Butler and Rahman, 1981
dinitramine	white clover	0.36-0.48	pre-plant incorporated	Butler, 1980
	pea	0.6	preplant	Meeklah, 1981
	sunflower	0.36 - 0.48	preplant	Butler and Rahman, 1981
diquat	white clover	0.4 - 0.6	after 6 months	Butler, 1980
EPTC	lotus	4.3 - 5.0	preplant incorporated	Butler, 1980
	sunflower	4 - 5	preplant	Butler and Rahman, 1981
ethofumesate	lotus	0.75 - 1.0	mature stands	Butler, 1980
flamprop-methyl	white clover	0.7 - 1.0	post emergence	Butler, 1980
	tick bean	0.7 - 1.0	post emergence	Butler and Rahman, 1981
fluazifop-P-butyl	clover	1.15 - 3.75	mature	O'Connor, 1994
	pea	0.125 - 0.25	post emergence	O'Connor, 1994
haloxyfop	clover	species dependant 0.3	all stages	O'Connor, 1994
	pea		post emergence	O'Connor, 1994
hexazinone	lucerne	0.9 - 1.35	mature stands	Meeklah, 1984
MCPB	white clover	1.5	post emergence	Butler, 1980
	red clover	1.0 - 1.4	establishment	Butler, 1980
	pea	1.0 - 1.6	post emergence	Meeklah, 1981
	tick bean	0.6 - 1.6	six node	Butler and Rahman, 1981
methabenzthiazuron	white clover	1.4	post emergence	Butler, 1980
	pea	1.1 - 1.4	post emergence	Meeklah, 1981
metribuzin	pea	0.18 - 0.35	post emergence	Meeklah, 1981
nitralin	pea	1.0 - 2.0	preplant	Meeklah, 1981
	sunflower	0.75 - 1.1	preplant	Butler and Rahman, 1981

paraquat	lotus	0.3 - 0.5	mature crops	Butler, 1980
pendimethalin	sunflower	1 - 1.5	preplant	Butler and Rahman, 1981
	pea	1.0 - 2.0	pre emergence	O'Connor, 1994
prometryn	sunflower	1.0	pre emergence	Butler and Rahman, 1981
	pea	0.5 - 0.75	two - three nodes	O'Connor, 1994
propyzamide	white clover	1.2	post emergence	Butler, 1980
	red clover	1.2	first true leaf	Butler, 1980
	lotus	1.2	post emergence	Butler, 1980
quizalofop-P-ethyl	clover	0.025 - 0.1	mid-October	O'Connor, 1994
	pea	0.25 - 1.0	post emergence	O'Connor, 1994
sethoxydim	clover	0.28 - 0.93	post emergence	O'Connor, 1994
	pea	0.28 - 0.93	post emergence	O'Connor, 1994
simazine	tick beans	1.2	pre-emergence	Butler and Rahman, 1981
terbuthylazine	pea	0.75 - 1.0	pre-emergence	O'Connor, 1994
tri-allate	white clover	1.4 - 1.7	preplant incorporated	Butler, 1980
	pea	1.4 - 1.7	preplant	Meeklah, 1981
trifluralin	white clover	0.8 - 1.2	preplant incorporated	Butler, 1980
	red clover	0.8 - 1.2	preplant incorporated	Butler, 1980
	lotus	0.8 - 1.2	preplant incorporated	Butler, 1980
	pea	0.6 - 1.0	preplant	Meeklah, 1981
	sunflower	0.8 - 1.2	preplant	Butler and Rahman, 1981
	tick beans	0.8 - 1.2	preplant	Butler and Rahman, 1981
2,4-DB	white clover	1.5	post emergence	Butler, 1980
	lotus	1.2 - 1.5	three - five leaf stage	Butler, 1980
2,2-DPA	lotus	6.0	mature stands	Butler, 1980

[1] White clover (*Trifolium repens*), red clover (*Trifolium pratense*), pea (*Pisum sativum*), lotus (*Lotus pedunculatus*), lucerne (*Medicago sativa*), sunflower (*Heliothus annuus*), tick bean (*Vicia faba*).

Appendix 4.6 Product names, volumes and retail prices of herbicides used in the weed control study.

Active ingredient (AI)	Product	% AI	Product volume	Retail price (A$)[1]	Application rate (kg ai/ha)	Cost (A$/ha)
acifluorfen	Blazer	24.0	10 l	328.90	0.45	61.67
asulam	Asulox	40.0	20 l	305.35	1.20	45.80
atrazine	Atradex 900WG	90.0	10 kg	99.55	0.99	10.95
bentazone	Basagran	48.0	20 l	548.90	0.96	54.89
bromoxynil	Buctril 200	20.0	20 l	270.00	0.40	27.00
bromoxynil + diflufenican	Jaguar	25.0 2.5	5 l	142.60	0.25 0.03	28.52
chlorthal dimethyl	Dacthal 750WP	75.0	2.5 kg	87.60	8.25	385.44
diflufenican	Brodal	50.0	5 l	730.00	0.10	29.20
ethofumesate	Tramat	20.0	10 l	990.00	2.00	990.00
flumetsulam	Broadstrike	80.0	0.5 kg	288.65	0.02	14.43
glyphosate	Roundup	36.0	20 l	283.12	1.80	70.78
haloxyfop	Verdict	10.4	20 l	1092.20	0.16	84.00
hexazinone	Velpar L	25.0	20 kg	696.46	1.00	139.20
imazapic	Cadre	20.0	n/a	n/a	0.07	n/a
imazaquin	Scepter	20.0	n/a	n/a	0.20	n/a
imazethapyr	Spinnaker	24.0	5 l	517.10	0.07	30.16
metolachlor	Dual	72.0	20 l	348.70	1.44	34.87
metribuzin	Lexone DF	75.0	2 kg	263.77	0.56	9.85
oryzalin	Surflan 500 Flowable	50.0	20 l	563.50	3.40	191.59
paraquat	Gramoxone	20.0	20 l	189.20	0.40	18.92
pendimethalin	Stomp 330E	33.0	20 l	221.45	0.99	33.22
propyzamide	Kerb	50.0	1.0 kg	118.00	1.00	236.00
pyridate	Tough	45.0	20 l	677.50	0.90	67.75
terbacil	Sinbar	80.0	1 kg	101.32	2.40	303.96
trifluralin	Treflan	40.0	20 l	135.85	0.84	14.26

[1] Retail prices quoted by IAMA, 8 August 1997

n/a Not available in Australia on 8 August 1997

Appendix 5.1 Soil analysis at Brian Pastures Research Station (Gayndah), South-East Queensland, 17 June 1996.

Soil component	Units	Value
Electrical conductivity	mS/cm	0.18
Chloride[1]	mg/kg	54.0
Nitrate Nitrogen[1]	mg/kg	15.0
Phosphorous[2]	mg/kg	51.0
Sulphur[1]	mg/kg	14.0
Calcium	meq%	25.0
Magnesium	meq%	12.0
Sodium	meq%	0.84
Potassium	meq%	0.88
Copper[1]	mg/kg	3.3
Zinc[1]	mg/kg	2.4
Manganese[1]	mg/kg	45.0
pH[3]		7.15

[1] Extractable
[2] Bicarbonate extractable
[3] Water

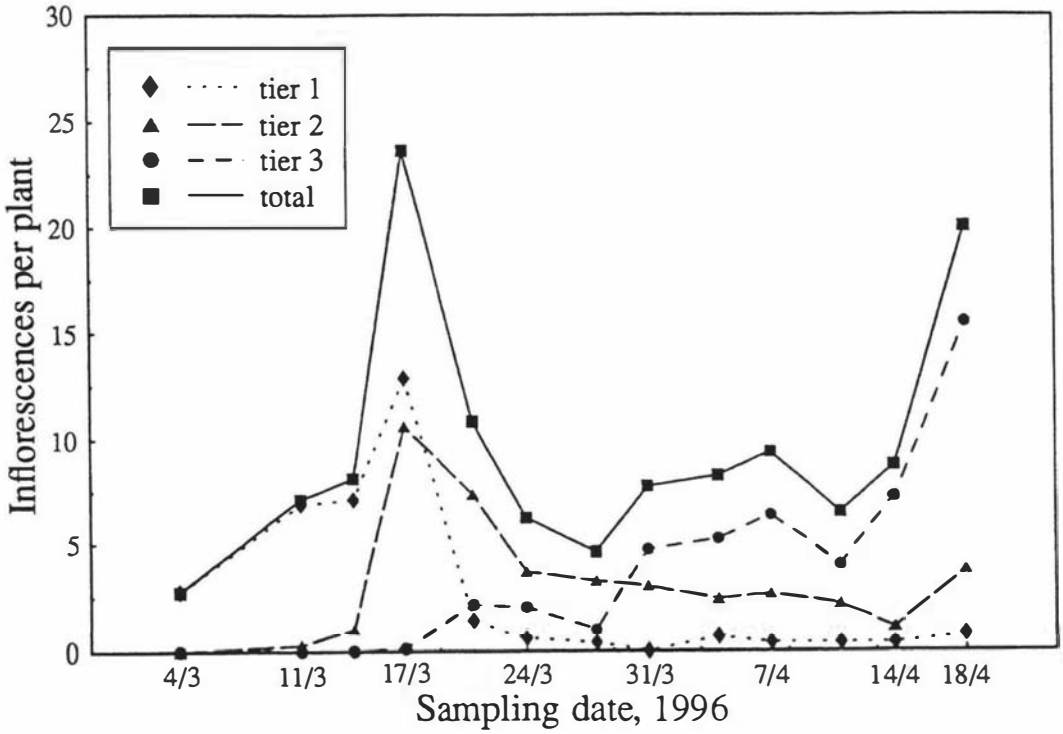
note: all measurements to 10 cm depth
note: as reported by the Agricultural Chemistry Branch, Agricultural Research Laboratories, Queensland Department of Primary Industries, Indooroopilly, Queensland.

Appendix 5.2 Climatic and irrigation data at Gayndah, South-East Queensland, 1995/1996.

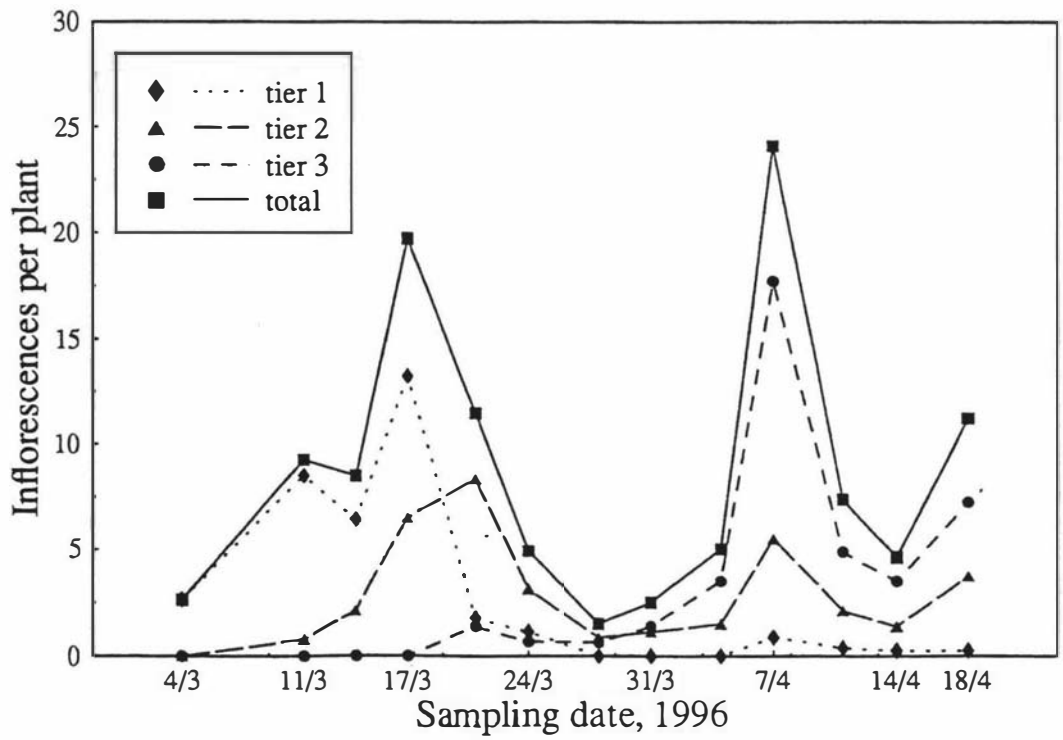
Month	Total rainfall (mm)	Total irr. (mm)	Total water applied (mm)	Long term total rainfall (mm)	Mean min. temp. (°C)	Mean max. temp. (°C)	Long term mean min. temp (°C)	Long term mean max. temp. (°C)	Frosts[1]
Oct.	87.0	-	87	61.6	15.6	28.5	14.7	29.0	0
Nov.	143.0	-	143	72.1	19.6	32.1	17.5	30.9	0
Dec.	132.6	-	133	105.0	19.2	31.1	19.3	32.0	0
Jan.	259.4	50	309	110.4	20.9	31.3	20.2	32.1	0
Feb.	37.4	100	137	94.1	19.3	32.5	20.1	31.6	0
March	21.3	100	121	71.0	18.0	31.3	18.4	30.4	0
April	21.6	75	97	37.3	11.5	29.9	15.2	28.3	0
May	102.0	-	102	40.1	13.3	24.6	11.6	24.9	0
June	11.0	50	61	29.4	9.7	23.2	8.0	22.2	0
July	26.6	25	52	33.8	5.8	21.6	6.5	21.6	3

[1] Air temperatures less than 0°C

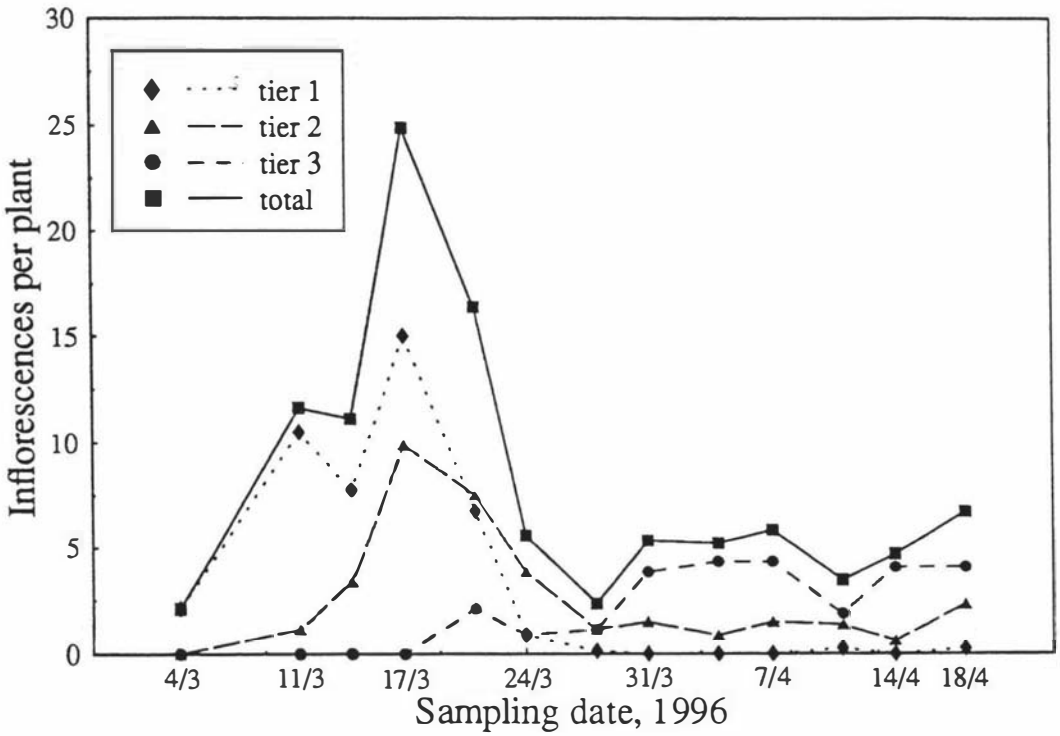
Appendix 5.3 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Marc' not exposed to pre-harvest treatment and combine harvested on 29 April 1996 (Treatment 1).**



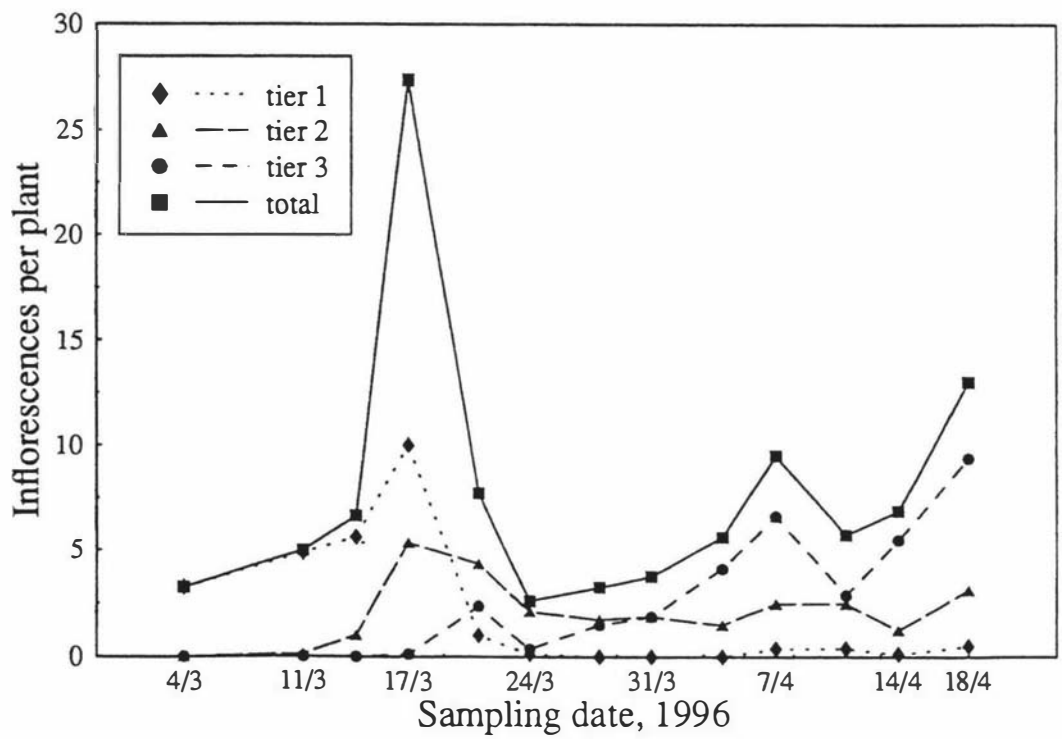
Appendix 5.4 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Marc' treated with paclobutrazol (1.0 kg ai/ha) on 11 April 1996 and combine harvested on 29 April 1996 (Treatment 2).**



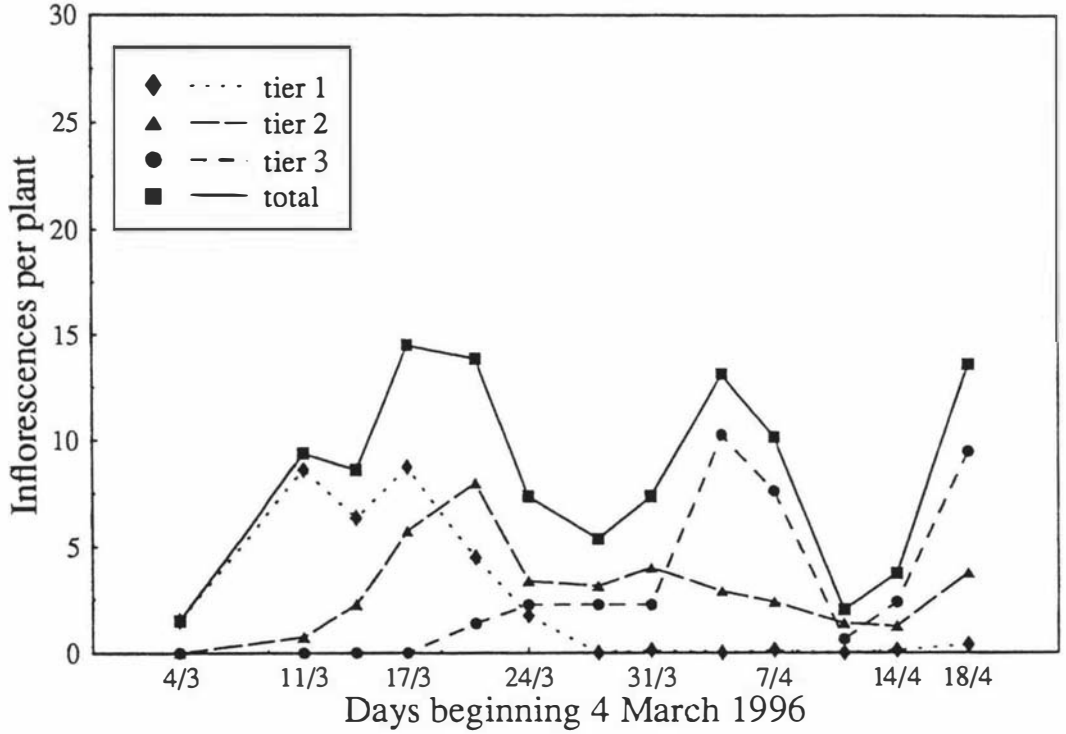
Appendix 5.5 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Marc' treated with diquat (0.8 kg ai/ha) on 18 April 1996 and combine harvested on 29 April 1996 (Treatment 3).**



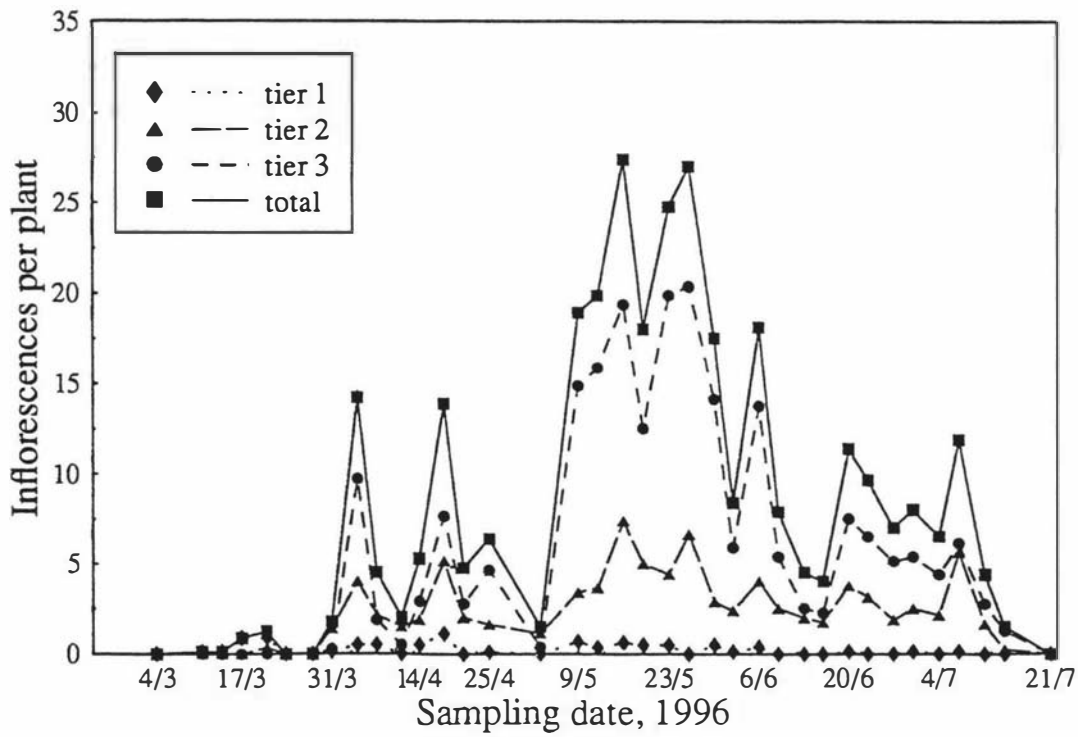
Appendix 5.6 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Marc' exposed to no pre-harvest treatment and keyhole harvested on 29 April 1996 (Treatment 4).**



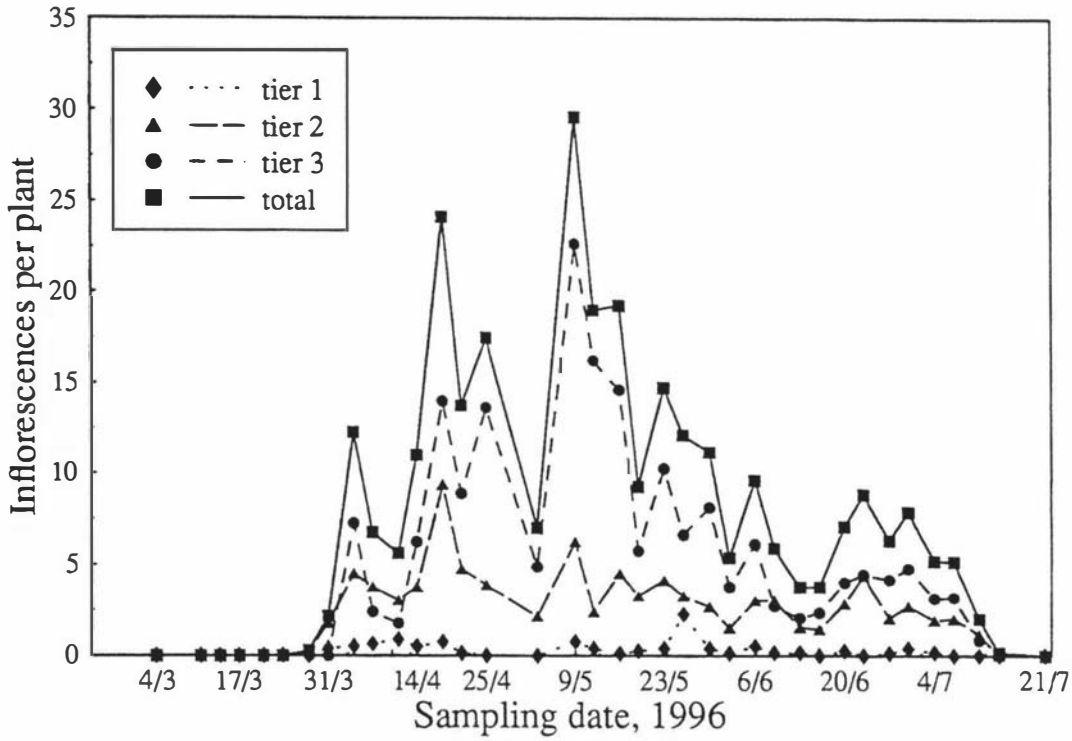
Appendix 5.7 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Marc' treated with glue (Agropol 63029 @ 133 l/ha) on 18 April 1996 and combine harvested on 29 April 1996 (Treatment 5).**



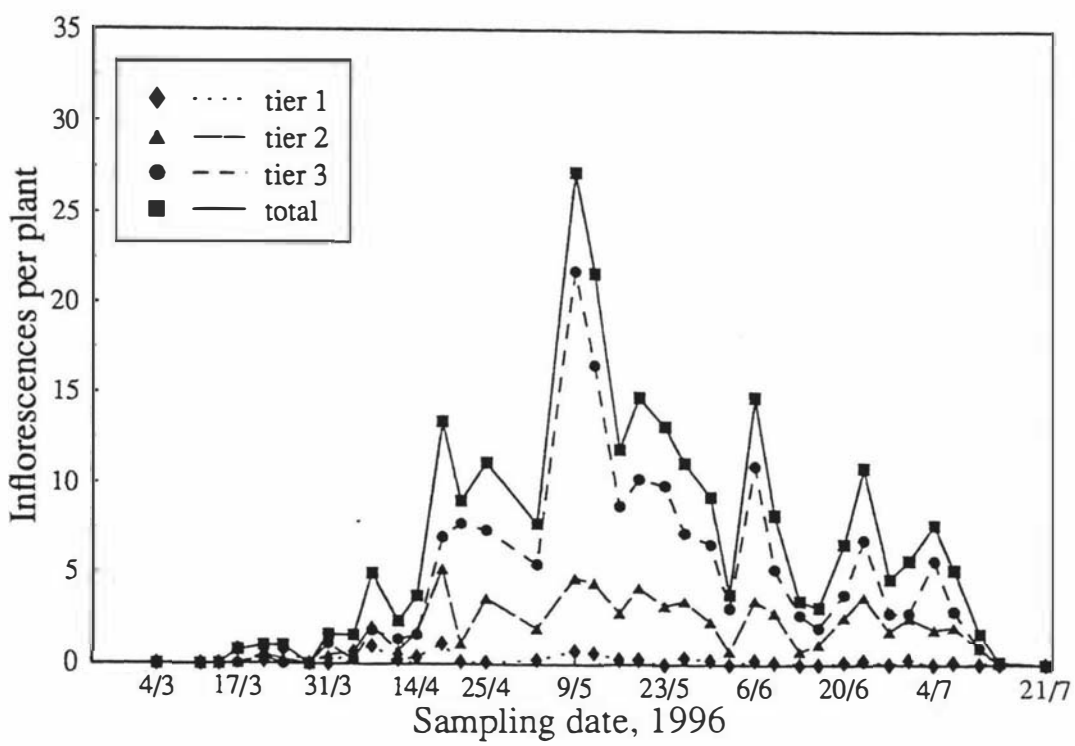
Appendix 5.8 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Bayamo' treated with paclobutrazol (1.0 kg ai/ha) on 20 May 1996 and combine harvested on 1 August 1996 (Treatment 7).**



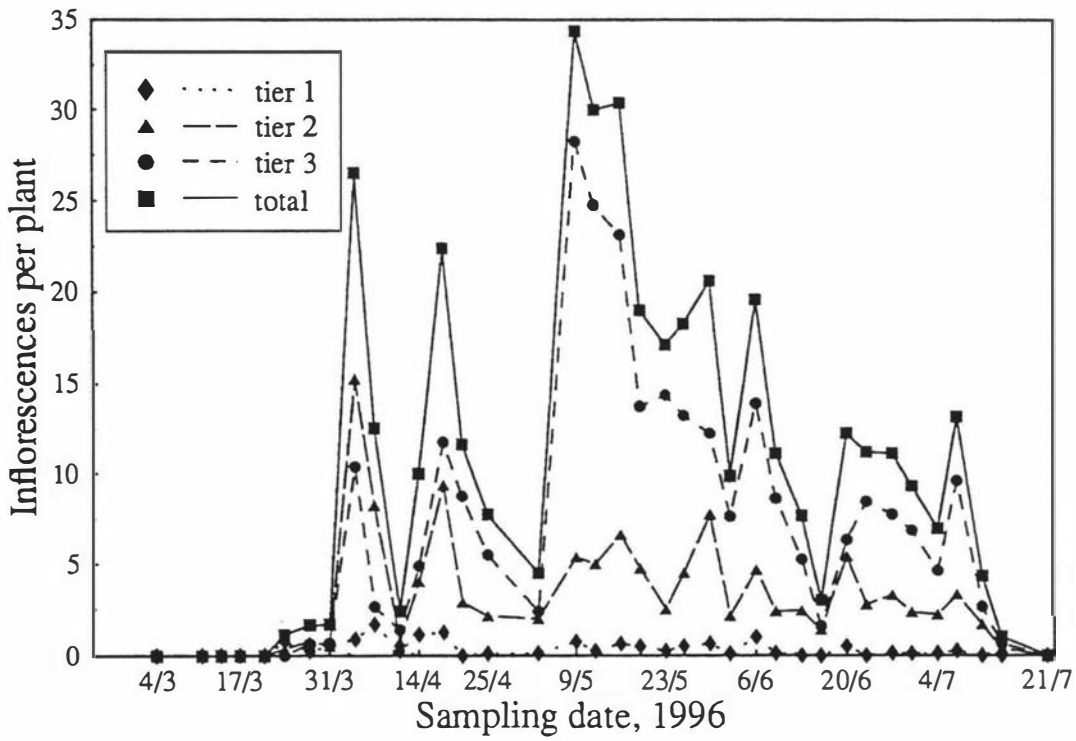
Appendix 5.9 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Bayamo' exposed to no pre-harvest treatment and keyhole harvested on 1 August 1996 (Treatment 8).**



Appendix 5.10 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Bayamo' exposed to no pre-harvest treatment and combine harvested on 1 August 1996 (Treatment 9).**



Appendix 5.11 **Seasonal flowering distribution of *Desmanthus virgatus* cv. 'Bayamo' exposed to no pre-harvest treatment and combine harvested on 1 August 1996 (Treatment 10).**



Appendix 5.12 **Seasonal distribution of mean number of seeds per pod of untreated and paclobutrazol treated *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' plants.**

Days after sowing (17 December)	Cultlvar 'Marc' untreated	Cultivar 'Marc' paclobutrazol	Cultivar 'Bayamo' untreated	Cultivar 'Bayamo' paclobutrazol
87	**8.78** 1.08	**9.21** 0.98	**8.41** 4.81	**12.60** 1.41
101	**7.43** 3.09	**8.42** 0.61	**9.71** 1.52	**9.84** 0.84
108	**2.00** -	**8.04** 2.00	**8.00** 2.00	**9.67** 1.77
115	**7.19** 1.49	**9.33** 3.79	**12.50** 2.60	**8.25** 2.25
122	**9.74** 1.63	**12.50** 1.51	**10.25** 2.25	**11.84** 1.84
150	**13.25** 0.95	**11.57** 1.53	**9.18** 1.38	**9.96** 0.76
157	**11.17** 0.92	**-** -	**12.07** 1.37	**10.62** 1.86
164	**13.56** 0.78	**-** -	**9.63** 2.15	**9.50** 1.50
171	**7.00** -	**-** -	**10.33** -	**8.65** 1.24
178	**-** -	**-** -	**8.71** -	**-** -
185	**-** -	**-** -	**8.50** 1.00	**-** -

0.00 Mean
0.00 Standard error
- No value

Appendix 6.1 **Effects of paclobutrazol treatments (applied 28 August 1996) on seed yield components (SYC) of *Desmanthus virgatus* cvs. 'Marc' and 'Bayamo' grown in glasshouse conditions.**

Tagging Date	SYC	'Marc' (0 kg ai/ha)		'Marc' (0.5 kg ai/ha)		'Marc' (1.0 kg ai/ha)		'Bayamo' (0 kg ai/ha)		'Bayamo' (1.0 kg ai/ha)	
28 Aug.											
	Flor/inf	3.78	c	4.69	b	4.38	bc	5.95	a	6.22	a
	Ipd/um	2.61	a	2.74	a	2.44	a	3.02	a	3.31	a
	Mpd/um	2.35	a	2.67	a	2.37	a	2.72	a	3.21	a
	S.Ipd	61.27	a	51.62	a	43.75	a	48.08	a	48.54	a
	S.Mpd	94.70	a	95.20	a	87.87	a	73.04	a	87.97	a
	T,anth	4.53	b	4.16	b	4.71	b	6.43	a	6.64	a
	T,Ipd	12.96	ab	11.19	c	12.56	b	14.71	a	15.01	a
	T,Mpd	27.80	c	28.32	c	29.99	b	33.05	a	33.57	a
	T,dehis	34.25	cd	32.14	d	37.33	bc	47.27	a	43.58	ab
	D,Ipd	8.44	a	7.03	b	7.82	ab	8.27	ab	8.36	ab
	D,Mpd	14.88	b	17.09	a	17.41	a	17.88	a	18.40	a
	D,dehis	6.45	b	3.81	b	7.34	b	14.23	a	10.63	ab
	Seed/pd	23.44	a	23.02	a	20.18	ab	17.27	b	14.77	b
12 Sept.											
	Flor/inf	5.61	b	5.64	b	7.76	a	5.95	b	6.47	b
	Ipd/um	3.17	a	2.51	a	3.00	a	3.91	a	3.66	a
	Mpd/um	2.60	a	2.40	a	2.60	a	3.60	a	3.35	a
	S.Ipd	16.37	a	21.49	a	28.27	a	43.01	a	42.50	a
	S.Mpd	119.15	a	61.70	b	97.87	a	87.23	ab	87.23	ab
	T,anth	4.00	ab	4.00	ab	4.00	b	4.00	ab	5.50	a
	T,Ipd	12.41	b	14.57	b	14.08	b	18.67	a	18.67	a
	T,Mpd	26.25	a	26.35	a	26.25	a	29.75	a	29.00	a
	T,dehis[1]	42.80		46.80		42.80		53.80		42.80	
	D,Ipd	9.58	bc	8.58	c	10.08	bc	14.08	a	12.58	ab
	D,Mpd	12.80	a	13.90	a	12.30	a	11.80	a	11.05	a
	D,dehis	15.80	b	21.80	ab	15.80	b	24.30	a	14.30	b
	Seed/pd	20.95	a	20.11	a	18.86	a	14.70	a	21.74	a

Flor/inf	florets/inflorescence
Ipd/um	immature pods/umbel
Mpd/um	mature pods/umbel
S.Ipd	% florets surviving to form immature pods
S.Mpd	% immature pods forming mature pods
T, anth	days from tagging to anthesis
T, Ipd	days from tagging to immature pod
T, Mpd	days from tagging to mature pod
T, dehis	days from tagging to pod dehiscence
D, Ipd	days fom anthesis to immature pod
D, Mpd	days from immature pod to mature pod
D, dehis	days from mature pod to pod dehiscence
Seeds/pd	Seeds/pod

[1] Mean separation procedures not conducted due to insufficient degrees of freedom

Appendix 6.2 **Effects of paclobutrazol treatments (applied 15 October 1996) on seed yield components (SYC) of *Desmanthus virgatus* cv. 'Marc' grown in glasshouse conditions.**

Tagging Date	SYC	'Marc' (0 kg ai/ha)		'Marc' (1.0 kg ai/ha)	
15 Oct.					
	Flor/inf	6.13	a	5.50	a
	Ipd/um	2.02	a	2.68	a
	Mpd/um[2,3]	-	-	-	-
	S.Ipd	28.04	a	33.55	a
	S.Mpd[2,3]	-	a	-	a
	T,anth	5.04	a	5.17	a
	T,Ipd	11.82	a	10.24	a
	T,Mpd[3]	25.00	a	25.00	a
	T,dehis[2]	-	-	-	-
	D,Ipd	7.06	a	5.32	b
	D,Mpd[3]	-	-	-	-
	D,dehis[2]	-	-	-	-
	Seed/pd	25.63	a	23.59	a
30 Oct.				-	-
	Flor/inf	5.84	a	5.21	a
	Ipd/um	2.93	a	3.93	a
	Mpd/um[2]	-	-	-	-
	S.Ipd	31.57	a	39.35	a
	S.Mpd[2]	-	-	-	-
	T,anth	5.50	a	5.09	a
	T,Ipd[1]	11.30	-	12.00	-
	T,Mpd[2]	-	-	-	-
	T,dehis[2]	-	-	-	-
	D,Ipd[1]	5.80	-	6.91	
	D,Mpd[2]	-	-	-	-
	D,dehis[2]	-	-	-	-
	Seed/pd[2]	-	-	-	-

Flor/inf	florets/inflorescence
Ipd/um	immature pods/umbel
Mpd/um	mature pods/umbel
S.Ipd	% florets surviving to form immature pods
S.Mpd	% immature pods forming mature pods
T, anth	days from tagging to anthesis
T, Ipd	days from tagging to immature pod
T, Mpd	days from tagging to mature pod
T, dehis	days from tagging to pod dehiscence
D, Ipd	days fom anthesis to immature pod
D, Mpd	days from immature pod to mature pod
D, dehis	days from mature pod to pod dehiscence
Seeds/pd	Seeds/pod

1 Mean separation procedures not conducted due to insufficient degrees of freedom

2 Trial completed before stage of development was achieved

3 Harvesting occurred when over half of pods had become mature (25 days)

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